American Association
of Equine Practitioners

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66th ANNUAL CONVENTION PROCEEDINGS

December 2020

American Association of Equine Practitioners

PROCEEDINGS

66th Annual Convention
December 2020

Proceedings of the 66th Annual Convention of the American Association of Equine Practitioners

Program Chair: Scott A. Hay, DVM

ACKNOWLEDGMENTS
Charlie Scoggin, DVM, MS, DACT, Educational Programs Committee Chair
Carey M. Ross, Scientific Publications Coordinator

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of Equine Practitioners

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Policy Statement

The primary purpose of publishing the Proceedings is to provide documentation of the scientific presentations in abstract form, available at the AAEP Annual Convention. Its further purpose is to offer easily accessible information that will assist the AAEP membership, and others in the equine industry, in the daily responsibility of providing the best possible care for the horse.

Mission Statement

To improve the health and welfare of the horse, to further the professional development of its members, and to provide resources and leadership for the benefit of the equine industry.

Future AAEP CE Dates

2021	360° on Ophthalmology	Gainesville, Florida	June 23–26
2021	Summer Focus Conference and Labs – Sport Horse Pre-Purchase Exam	Lexington, Kentucky	
2021	67th Annual Convention	Nashville, Tennessee	December 4–8
2022	68th Annual Convention	San Antonio, Texas	November 18–22
2023	69th Annual Convention	San Diego, California	November 29–Dec 3
2024	70th Annual Convention	Orlando, Florida	December 7–11

Want to know how your AAEP Annual Convention program came together?

The Scientific Review & Editorial Committee (SREC) is charged with creating and reviewing educational content to produce high-quality CE for the AAEP. The committee is composed of AAEP member volunteers from both small and large private practices as well as academia and industry. Members include both general practitioners and specialists.

The 2020 program includes invited papers for the "In-depth" and "How to" sessions as well as sessions comprised of papers that independent authors submitted for consideration. Topic choices for the invited "In-depth" and "How to" sessions are based on member feedback from AAEP CE Needs Analysis surveys. Topic session leaders are selected by the Program Chair, and then these session leaders invite a slate of speakers to prepare the papers that become an "In-depth" overview or a series of related "How to" talks. Although invited, these papers undergo a rigorous peer review process by the SREC.

Papers submitted by independent authors are each assigned 3 reviewers from the SREC. The reviewers do not know the names of the authors. Content is scored using the criteria of Study Design, Study Quality, Innovation and Impact, Practicality, and Manuscript Quality. This year 158 papers were submitted for the 71 available slots on the program.

Non-scientific sessions addressing business, ethical, and industry concerns are also planned as the scientific program materializes. Speakers who are invited to participate in these sessions prepare papers that are also reviewed by members of the SREC for inclusion in the Proceedings.

The peer review process for the AAEP Proceedings is rigorous. It requires an enormous effort by every one of the 50 members of the SREC to create the best possible program for the AAEP membership. Many volunteer hours were spent putting together the 2020 program, so please thank them for all their hard work creating this program for you.

From Your President

AAEP® American Association of Equine Practitioners
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Dear AAEP Members & Guests:

The 2020 Annual Convention Program Chair, Scott Hay, and the Educational Programs Committee and Scientific Review & Editorial Committee (EPCSREC) have kept with our value and history of unparalleled continuing education, both through traditional and new, creative means. In the 2020 conference you will find our traditional educationally packed proceedings book as well as the opportunity to experience the hard work that has gone into transforming our face-to-face meeting into an innovative AAEP Virtual Convention rich with traditions you have come to expect and enjoy.

Specifically, you will experience the AAEP's high-quality continuing education, along with a first-class trade show that will offer one-on-one opportunities to meet with exhibitors, and social events to allow attendees to mingle, catch up with old friends and network.

The AAEP's EPCSREC worked many hours to develop this program and with the exception of hands-on labs, the content for the virtual program will remain fundamentally the same. We're excited about collaborating with speakers to create dynamic virtual presentations and attendees will have access to ALL educational sessions. For the first time ever, you will have the opportunity to receive as many hours of continuing education as AAEP offers. Our hope is to expose even more equine veterinarians to the AAEP through this platform.

The Virtual Trade Show promises to be exceptional so be sure to thank our many exhibitors and in particular, our Educational Sponsors. Their support for the AAEP is a key part of our ability to continue to provide such high-quality continuing education.

As this unusual year comes to a close, please know that AAEP represents you, the equine veterinarian, on many issues. I was proud to represent the AAEP and saw the impact AAEP members have on the veterinary and equine industry. The Board of Directors have been outstanding, and I would like to thank each of them for working so hard towards the mission of our organization. It has been a pleasure to serve as AAEP President in 2020.

I look forward to 'seeing you' online!

David D. Frisbie, DVM, PhD, DACVS, DACVSMR
2020 AAEP President

Raising the Standard in Horse Health

From Your President-Elect and Program Chair

American Association of Equine Practitioners
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Hello AAEP members, students, and guests and welcome to the AAEP 66th AAEP Virtual Annual Convention & Trade Show! As the 2020 Program Chair, I must say, it has been an interesting year.

Although disappointed to not be able to see everyone in person, we are excited about the opportunities for education and connection presented by a Virtual Convention & Trade Show. We will work hard to bring you the unique events you love and are committed to virtually hosting many of the popular elements, including peer-reviewed education and connection to Trade Show exhibitors from the equine industry.

This program would not have been possible without the members of the Educational Programs and Scientific Review & Editorial Committees, led by Chair Dr. Charlie Scoggin and Dr. Tracy Norman. The committee members put an extraordinary amount of time into selecting topics and reviewing papers in order to present a high quality and balanced meeting for our broad range of member interests.

Some "Must See" virtual offerings this year include. . .

- **The Kester News Hour:** Always popular, the same exciting format debuted in 2019 will be offered once again and include anchors, a forecaster, sportscaster, and field reporter. This will be a fast-paced, cutting edge session with the latest veterinary research and equine news topics and an abundance of take-home information.
- **Milne Lecture:** Dr. John Hubbell, world renowned expert in equine anesthesia and pain management, will trace the development of current anesthetic methods, identify current-day best practices and areas of needed improvement, and postulate pathways for enhancing the safety of equine anesthesia in the future.
- **In-depth Sessions:** We'll go "in-depth" examining lameness, imaging, neonatology, and medication and therapeutics for performance horses.
- **How-to Sessions:** Practical information and techniques will be presented on how to manage hoof lameness, nutrition, and medication and therapeutics for performance horses. These talks are intended to allow the practitioner to go back to their practice and immediately implement.
- **Other Sessions not to miss are** Basic to Basics: The Acute Abdomen in the Field; Ethics–Handling Difficult Conversations; Safety Issues and Efforts in Equine Sport: Past, Present, and Future; and Physical Wellbeing.
- **Business Education:** The business education theme for 2020 is "The Healthy Practice" and topics will include student loan repayment strategies, cannabis and legal conundrums, pregnancy in practice, and much more to help you manage your practice and personal life.
- **Trade Show:** Be sure to support our 2020 exhibitors and spend time in the Virtual Trade Show. You will be able to view products, show specials, and interact in real time with sales staff.
- **Table Topics:** These interactive sessions will be offered in full force with many of your favorites as well as some new topics. Facilitators with different perspectives will moderate these discussions, answer attendee questions, and provide their input.

I want to thank the AAEP Board, Educational Programs Committee, staff, and everyone who has helped make this meeting happen. Program planning and pivoting to a virtual convention experience will be a challenge but we have such a great group of volunteers and members, I have no doubt it will be a success!

We appreciate your patience and we'll continue to do everything we can to maintain the same level of education and community our members are accustomed to. Thank you!

Sincerely,

Scott A. Hay
2020 AAEP President-Elect

Raising the Standard in Horse Health

2020 AAEP Board of Directors

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2020 AAEP Awards

Distinguished Life Member – Dr. Suzi L. White
The AAEP Distinguished Life Member designation is awarded to a member in recognition of outstanding contribution to the association throughout their career.

Distinguished Educator Award (Mentor) – Dr. Stephen E. O'Grady
Awarded to an individual who by his or her actions and commitment has demonstrated a significant impact on the development and training of equine practitioners through mentoring.

Distinguished Service Award – Mr. Keith Kleine
Awarded to an individual who has provided exemplary service to the AAEP or a similar organization to the benefit of the horse, horse industry, or the profession of equine veterinary medicine.

Sage Kester Beyond the Call Award – Dr. Scott E. Palmer
This award is named in honor of its first recipient, the late General Wayne O. "Sage" Kester, DVM, and represents the highest honor bestowed by the AAEP upon a current or former member. The award is presented to an individual who has made significant and long-lasting contributions to equine veterinary medicine and the community. This individual not only possesses the qualities of a leader with a strong commitment to the health and welfare of the horse, but also impacts and improves the lives of others through service above self.

AAEP Research Award – Dr. Katrin Hinrichs
The AAEP Research Award recognizes an individual who has recently completed research that has or will make a significant impact on the diagnosis, treatment or prevention of equine disease.

The Lavin Cup – New Vocations
Named for AAEP past president, A. Gary Lavin, VMD, this award is presented to a non-veterinary individual or organization that has demonstrated exceptional compassion or developed and enforced rules and guidelines for the welfare of the horse.

General Instructions for Authors
67th AAEP Convention
Nashville, TN
December 4–8, 2021

ALL papers must be submitted online by March 15, 2021, 3:00 p.m. ET.

Presentations for the AAEP Convention will be selected directly from the review-ready submissions to the AAEP. Submissions may include case series with follow-up data, or the results of experimental or observational studies as scientific papers, as well as "How to" and review papers. Selection will be made by the Scientific Review & Editorial Committee (SERC). The quality of the submission will determine the selection. Missing data or proposed, but not completed, procedures will exclude the submission from consideration. AAEP invites information dealing with any subject germane to equine practice, but special consideration will be given to submissions by practitioners and material with practical content or new information. At least one author of a report describing diagnosis, treatment, or the interpretation of medical information should be a veterinarian.

All submissions should strictly adhere to the Instructions for Authors. Submissions will be ranked using the AAEP Scoring Criteria and the highest-ranking papers will be selected for the available time.

Authors are expected to acknowledge all sources of funding or support for the work described and to disclose to the SREC any financial interest (including ownership, employment, consultancy arrangements, or service as an officer or board member) they have with companies that manufacture or sell products that figure prominently in the paper or with companies that manufacture or sell competing products. Such an interest will not necessarily influence the decision to accept or reject a submission for the program, but must be included in the Acknowledgments section for the convention Proceedings.

Guidelines:

Failure to adhere to the following format will result in non-acceptance. It is the author's responsibility to convince the SREC of the value of the submission, as well as to portray to the reader the contents of the presentation. **Specific instructions for Scientific papers, "How to" papers, Review papers, ≤ 250 word abstracts, and Business papers can be found in their respective sections.**

Format:

- 12 point, Times New Roman font
- Double-spaced
- 1" margins

Proceedings should be written in the third person. Avoid the use of the first person and pronouns such as I, we, my, mine, us, our, ours.

Example of first vs. third person:
Rather than stating in the first person: "We concluded from our results that A plus B did not equal C", use the third person: "The results of the study indicated that A plus B did not equal C".

Headings should include (but are not limited to) the following:

1. Take Home Message
2. Introduction
3. Materials and Methods
4. Results
5. Discussion
6. Acknowledgments
   i. Declaration of Ethics
   ii. Conflicts of Interest
7. References

Title:

The title should be 15 words or fewer, at the top and on the first page.

Example:
Upper Respiratory Dysfunction in Horses During High Speed Exercise

Take Home Message:

This should be a concise summary of the main conclusion and should be no longer than two or three sentences (approximately 50 words). <u>"How to" papers do not require a take-home message.</u>

Example:
Local anesthetic injected into the coffin joint is not selective for only this joint. Such injections will desensitize much of the navicular bone and its suspensory ligaments.

Introduction:

The rationale for the submission should be given briefly and significant published work acknowledged here. The clinical significance should also be included, as well as a clear statement of the objective or purpose of the submission. The statement of objectives is usually found in the last sentence of the Introduction.

Materials and Methods:

This section should describe experimental methodology in the case of a didactic study or, in the case of a clinical study, should include a description of the population from which the animals were selected and how they were selected for inclusion in the report.

Data obtained and how they were obtained must be described. A description of the statistical methods used to summarize data, test hypotheses, and characterize the significance of results should also be included. Normality of the data should be described, and statistical analysis should be appropriate for the distribution of the data (parametric or non-parametric). For weights and measures, metric units should be used. Dosages should be expressed entirely in metric units and with specific time intervals.

> Example:
> 22 mg/kg, q 12 h, IV (not 10mg/lb, BID, IV)

Results:

Actual results with numbers and data must be presented. When possible, quantify findings (mean, median, proportion) and present them with appropriate estimates of measurement error or uncertainty (such as standard deviation (SD), standard error (SE) or confidence interval) in addition to the results of hypothesis testing. If the data can be well represented with a graph or figure, these *are encouraged* if subsequent publication is not anticipated. If numbers and data are not presented due to concerns regarding publication in a refereed journal, indications of relative differences between groups such as odds ratios, % change, and significant differences must be included in the submission to be considered acceptable. In these instances, the authors should submit the data in the form of means, standard deviations, or other descriptions of comparisons among groups in an appendix, which will not be published and only used for review purposes.

Discussion:

Important findings documented in the results of the study should be stated. Results should be related to other work which has been done and how the results differ or agree with previously published work and why any differences may have occurred should be discussed. The practical take home message for the equine practitioner should be clearly defined and stated in the summarizing final statement. This statement may be longer, but should be similar in content to the take home message at the beginning of the paper.

The following items must be fully explained in the paper: the number of horses that have been worked on, how many will be affected, and evidence that the procedure works and is safe.

Recommended Nomenclature:

Anatomy and anatomic planes should be described using standard nomenclature following the guidelines developed by Nomina Anatomica Veterinaria (http://www.wava-amav.org/downloads/nav_2012.pdf)

Acknowledgments:

Acknowledgments should include financial and material support for research (e.g., Grayson-Jockey Club Research Foundation, AQHA Foundation) and technical support for work performed. Authors are expected to disclose the nature of any financial interests (including ownership, employment, consultancy arrangements, or service as an officer or board member) they have with companies that manufacture or sell products that figure prominently in the submission or with companies that manufacture or sell competing products.

Declaration of Ethics:

A Declaration of Ethics statement should be included in the paper under the Acknowledgments section. Authors must declare if they have adhered to the Principles of Veterinary Medical Ethics of the AVMA (https://www.avma.org/KB/Policies/Pages/Principles-of-Veterinary-Medical-Ethics-of-the-AVMA.aspx)

1. If your paper or presentation references the use of a compounded pharmaceutical, please be certain that you are familiar with the FDA guidelines on the use of compounded pharmaceuticals and that the product you reference is in compliance. See section below regarding papers using compounded medications or medical devices.
2. All submissions should cite levels of evidence-based medicine.

You should plan to include any ethical considerations as part of your oral presentation if your paper is accepted.

Conflicts of Interest:

Authors are expected to disclose the nature of any financial interests they have with companies that manufacture or sell products that figure prominently in the submission or with companies that manufacture or sell competing products. (This includes ownership, employment, consultancy arrangements, or service as an officer or board member.) A Conflict of Interest statement should be included in the paper under the Acknowledgments section whether a conflict exists or not.

> Example of COI Statement
> *Conflict of Interest: Dr. Jane Doe has served as a paid technology analyst for the venture capitalists that initiated the formation of Company ABC and served as a member of the Board of Directors of Company ABC from its inception until 2008. Company ABC is currently commercializing the use of Product XYZ. Dr. Jane Doe has also served as a paid consultant and continues to serve on the Company ABC Advisory Board. Dr. John Doe has no conflict of interest.*

All authors are required to disclose any actual or potential conflict of interest including any financial, personal or other relationships with other people or organizations within three years of beginning the submitted work that could inappropriately influence, or be perceived to influence, their work.

At the point of submission, the American Association of Equine Practitioners' (AAEP) policy requires that authors must disclose and describe the nature of any actual or potential financial and/or personal relationships they have with companies that manufacture or sell products that figure prominently in the submission or with companies that manufacture or sell competing products.

It is the Submitting author's responsibility to ensure that all authors adhere to this policy.

1. Any and all authors listed on the paper must disclose any actual or potential conflicts of interest.
2. Any and all authors listed on the paper must disclose if no conflict exists.
3. The nature of the conflict (actual or potential) needs to be described.

References:

References to published works should be limited to what is relevant and necessary. Number references in the text with superscript numbers consecutively in the order in which they are first cited. Under References, list all authors when there are three or fewer; list only the first three and add "et al." when there are four or more. The author is responsible for the formatting and accuracy of all reference citations. Since readers frequently depend upon the reference citations to guide them in further reading, it is imperative that the citations are correct so that libraries can locate the papers a reader may wish to obtain.

Examples:

Journal article:

Auer JA, Martens RJ, Williams EH. Periosteal deformities in foals. *Am J Vet Res* 1982;181:459–466.

Murphy CJ, Lavoie JP, Groff J, et al. Bilateral eyelid swelling attributable to lymphosarcoma in a horse. *J Am Vet Med Assoc* 1989;194:939–942.

Some common journal abbreviations include: *Acta Vet Scand, Am J Vet Res, Can J Vet Res, Can Vet J, Cornell Vet, Compend Contin Educ Pract, Equine Vet J, Equine Vet J Suppl, J Am Vet Med Assoc, J Vet Diagn Invest, J Vet Intern Med, Prev Vet Med, Vet Clin North Am Equine Pract, Vet Radiol, Vet Rec, Vet Surg.* Other journal names should be abbreviated in accordance with the National Library of Medicine and *Index Medicus*.

Book:

Turner AS, McIlwraith CW. *Techniques in large animal surgery*. Philadelphia: Lea and Febiger, 1982;186–191.

Banks P, Bartley W, Birt LM. *The biochemistry of the tissues 2nd ed.* London: John Wiley & Sons, 1968;24.

Devlin TM, ed. *Textbook of biochemistry with clinical correlations*. New York: John Wiley & Sons, 1982; 14–36.

Chapter in a book:

Axelrod B. Glycolysis. In: Greenberg DM, ed. *Metabolic pathways, vol 1. 3rd ed.* New York: Academic Press, 1967; 112–145.

Kainer RA. Functional anatomy of equine locomotor organs. In: Stashak TS, ed. *Adams' lameness in horses 4th ed.* Philadelphia: Lea and Febiger, 1987;12–18.

Proceedings:

Divers TJ. Acute renal failure in horses and cattle, in *Proceedings*. 3rd Am Coll Vet Int Med Forum 1985; 93–95.

Lamb CR, Koblik PD, O'Callaghan MW, et al. Comparison of bone scintigraphy and radiography as aids in the evaluation of equine lameness: Retrospective analysis of 275 cases, in *Proceedings*. Am Assoc Equine Pract 1989;35: 359–368.

Footnotes:

References to dissertations, theses, abstracts, personal communications and papers submitted but not yet accepted for publication should be footnoted:

Jones CD. The selective advantage of the ABO blood groups [thesis]. Ithaca, NY: Cornell University; 1990.

Bramlage LR. Lexington, KY. (personal communication) 1996.

Smith AB. Unpublished data. January 1990.

Evans LH. Entrapment of the epiglottis. Am Assoc Equine Pract. In Press 1981.

Products and equipment should be identified by chemical or generic names or descriptions.

All products should be footnoted, along with the manufacturer's full address. A trade name may be included in a lettered footnote along with the name and location (full mailing address including zip code) of the manufacturer when the product or equipment was essential to the outcome of the experiment or treatment.

Example:
All horses were sedated with a combination of detomidine HCL[a] (10-20 mg/kg IV) and butorphanol tartrate[b] (0.01-0.02 mg/kg IV).
[a] Dormosedan® Orion Corporation, Espoo, Finland.
[b] Torbugesic®, Fort Dodge Animal Health, Fort Dodge, IA 50501.

Figures:

- The resolution should be at least 300 dpi.
- Figures should be cited in the text in parentheses (Fig. 1) consecutively in the order in which they are first mentioned.
- The figure itself should also be numbered to correspond to the citation in the text.
- Figures must include captions, 40 words or fewer.

Tables:

Tables should be self-explanatory and should supplement the text. Provide a concise, descriptive title for each table.

Figures, tables, and text should all be included in the same document.

Permissions:

If you wish to use previously published material, including text, photographs, or drawings, you must acknowledge the original source and submit written permission from the copyright holders (author and publisher) to reproduce the material. Provide this permission when you submit your original manuscript.

IACUC Approval:

AAEP is dedicated to the humane use of animals in scientific research in accordance with the Institutional Animal Care and Use Committee (IACUC).

Compounded Medications or Medical Devices:

To be considered for selection on the Annual Convention program, abstracts that include the use of compounded drugs must adhere to the tenets described in the AAEP Equine Veterinary Compounding Guidelines. Specifically, compounded drug or medical devices cannot be used in lieu of an FDA-approved product if the approved product has a label indication for the purpose or condition being evaluated or described in the paper.

An exception to this policy will be made for papers reporting clinical trials conducted in fulfillment of the requirements for the approval of a new drug (FDA) or biologic (USDA).

Submitted papers that use compounded drugs or medical devices will undergo a secondary review by an individual(s) with expertise in this area. The individual(s) will then make a recommendation about the suitability of the submission for potential inclusion in the program.

Standard of Care:

The AAEP is sensitized to having people use the term "Standard of Care" from the podium. If you plan to do this, please include this in your abstract or written submitted material so the SREC can confirm its agreement with your statement.

1. A diagnostic and treatment process that a clinician should follow for a certain type of patient, illness, or clinical circumstance. Adjuvant chemotherapy for lung cancer is "a new standard of care, but not necessarily the only standard of care." (New England Journal of Medicine, 2004).
2. In legal terms, the level at which the average, prudent provider in a given community would practice. It is how similarly qualified practitioners would have managed the patient's care under the same or similar circumstances. The medical malpractice plaintiff must establish the appropriate standard of care and demonstrate that the standard of care has been breached.

Deadline:

ALL papers must be submitted online by March 15, 2018, 3:00 p.m. E.T.; under no circumstances will submissions received after the deadline be considered or reviewed. ALL deadlines must be adhered to in order to have the published Proceedings available at the meeting.

Review Process:

To respect the integrity of the Annual Convention program and ensure the fairness of the review process, AAEP has adopted blind reviewing in which the identity of the authors and reviewers are not known to each other. Papers will be reviewed, scored, and selected by the SREC. Please follow the blinding guidelines below.

Blinding Guidelines:

- The title page and/or front matter of the blinded version of a paper should contain no references to any author or to his/her affiliation.
- All unpublished works by an author of the submitted manuscript should be blinded.
- When referring to an author's publication, the form of third person should be used.
- Any acknowledgments that identify any authors should be removed from the blinded version. Also, please delete any notes that indicate affiliation, conference presentations, grants, author or departmental websites, etc.
- Do not use author name or affiliation in the names of the submitted files.

Scoring Criteria:

One goal of the SREC in choosing submissions for the AAEP annual meeting is to combine the best available clinical research with clinical experience and expertise to meet the needs of our patients. The AAEP Scoring Criteria can be requested from cross@aaep.org.

Pre-Press Approval:

Authors will have final approval at the page proof stage. Changes/updates in numbers, dosages or inappropriate grammar may be made within one week of receiving page proofs. Final grammatical changes will be the decision of the editors. Substantial changes or removal of any data will result in forfeiture of complimentary registration and travel, and exclusion from the program.

Honorarium:

Presenting authors will receive one complimentary registration and a check for $550 to help support travel.

Mentors for Authors:

Paper submissions by private practitioners and first-time authors are highly encouraged. The AAEP has a list of members in various areas of expertise who have agreed to volunteer their time to mentor an author who needs guidance. To see this list, email Carey Ross at cross@aaep.org.

Scientific Papers: Guidelines for Authors 67th AAEP Convention Nashville, TN December 4–8, 2021

ALL papers must be submitted online by March 15, 2021, 3:00 p.m. ET.

Authors who do ***not*** intend to publish in a refereed journal are welcome to submit a Scientific Paper.

Scientific Paper selection will be made by the Scientific Review & Editorial Committee (SREC). The quality of the Scientific Paper will determine the selection. Missing data or proposed, but not completed, procedures will exclude the Scientific Paper or other paper from consideration. AAEP invites information dealing with any subject germane to equine practice, but special consideration will be given to presentations by practitioners and material with practical content or new information. At least one author of a report describing diagnosis, treatment, or the interpretation of medical information should be a veterinarian.

Scientific papers should be formatted as described in the General Instructions for Authors. Scientific papers should be no fewer than 600 words, with no upper word limit.

The "How to" Paper: Guidelines for Authors 67th AAEP Convention Nashville, TN December 4–8, 2021

ALL papers must be submitted online by March 15, 2021, 3:00 p.m. ET.

"How to" papers are presented to describe and explain a technique or procedure used in equine veterinary medicine or the equine industry. The technique should be relatively new or not widely understood or used in practice. The goal of the "How to" paper is to give equine veterinarians the information they need to critically evaluate the pros and cons of the technique and implement it in their practice if they choose.

"How to" papers can be patterned after a modification of the style for a Scientific Paper supporting a scientific presentation. Refer to General Instructions for Authors as you prepare your submission. How to papers should be no fewer than 600 words, with no upper word limit.

The title should begin with "How to . . ." and clearly identify the technique or procedure that will be presented. A "Take Home Message" is not required for "How to" papers. The Introduction should include why you use the technique. If there is a problem with the traditional methods or if the currently used method can be improved, this should be explained.

The Materials and Methods section should explain exactly how the technique is performed so that another veterinarian familiar with the subject area could follow your example. You may use a step-by-step method for the paper and the presentation. All medications, supplies, and equipment used should be described using generic names. Trade names and addresses of commercial products critical to the technique can be included in a footnotes section.

The Results section should include a summary of what happens when you use this technique. The number of horses treated in this manner and an assessment of the outcome should be included. You may use personal assertions or data to assert its value, but you must explain how you determined that the technique works.

In the Discussion section, you can give your personal views as to why you think the technique works. Discuss the pros and cons of your approach. Explain how the technique has helped you in your practice and why this should be important to your colleagues. The end of the discussion should contain a summary of the technique and its advantages in the take home message. Case selection, case study number, and case follow up should all be included.

Review Paper: Guidelines for Authors 67th AAEP Convention Nashville, TN December 4–8, 2021

ALL papers must be submitted online by March 15, 2021, 3:00 p.m. ET.

Review papers are presented for the purpose of updating the membership on a new subject or for gathering information that may be conflicting. The aim of the paper is to help the membership put the information in perspective, and to make judgments on conflicting information. A review paper will not principally present original data; the goal is to clarify existing knowledge on a subject and help the membership better use the information in their day-to-day practice.

Review papers should generally be formatted as described in the "General Instructions for Authors" except where otherwise noted here. The paper should be titled "Review of Some Subject." The content of review articles should be organized with headings and subheadings that provide a logical flow to the material presented. A "Take Home Message" is required for a Review Paper. The Introduction should define the subject matter and put it in context, explaining why the review is necessary. The purpose of the review paper should be clearly stated in the Introduction.

Agreement and disagreement within the subject matter should be identified along with the strengths and limitations of the information sources. Reference should be made to the authors who generally support the opinions stated. The author's perspective, including his/her own interpretation of the information if it is different from previously published opinions, should be included. The end of the discussion should contain a summary and the conclusion that the author has drawn for the audience, based upon the reviewed data. As with a Scientific Paper, a "Take Home Message" should be provided by the author that summarizes the practical application of the information for the practitioner.

An appropriately complete reference list should be included. The format for references is the same as that described in the "General Instructions for Authors." Review papers should be no fewer than 600 words, with no upper word limit.

Illustrations should be provided in the format described in "General Instructions for Authors". If previously published material is submitted, including text, photographs or drawings, the author must acknowledge the original source and submit written permission from the copyright holders (author and publisher) to reproduce the material. This permission must accompany the original manuscript at the time of submission.

Abstracts ≤ 250 Words: Guidelines for Authors *For those who intend to publish in a refereed journal* 67the AAEP Convention Nashville, TN December 4–8, 2021

ALL papers must be submitted online by March 15, 2021, 3:00 p.m. ET.

To encourage submission of the newest scientific information for inclusion in the AAEP Annual Convention program and simultaneously not jeopardize future publication of this material in a refereed journal, the following criteria have been developed for these submissions of Scientific Papers that will be published in the AAEP Proceedings.

In such instances, the published abstract can be ≤ 250 words. However, these "abbreviated abstracts" should follow a structured format with the same subheadings (Take Home Message, Introduction, Materials and Methods, Results and Discussion) as the full-length scientific paper. <u>Please be aware that the Take Home Message is included in the total word count.</u> The abbreviated abstract does not need references, but appropriate acknowledgments should be included. Note that this abbreviated abstract format does not apply to Review, How to, or In-depth Papers. **A full paper** conforming to the General Instructions for Authors must also be submitted to allow the reviewers to assess the experimental design, materials and methods, statistical analyses, results (with graphs, tables, charts, etc.) and a discussion of the results as it pertains to interpretation and conclusions (**see specific guidelines below for full papers**). The submitting author must include a statement that only the short abstract can be published in the AAEP Convention Proceedings. It remains the author's responsibility to preserve their right to publish in a refereed journal by contacting the respective journal to discuss their prior-publication criteria so that an accepted abbreviated abstract will not jeopardize publication in a refereed journal. These submitted abbreviated abstracts should be identified with the words "RESEARCH ABSTRACT" at the end of the title.

Guidelines for Full Papers

- 1500 words
- 12-point font
- 1" margins
- When submitting online, please put both papers in one document; the 250-word abstract should be first, followed by the full-length scientific paper.

A full paper must be included with all 250-word abstracts in order for the abstract to be considered for the program.

Business of Practice Papers: Guidelines for Authors 67th AAEP Convention Nashville, TN December 4–8, 2021

ALL papers must be submitted online by March 15, 2021, 3:00 p.m. ET.

The general theme for the 2021 Business of Practice Sessions is "Practice Transitions." Several potential topics are listed below, and practitioners with expertise or experience in these areas are encouraged to submit papers to be considered for presentation. Please keep in mind that all submissions must follow the guidelines as outlined below and that accepted papers are allotted a total speaking time of 20 minutes (15 minutes presentation time + 5 minutes questions). The following topic suggestions are intended to spark ideas that relate to the Scientific Review & Editorial Committee (SERC) theme; however we also welcome paper submissions on any topic pertaining to the Business of Practice.

Potential Topics:

- Valuation methodologies and strategies for improvement
- Practice exit strategies
- Personal financial planning
- DVM transitions into practice: How to best onboard and incorporate for success
- Staff transitions: Career ladders, how to incorporate new skills and roles for staff (technician to manager, practice manager, etc.)
- How to leverage newly upgraded staff to increase doctor efficiency & profitability
- Telehealth: Impacts on practice and how to incorporate
- Collaborative practice models: Strategies used by corporate practices & private equity groups
- How to transition practice offerings to specific market segments (instead of broadly defined equine practice)

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Guidelines:

Failure to adhere to the following format will result in non-acceptance. It is the author's responsibility to convince the SREC of the value of the submission, as well as to portray to the reader the contents of the presentation. You may request examples of previously accepted Business papers from cross@aaep.org.

Headings may include (but are not limited to) the following:

1. Take Home Message (not required for "How to" papers. See section at the end of this document for 'How to" paper guidelines).
2. Introduction
3. Solution
4. Results
5. Discussion
6. Acknowledgments
   i. Declaration of Ethics
   ii. Conflicts of Interest
7. References

Title:

The title should be 15 words or fewer, at the top and on the first page.

> Example:
> Breaking the Silence: Disclosing Medical Errors

Take Home Message:

This should be a concise summary of the main conclusion and should be no longer than two or three sentences (approximately 50 words). "How to" papers do not require a take-home message.

> Example:
> In circumstances where a medical error results in an adverse outcome, a thoughtful response on the part of the veterinarian, staff, and practice is required. This paper will review communication techniques for constructively responding to these difficult situations.

Introduction:

Significant published work should be acknowledged here. A clear statement of the business challenge, or the objective or purpose of the submission, should be included. The statement of objectives is usually found in the last sentence of the Introduction.

Solution:

A description of a single or multiple business solutions are explained in detail.

Results:

Any results should be presented in this section. If the data can be well represented with a table or figures, these *are encouraged.*

Discussion:

Important findings documented in the solution or results of the study should be stated. Solutions or results can be related to other work that has been done and how the results differ. The practical take home message for the equine practitioner should be clearly defined and stated in the summarizing final statement. This statement may be longer, but should be similar in content to the take home message at the beginning of the paper.

Acknowledgments:

Acknowledgments should include financial and material support for research and technical support for work performed. Authors are expected to disclose the nature of any financial interests (including ownership, employment, consultancy arrangements, or service as an officer or board member) they have with companies that manufacture or sell products that figure prominently in the submission or with companies that manufacture or sell competing products.

Declaration of Ethics:

A Declaration of Ethics statement should be included in the paper under the Acknowledgments section. Authors must declare if they have adhered to the Principles of Veterinary Medical Ethics of the AVMA (https://www.avma.org/KB/Policies/Pages/Principles-of-Veterinary-Medical-Ethics-of-the-AVMA.aspx)

1. If your paper or presentation references the use of a compounded pharmaceutical, please be certain that you are familiar with the FDA guidelines on its use and that the product you reference is in compliance. See section below regarding papers using compounded medications or medical devices.
2. All submissions should cite levels of evidence-based medicine.

You should plan to include any ethical considerations as part of your oral presentation if your paper is accepted.

Conflicts of Interest:

Authors are expected to disclose the nature of any financial interests they have with companies that manufacture or sell products that figure prominently in the submission or with companies that manufacture or sell competing products. (This includes ownership, employment, consultancy arrangements, or service as an officer or board member.) In addition, if the author provides veterinary business consulting services, or earns income through veterinary business educational offerings, this should be disclosed. A Conflict of Interest statement should be included in the paper under the Acknowledgements section whether a conflict exists or not.

Example of COI Statement

Conflict of Interest: Dr. Jane Doe has served as a paid technology analyst for the venture capitalists that initiated the formation of Company ABC and served as a member of the Board of Directors of Company ABC from its inception until 2008. Company ABC is currently commercializing the use of Product XYZ. Dr. Jane Doe has also served as a paid consultant and continues to serve on the Company ABC Advisory Board. Dr. John Doe has no conflict of interest.

All authors are required to disclose any actual or potential conflict of interest including any financial, personal, or other relationships with other people or organizations within three years of beginning the submitted work that could inappropriately influence, or be perceived to influence, their work.

At the point of submission, the AAEP policy requires that authors must disclose and describe the nature of any actual or potential financial and/or personal relationships they have with companies that manufacture or sell products that figure prominently in the submission or with companies that manufacture or sell competing products. (This includes ownership, employment, consultancy arrangements, or service as an officer or board member.)

It is the Submitting author's responsibility to ensure that all authors adhere to this policy.

1. Any and all authors listed on the paper must disclose any actual or potential conflicts of interest.
2. Any and all authors listed on the paper must disclose if no conflict exists.
3. The nature of the conflict (actual or potential) needs to be described.

References:

Submissions may include references. References to published works should be limited to what is relevant and necessary. Number references in the text with superscript numbers consecutively in the order in which they are first cited. Under references, list all authors when there are three or fewer; list only the first three and add "et al." when there are four or more. The author is responsible for the formatting and accuracy of all reference citations. Since readers frequently depend upon the reference citations to guide them in further reading, it is imperative that the citations are correct so that libraries can locate the papers a reader may wish to obtain. Reference examples can be found in the General Instructions for Authors.

Footnotes:

References to personal communications and papers submitted but not yet accepted for publication should also be footnoted:

Figures:

- The resolution should be at least 300 dpi.
- Figures should be cited in the text in parentheses (Fig. 1) consecutively in the order of which they are first mentioned.
- The figure itself should also be numbered to correspond to the citation in the text.
- Figures must include captions, 40 words or fewer.

Tables:

Tables should be self-explanatory and should supplement the text. Provide a concise, descriptive title for each table.

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Deadline:

ALL papers must be submitted online by March 15, 2021, 3:00 p.m. E.T.; under no circumstances will submissions received after the deadline be considered or reviewed. ALL deadlines must be adhered to in order to have the published Proceedings available at the meeting.

Review Process:

Papers will be reviewed, scored, and selected by the SREC. Since the presentation ability of business speakers is crucial, the review for these papers requires a two-step process:
1. Initial acceptance of the paper while the author is blinded.
2. The process becomes un-blinded before final selections are made.

This two-step review process was implemented to protect the association from selecting speakers whose presentations may have a strong commercial bend.

Blinding Guidelines:

- The title page and/or front matter of the blinded version of a paper should contain no references to any author or to his/her affiliation.
- Any acknowledgments that identify any authors should be removed from the blinded version. Also, please delete any notes that indicate affiliation, conference presentations, author or departmental websites, etc.

- Do not use author name or affiliation in the names of the submitted files.

Scoring Criteria:

The subject matter is relevant to the business operations of a veterinary business. How-to cases should be based upon personal experience in a veterinary business. Papers describing a business process should be applicable to an equine veterinary business and should be supported by references from business publications.

Pre-Press Approval:

Authors will have final approval at the page proof stage. Changes/updates may be made within one week of receiving page proofs. Final grammatical changes will be the decision of the editors. Substantial changes or removal of any data will result in forfeiture of complimentary registration and travel, and exclusion from the program.

Reimbursement:

Presenting authors will receive one complimentary registration and a reimbursement of $550 to help support travel.

Mentors for Authors:

Paper submissions by private practitioners and first-time authors are highly encouraged. Please email Carey Ross (cross@aaep.org) to request a list of members in various areas of expertise who have agreed to volunteer their time to mentor an author who needs guidance.

"How to" Paper Submissions for Business of Practice Sessions:

"How to" papers are presented to describe and explain a technique or procedure that relates to the business of practice. The goal of these papers is to give equine veterinarians the information they need to critically evaluate the pros and cons of the technique and implement it in their practice if they choose.

"How to" papers should follow the same guidelines in this document, except where otherwise noted below.

The Title should begin with "How to . . ." and clearly identify the technique or procedure that will be presented.

A "Take Home Message" is not required for "How to" papers.

The Introduction should include why you use the technique. If there is a problem with the traditional methods or the currently used method can be improved, this should be explained.

The Materials and Methods section should explain exactly how the technique is performed so that another veterinarian familiar with the subject area could follow your example. You may use a step-by-step method for the paper and the presentation.

The Results section should include a summary of what happens when you use this technique. You may use personal assertions or data to assert its value, but you must explain how you determined that the technique works.

In the Discussion section, you can give your personal views as to why you think the technique works. Discuss the pros and cons of your approach. Explain how the technique is helpful and why this should be important to your colleagues. The end of the discussion should contain a summary of the technique and its advantages in the take home message. Case selection, case study number, and case follow up should all be included.

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The Veterinarian's Role in Emergency Management

Wesley Bissett, DVM, PhD; Deb Zoran, DVM, PhD, DACVIM; Jen Kleman, DVM; and Leslie Easterwood, DVM, MA

Authors' address: Texas A&M Veterinary Emergency Team, Texas A&M College of Veterinary Medicine and Biomedical Sciences, College Station, TX 77843; e-mail: wbissett@cvm.tamu.edu.

1. Introduction

Climate change and the resulting increased severity of weather-related events remains a topic that is still being vigorously debated at the national level. Regardless of personal stance on this issue, there is mounting evidence that weather conditions in the United States appear to be trending toward weather events of increased severity. One indicator of increased severity of inclement weather patterns lies in the number of incidents that become federally declared disasters. The Robert T. Stafford Disaster Relief and Emergency Assistance Act of 1953 authorized the President to provide federal assistance to jurisdictions impacted by disasters.[2] The disaster declaration process begins at the local level with local disaster declarations being declared when the incident overwhelms local response capabilities. The next step occurs at the level of the state government followed by a federal declaration when state resources cannot meet the needs of the incidents and when the costs of responding to an incident reaches prespecified financial costs. An easy way to think about this is considering the financial triggers for a federal declaration as being similar to an individual's deductible that's paid prior to their insurance kicking in. In the case of a federal disaster declaration, the deductible is the amount of uninsured losses including the costs of response reaching a population-based level. While there have been adjustments in policy during the time since the Stafford Act was passed, there has been an increase in the numbers of declarations that have occurred (Fig. 1).

The discipline of Emergency Management has developed as a mechanism for jurisdictions to provide for their citizens by mitigating risks, developing emergency response plans, being involved in response, and completing the recovery process when disasters happen. Emergency managers follow an all-hazards approach with "all-hazards" being defined as extreme weather or natural events, man-made events including terrorism, or failures of industrial facilities and technological systems. The vast majority of incidents are handled by local first responders. These incidents are categorized as low-risk/high-frequency incidents. High-risk/low-frequency incidents are those that cause such severe damage that first local and then state resources are potentially unable to fulfill all response requirements.[4]

NOTES

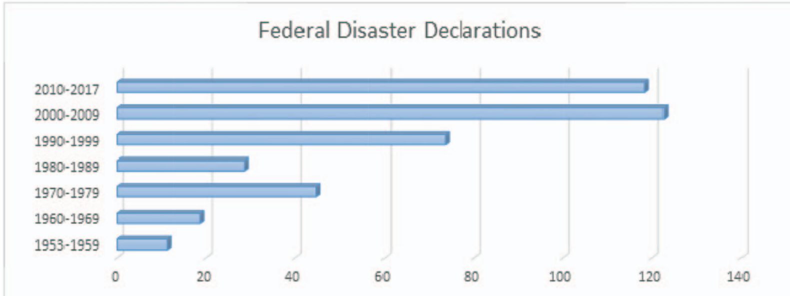

Fig. 1. Average annual federal disaster declarations by decade.[3]

An additional way to separate disasters is by the amount of prenotification that is provided prior to an incident. Hurricanes typically provide ample warning allowing mitigative steps to be taken and response plans to be coordinated prior to the incident occurring. No-notice events provide little to no advance notice and preclude pre-emptive mitigative steps. Examples include tornadoes, mudslides, explosions, and other spontaneously occurring incidents.

Disaster scenarios, with the exception of biological events, are in the authors' opinion, by their very nature, chaotic events with chaos often being at its worst during the first 24 to 48 hours. This chaos occurs for many reasons including loss of infrastructure, up-surge in physical threats, and influx of first responders, media, and the self deployed. Hurricane Harvey provides an excellent example of why this chaos occurs. This hurricane acted differently than expected during the immediate prelandfall period. It was, at a point within 72 hours of landfall, predicted to be not much more than a "rain event." This prediction did not trigger the normal evacuation and preparation protocols. By the time the hurricane intensified to a Category IV storm, evacuation of many coastal communities was not possible and many either had to make a hasty evacuation or "ride out" the storm. The Texas A&M Veterinary Emergency Team (VET) was deployed to Nueces County, Texas pre-landfall and was positioned at the National Guard Armory just west of Corpus Christi, Texas. Team members deployed into the field shortly after landfall and were met with numerous destroyed buildings, downed trees and power lines, and a general loss of normal infrastructure. Landfall had introduced a number of risks including the potential for sudden collapse of damaged buildings and trees, electrocution, torrential rainfall and subsequent flooding, and potential for toxic exposures in contaminated floodwaters.

It is important at this point to understand the differences between the majority of the first-response community and those focused on responding on behalf of animals. Firefighters, emergency medical technicians (EMTs) and paramedics, and law enforcement officers constitute what many typically think of as first responders. National standards for firefighters have been established by the National Fire Protection Association and provide guidance for a wide range of activities that may occur across the different stages of emergency management.[5] Law enforcement officers also work under established standards, in the case of Texas, regulated by the Texas Commission on Law Enforcement.[6] EMTs and paramedics operate under similar codes and regulations. These first responders are in addition, employed by local and state jurisdictions. They have a similar "language", organizational structure, and standards of training for working in hazardous environments. They, as well as elected officials and other governmental employees, have legislated requirements for protecting their citizens and property within their jurisdictional areas.

The characteristics described above differ from the general public and specifically from those involved in animal-related industries. The majority of veterinarians and veterinary technicians are engaged in the performance of "small-business" operations or are employed by corporate veterinary medical companies and are not gainfully employed by governmental entities. This community is exquisitely trained to perform preventive, medical, and surgical interventions but most do not have the training that is required for operating in a disaster theater, nor are they able to be self sustaining when normal infrastructures are compromised. These characteristics combined with the risks and responsibilities of government and the training of organized first responders often leads to problems during the response phase of emergency management. These problems often stem from animal-focused first responders not understanding the approaches that are employed by local jurisdictions to protect life, health, and property of first responders and citizens, the accountability that is required across layers of government, and the inability to be self sustaining in an infrastructure-poor environment.

National Incident Management System

The National Incident Management System (NIMS) was established in the aftermath of the 2005 Hurricanes, Katrina and Rita. These storms demonstrated the need for a comprehensive approach for incident management that spans all levels of government. NIMS provides the framework that allows all levels of government, the private sector, and nongovernmental organizations to respond to a disaster in a cohesive and coordinated fashion without usurping local control of incident response.[7]

A key component of NIMS is the Incident Command System (ICS). The ICS is a management system used for managing disaster response. It is organized into 5 functional areas including command, operations, planning, logistics, intelligence, and finance, and administration.[8] Understanding ICS is a foundational concept that must be understood and adhered to by all involved as first responders. It is also important to recognize that the decision to respond to a disaster is not solely an individual decision. Individuals do not have the right to decide on their own that it is appropriate to rush toward the scene of a disaster. The reason for the decision not being up to the individual lies in the chaos that is created by the disaster and jurisdictional requirements to protect life, health, and property with the safety of the first responder being the highest priority. Self deployment puts the veterinarian in a position of legal risk given that the statutory protections afforded to first responders do not apply to the self-deployed and professional liability policies may not extend into the disaster theater. Many jurisdictions require people to be credentialed to participate in disaster response and the absence of credentials may put the person at legal risk. The self-deployed volunteer is also at a disadvantage from the perspective of having access to resources that may be necessary to support themselves and deliver veterinary medical care in the incident. This often results in the self-deployed volunteer becoming an additional problem for the jurisdiction to deal with. An additional consideration is that all jurisdictions should have animal-focused emergency plans. A component of these plans is a process for ensuring that animals are reunited with their owners. There are numerous anecdotal examples of self-deployed volunteers either intentionally or as a result of a lack of awareness of local plans, transporting animals out of the area thereby excluding any potential for reuniting with their owner.

The process for deploying a first responder or team depends on the level of government under which you are operating. In the case of a local response, the order or request to deploy will come from either the county judge, mayor, or their designee. The process for deploying a state-level asset is more complicated and is described below. The process depicted is based on the Texas model. Other states will be similar but there may be slight differences.

1. A request for assistance (ICS form 213) is developed at the local level by emergency services officers or office of emergency management. Note, in Texas this is a State of Texas Assistance Request (STAR) form and in other states the form may be designated differently as well.
2. In Texas, the STAR is reviewed by the District Disaster Committee to determine whether regional resources capable of meeting the need may be available.
3. If not, the STAR (ICS 213) is sent to the State Emergency Operations Center where it is either approved or not.
4. State-level teams only deploy under a state-approved request (STAR).

Resource

The American Association of Equine Practitioners (AAEP) and its charitable arm, The Foundation for the Horse, can also serve as resources. A network of people, following the above protocols, is important; these two groups can help connect you with like-minded, caring professionals in your area. The Foundation may also be able to provide financial support during times of need, and its staff may be able to assist with communicating your needs to other practitioners, industry partners, and suppliers, again, following the above protocols.

The Foundation for the Horse also invites AAEP-member veterinarians in the United States and Canada to join its State & Provincial Equine Emergency & Disaster (SPEED) network. The SPEED Veterinary Liaisons serve as disaster communication liaisons. A major goal of this network is to facilitate communications regarding urgent needs, longer-term needs, overall status, and where resources will be most useful for the wellbeing of horses, especially during times of disaster.

For more information about the SPEED network or resources from The Foundation for the Horse or AAEP, please contact Keith Kleine at kkleine@aaep.org.

Participating in Organized Emergency Response

Veterinarians and veterinary technicians have several mechanisms for getting involved in emergency response including participating as an agent of the jurisdiction in which they are responding, becoming a member of a state-level team such as the Texas A&M Veterinary Emergency Team, Oklahoma Large Animal First Response Team, Florida SART, or the Louisiana State Animal Response Team, or becoming a volunteer with a nongovernmental organization such as the ASPCA, American Humane, or Code 3.

Self-deployed volunteers were a significant component of the 2017 Hurricane Harvey response. They no doubt saved human and animal lives, but there are significant disadvantages of being a self-deployed volunteer. The self-deployed sector is typically fragmented and based on individual decisions and standards. The level of training required is also an individual decision so people often go into situations for which they are not prepared. The self-deployed volunteer is also typically not able to mount a self-sustainable response, nor are they familiar with a jurisdiction's plans for managing the animal component of response. The Texas A&M VET responds with the equipment and supplies to be a completely self-supporting veterinary medical unit for up to 5 days and have developed the mechanisms of support that allow the team to be self sufficient for extended periods. In the case of Hurricane Harvey this was a 21-day deployment. The self-deployed volunteer may also not be cognizant of the risks they will face or the steps for mitigating the risks they will encounter. The reality is that any of these may present an additional problem for an already-stressed community.

Participating as an agent of a local jurisdiction is an additional way to assist as a first responder. This approach is highly recommended and can be accomplished through being written into a local jurisdiction's emergency plan or via a Memorandum of Understanding, Memorandum of Agreement, or an emergency contract. These all provide a recognized role and the ability to interact with and benefit from the rest of the first-responder community. They also provide a measure of liability protection. Liability protections will be discussed in a later session. Memoranda of Understanding should be carefully considered and all aspects of the agreement, including reimbursement mechanisms and requirements should be thoroughly reviewed.

State-level teams provide a mechanism for veterinarians and veterinary technicians to participate as a first responder. The Texas A&M VET provides the deployable veterinary medical resource in the state of Texas. Veterinarians may join the team through participating in the Texas Veterinary Medical Reserve Corps (TVMRC). The TVMRC is recognized at the state and federal level and is a component of the Medical Reserve Corps System organized under the Department of Health and Human Services at the federal level. Monthly training sessions and biannual exercise opportunities are provided to ensure that members are prepared for the rigors and risks associated with emergency response. They are also supported through a response and provided the tools with which to work and the support necessary to meet daily first-responder needs. The disadvantage is that deployments may be lengthy with a 14-day deployment being within the realm of possibility.

Training Requirements

The training requirements required of first responders is dependent on the type of response they will be involved in. This can range broadly depending on the assigned missions. The basic requirement that all first responders must have is a basic understanding and certification in the National Response System, National Incident Management System (NIMS), and the ICS. This training is available online at https://training.fema.gov/nims/.[9]

The courses that are typically required include the following:

- ICS-100: Introduction to the ICS
- ICS 200: ICS for Single Resources and Initial Action Incidents
- IS-700: National Incident Management System, An Introduction
- IS800: National Response Framework, An Introduction

Additional training may be necessary depending on the functions associated with one's participation in emergency response.

Conclusion

Participating as a first responder can be immensely rewarding on both a personal and professional level. The authors strongly recommend that participating in an organized fashion and recognize that there is a level of structure and organization that will likely be very different than what is experienced on a daily basis. This structure and organization is designed with safety as the highest priority, allows one to respond under the broad umbrella that is emergency response, and provides a level of accountability designed to ensure that animals and their owners are appropriately reunited.

2. Emergency Planning Structure

Emergency planning occurs across multiple layers with individuals, businesses, and local, regional, state, and federal levels of government all needing emergency plans for their area of responsibility. The focus of this presentation is involvement at the local level, but a brief discussion of each of the levels listed will be presented.

Individuals

Every family needs a plan that will allow the best opportunity to protect the health and wellbeing of all family members including their animals. Individual planning is also important for protecting the economic health of families.

Business Emergency Plans

Practice planning is covered in a different section, but all veterinary medical practices should develop emergency plans focused on protecting the health and well-being of staff, clients, protecting financial investments made in the practice, and allowing continuity of operations in the face of an emergency or disaster.

Local Jurisdictions

All emergencies begin and end locally. This simple statement implies a tremendous responsibility for local jurisdictions, elected officials, and employees. The planning effort is housed in the Office of Emergency Management. These offices can range from a part-time employee, an employee with additional duties, to a multi-person unit depending on the size of the jurisdiction. Animal-focused plans that are needed in all jurisdictions include emergency animal evacuation, rescue, veterinary medical support, mortuary management, and sheltering plans. Many emergency managers do not have animal-specific knowledge and may be unaware of many of the nuances that must be considered when planning for owners. They may also be unaware of the implications of the human-animal bond and the financial and cultural significance of agricultural species. The diversity of thought required to achieve the best plan requires a diverse audience of planning participants including veterinary medical professionals, extension agents, animal control officers, animal sheltering and welfare organizations, and representatives from agricultural entities.

Regional

Counties may elect to join and develop regional emergency plans. This may be performed when two counties agree to support each other and involve multiple counties organized into Councils of Governments. Regional planning allows resources to be pooled to support larger-scale responses.

State

The responsibility for planning for animals at the state level is typically ceded to Departments of Agriculture or Animal Health Regulatory Agencies. The Texas Animal Health Commission is the lead agency in Texas and is responsible for leading planning efforts for both household pets and livestock.

Federal

The Federal Emergency Management Agency (FEMA) in the Department of Homeland Security is the lead entity at the federal level. FEMA has delegated part of this responsibility to the United States Department of Agriculture in the case of infectious diseases in agriculturally important species and Department of Health and Human Service in the case of veterinary medical support. The National Guard also serves as a significant federal resource and has historically received mission assignments supporting animals.

Types of Emergency Plans

The two types of plans important to this discussion are operational and tactical plans.

- Operational plans link strategic or high-level goals with tactical plans. Protecting animal health and welfare is an example of a strategic goal. Operational plans define the missions, objectives, and responsibilities of what the plan is to accomplish and who will be responsible for accomplishing each component. "Who" is often defined as a department or agency rather than an individual. Operational plans should address animal evacuation, rescue, shelter, veterinary medical support, and carcass disposal or mortuary management.
- Tactical plans are focused on how missions will be accomplished and how operations will be performed. Tactical planning is critically important to the animal-focused areas of emergency planning given the diversity of the stakeholders and the fact that few of these stakeholders are directly involved as first responders on a daily basis. Tactical plans should detail the approaches to be used for animal evacuation, rescue, shelter, veterinary medical support, and carcass disposal or mortuary management. Tactical plans for a specific function should be developed prior to an incident and then reviewed and adjusted as daily mission requirements evolve.

Emergency Planning Process

A complete discussion of the planning process is beyond the scope of what can be provided in this presentation and proceedings. The following should be considered an overview discussion. The following points of consideration should be addressed regardless of which tactical plan is being developed.

Hazards and Risks

Identify the risks and hazards that have the potential to result in the need for emergency operations. This analysis should be broad and include natural disasters, including infectious diseases manmade or incited, incidents, and transportation accidents. It can be helpful to categorize the hazard by likelihood and consequence.

Animal Populations

Identify the approximate number of each species. The American Veterinary Medical Association (AVMA) Pet Calculator provides an estimate of pet populations based on the human population.[4] It is important to note that the AVMA Pet Calculator provides estimates for the horse population as well. The estimate that is provided is based on national averages and may need to be adjusted for regions where horse ownership is more prevalent. It is important to note that agricultural animals can be very difficult to evacuate out of harm's way and also present unique challenges during the response scenario.

Available Resources

A key part of the planning process is identifying resources that will or may be available for emergency response purposes. Resource categories to consider include the following:

- Human resources: The diverse groups that are necessary have been previously discussed. The important consideration is to include them in the planning process. Consider including personnel from the fire department when working on a tactical animal rescue plan.

- Facilities: Most areas of animal-focused emergency response require some type of facility. Many communities plan on using their existing animal shelters. The issue with this approach is that these typically are near capacity and cannot accommodate the needs created by a large-scale emergency or disaster. It is appropriate to consider using non-purpose designed structures. The most commonly encountered by the authors' team is livestock show facilities. These can be used to safely and humanely shelter large and small animals if appropriate biosafety and animal containment measures are factored into the plan. **It is not typically recommended that veterinary practices be used as jurisdictional resources.** The reasoning is that most communities cannot reimburse for associated expenses and use of the practice represents a significant financial burden for the practice owner. It also places the practice in a situation where they are basically providing for some animals at no cost while charging for those whose owners are present.
- Tools of the trade: The analogy the authors' most often used when discussing this area is that a fireman would not be sent to an apartment fire armed only with a garden hose. The same concept applies to animal focused emergency plans. Animal professionals, particularly veterinary medical professionals, are highly trained. They will be most effective when they have the tools of their trade.

Operational Approach

Think of this section as a cookbook. Define the A to Z steps for performing whatever function being planned.

Veterinary Medical Professional's Role

Animal-focused emergency plans require the input of people with knowledge of animal behavior, disease prevention, animal welfare, nutrition, and veterinary medicine. The veterinary medical professional is the one professional area that has a broad knowledge of all these topics. Knowledge is sorely needed, and investment of time and effort will yield a more effective response. The place to start is introducing yourself at the Office of Emergency Management. Most emergency managers are highly compassionate, skilled, and dedicated to serving people in the community.

Planning Resources

The planning process can be a daunting challenge. There are numerous resources that are available. One is the planning program available under the Texas A&M VET. Instructor-student teams that will travel to your community and assist in the planning process will be provided. These teams typically do most of the writing process and can typically bring a plan to 90% completion within a 2-week period. This service is available at no cost. Email Wesley Bissett at wbissett@cvm.tamu.edu if you are interested. The Texas A&M VET also have planning templates that you can access on the Texas A&M VET Web site.[17] Additional resources are available from animal health agencies.[18]

3. Injuries and Illnesses Commonly Encountered in Disaster Response

Introduction

Disasters invariably impact animals in some manner. They may be displaced, injured, highly stressed, or have chronic or undetected diseases worsen due to the stress of the situation or the inability of the owner to provide necessary medications. The types of injuries, illnesses, and goals of treatment vary with type of incident and the phase of emergency response operations. The following discussion is based on the experiences of the Texas A&M Veterinary Emergency Team across multiple deployments and tactical planning missions. The phases of emergency response that will be discussed in this presentation include evacuation, rescue, veterinary medical operations, and emergency sheltering. The perspective of the presentation is from the view of veterinary medical professionals responding on behalf of a local jurisdiction.

Evacuation

Pre-Incident Evacuation

Evacuation of animals can be separated into two distinct timeframes; *pre-incident and post-incident.* Hurricanes provide the best example of a pre-incident evacuation. Weather forecasting provides forward-leaning information and the ability to move nonagricultural animals from an impact area to one that is anticipated to be minimally impacted or not impacted at all. Human evacuees can also be separated into two distinct populations; the *self evacuees and functional- and access-needs citizens*. Jurisdictions have a statutory requirement for providing for evacuation of household pets belonging to functional- and access-needs citizens. The layman's description of a functional- or access-needs citizen is someone who will need assistance from a governmental entity to evacuate. There are many reasons a person may fall into the category of a functional- or access-needs citizen. These include health, economic, and self-mobility status. These scenarios may also indicate at least the potential for difficulties in accessing veterinary medical care for pets that will be evacuated. Animals may also be subdivided into two groups; household pets and livestock. FEMA defines household pets as "A domesticated animal, such as a dog, bird, rabbit, rodent, or turtle that is traditionally kept in the home for pleasure rather than for commercial purposes, can travel in commercial carriers and be housed in temporary facilities. Household pets do not include reptiles (except turtles), amphibians, fish, insects/arachnids, farm animals (including horses), and animals kept for racing purposes."[19] Livestock are defined in the Texas Agriculture Code as "Livestock means cattle, horses, mules, asses, sheep, goats, llamas, alpacas, exotic livestock, including elk and elk hybrids, and hogs, unless otherwise defined."[20] These are important distinctions given that it creates two classes of animals, one being household pets for which support is required statutorily and associated costs associated with this support is reimbursable during federally declared events and the second is livestock for which support under the Stafford Act will likely be limited to indirect response efforts. The United States Department of Agriculture will usually provide support through the USDA Livestock Indemnity Program.

The discussion means that veterinary medical support performed on behalf of a jurisdiction will be limited to household pets belonging to functional and access needs citizens during the evacuation phase. The goals of this veterinary medical support will likely be as follows:

- *Identify household pets that are not healthy enough to withstand the rigors of evacuation*. Animals that are not healthy enough to undergo evacuation create a second issue for jurisdictions in that there should be a plan for what will happen with these animals.
- *Categorize animals' risk status.* The Texas A&M VET recommends segregating animals into three categories.
  —Low-risk: The animal is healthy and does not represent a risk for other animals being evacuated, to human evacuees, or to the personnel performing the evacuation.
  —High-risk: The animal either due to a disease or behavioral condition represents a health threat to first responders and other animals and people being evacuated.
  —At-risk: The animal is considered to be an elevated risk for contracting diseases from others. This may be the result of age or medical conditions.
- *Stabilizing animals being evacuated.* This may involve treating a medical condition or pharmaceutically manipulating an animal's behavior.
- *Performing external parasite control.* This is performed to protect people, animals, equipment, and facilities.

Medical conditions that may be encountered during this phase of response are the same as what would be expected to be presented at a typical veterinary medical practice. There is an increased likelihood for injuries associated with conflicts between animals particularly if a jurisdiction does not have a good plan for segregating animals. **If a person is bitten, the same rules regarding potential rabies exposures apply. These rules are not waved because of the disaster setting. This applies across all phases of emergency response.** Providing treatment for external parasites will be helpful in limiting issues with the parasites establishing infections on other animals being evacuated or "setting up house" in vehicles used to transport animals to a receiving shelter.

Post-Incident Evacuation

Post-incident evacuation is defined as the evacuation of animals after the incident occurs and prior to a direct impact on the animals. Chemical plant explosions and transportation accidents provide one of the best examples of this type of evacuation. The issues discussed under pre-incident evacuation applies to this period as well. The differences between the two time frames are as follows:

- All species may be evacuated.
- Animals belonging to citizens other than the functional and access needs population may be supported.
- Evacuation will likely be hasty.
- The need for animal decontamination must be considered.

The goals of post-incident evacuation are the same as discussed above as are the conditions that can be expected. If evacuation is performed because of an explosion or other such event, behavioral changes, traumatic injuries, and ear injuries may be seen.

Rescue

Animal rescue operations may involve any species and the decision to intervene on an animal's behalf will be made by the jurisdiction and first responders that are on scene. A key point is understanding that the safety of first responders is always the highest priority. The goals of veterinary medical support during the rescue phase are as follows:

- Determine whether a rescue or recovery is appropriate.
  —A rescue is appropriate if the animal's condition is survivable given the support that can be provided in a disaster setting.
  —A recovery is appropriate when the animal's condition is not survivable given the support that can be provided in a disaster setting. Humane euthanasia is appropriate in these cases.
- Stabilize the patient prior to rescue and provide necessary care immediately after.
- Pharmaceutically intervene if necessary to protect the health and life safety of the animal and first responders.
- Provide animal-specific safety instructions to first responders.

- Ensure that rescue techniques do not create additional injury.

Medical conditions that may be encountered during the rescue phase are typically traumatic injuries such as abrasions, lacerations, fractures, burns, and chemical exposures. The Texas A&M VET has also found that dehydration is a common finding. This can occur even if the rescue is being performed in floodwaters. Animals will often not drink contaminated waters associated with flood conditions. It is important to recognize that definitive resolution of the injury or illness will not be performed during rescue operations. The goal is to stabilize the patient to the point that it can be safely rescued without making injuries and illnesses worse.

Veterinary Medical Operations

Veterinary medical operations is considered to be the phase of emergency response where animals are being presented to the veterinary medical team. There are several different characteristics that are different than normal practice experiences that are worthy of consideration.

- Most animals that are received will present without owners. They may be delivered by animal control officers, rescue groups, and good Samaritans. This means that the animals will not have normal historical findings and owner wishes into the decision-making process cannot be factored in. **It is important that the location from which the animal was rescued is documented.** This is a key piece of information that is necessary for the animal-owner reunion process.
- Many animals may be relatively normal with only minor or pre-existing conditions.
- Euthanasia decisions may need to be made in the absence of the owner. If responding as an officially recognized component of the response, presented animals will be considered as "wards of the jurisdiction." Establish the jurisdiction's expectations on these types of counties. The Texas A&M VET has been in a range of situations from limiting treatment to triage and stabilization where serious conditions are not treated to those where the jurisdiction wishes to do everything possible up through surgeries in order to save animals. The position of the VET is that animal welfare ultimately drives the decision-making process. If a jurisdiction does not wish to pursue extraordinary measures, the goal becomes keeping the animal comfortable until other options are identified. In cases where it is not humane to continue, and an owner is not available to provide consent for euthanasia or has not been identified, concurrence of two veterinarians is required before an animal will be euthanized.

The types of injuries that the authors have experienced during the deployments of the VET have varied with the type of disaster being responded to. A full discussion is beyond the scope of what can be provided in these proceedings so an overview is provided.

High-Wind Events

High-wind events such as hurricanes and tornadoes result in injuries that would be anticipated with high-velocity airborne debris impacting animals. Lacerations, puncture wounds, abrasions, soft-tissue injuries, and fractures are routinely encountered. Ophthalmic injuries are common and ear canals may be packed with debris.

Wildfires

Burns are the most common feature of this type of response. It is important to thoroughly evaluate hooves, paws, and udders as severe burns of these structures may result in chronic pain and lack of production. This is particularly important in livestock. Respiratory disease is a common finding as well with conditions typically increasing in severity over several days. Veterans of multiple wildfire deployments will often recommend salvaging by slaughter livestock that present immediately after the wildfire if mild lameness or respiratory disease is noted. The reasoning is that these conditions typically become much worse over 3 to 4 days. Dehydration is, as with most types of disaster, a common finding.

Floods

Responding to floods has been the most common reason for deployment of the Texas A&M VET. The VET has encountered numerous animals with submersion injuries. Most of these have been livestock. The authors' opinion is that more submersion injuries in large animals than small animals because small animals are seen will either reach a structure of some sort that will allow them to get out of the water or unfortunately drown. Submersion injuries may develop with less than 24 hours of exposure. The authors' opinion is that this occurs as a result of high bacterial and viral loads in floodwaters, velocity of flood waters, and increased sediment rates. Thoughts are that these combine to result in rapid damage of the epidermis. Submersion injuries are characterized by pitting edema and devitalization of the skin. These can be exceptionally challenging to treat given that these animals are very painful and susceptible to secondary infections. The VET has also encountered respiratory disease as a common secondary illness as well. Working with animals that are rescued from floodwaters comes with a significant risk to first responders. Animals should be decontaminated and personnel should wear personal protective equipment.

Gastrointestinal disease is also a common finding in flood impacted waters. Floodwaters are, as noted earlier, very contaminated. Bacterial and viral loads are typically elevated and waters often also contain a variety of toxic substances.

Explosions

Explosions result in similar issues as noted in high-velocity wind events. Additional issues that have been commonly encountered are ruptured eardrums. Pain management is a critical feature in successfully dealing with these cases.

Emergency Animal Sheltering

The conditions encountered while providing veterinary medical support for emergency animal sheltering operations are very similar to what is typically found in practice. There will be animals with chronic diseases and conditions that must be managed. Animals may decompensate due to the stress of being in an unusual environment. Stress-induced diarrheas are also a common finding. It is important to establish biosecurity measures to limit the spread of disease to other animals and people.

Conclusion

Serving as a first responder is the most professionally rewarding aspect of one author's (W.B.) 21-year career. It can be difficult and dangerous. It is exhausting. The key to responding well is to do so according to a tactical plan that has been developed with the risks and animal populations that are in your area in mind.

4. Decontamination, Triage, Field Euthanasia Decisions, and Other Important Veterinary Roles in the Disaster Environment

Decontamination (Decon)

Natural disasters and emergencies are an all too frequent increasing reality of daily life. Disaster situations often result in the intentional or unintentional release of hazardous materials into the environment. The Agency of Toxic Substances and Disease Registry estimates that in 2012 more than 15,000 chemical incidents occurred in the United States.[2] In addition to industrial accidents, disasters such as the World Trade Center terrorist attack, Hurricanes Katrina, Maria, Harvey, Michael, Florence, and Dorian, and the multiple wildfire events in the Western United States have all resulted in the release of hazardous materials into the environment. In addition to the debris left behind, destruction of buildings in any disaster can result in the release of asbestos, polycyclic aromatic hydrocarbons, metal compounds, dioxins, and volatile organic compounds liberated in the wreckage. The flooding associated with the multiple major hurricanes of recent years has led to the mixture of hazardous materials from damaged chemical plants, petroleum refining facilities, and commercial establishments into the environment, not to mention just the waste present from sewers and waste water facilities that is released/mingled into the floodwater. In each of these situations, the introduction of hazardous materials into areas that were occupied by survivors, S&R teams, and resident animals created a significant risk to human and animal health.

Animals (both companion and large animals) that are impacted by disasters are frequently exposed to these hazardous materials. In some cases, the contaminants are primarily external (e.g., as is the situation where horses are rescued from a contaminated environment where they have been standing in flood water). However, internal decontamination is also a very real concern for all animals rescued from a disaster environment as internalization of contaminates, from drinking contaminated water or eating contaminated foodstuffs, or through absorption or inhalation of hazardous substances (e.g., from smoke or chemical releases). Regardless of type, the presence of contaminants may result in potential serious or life threatening health complications. To mitigate the exposure and potential health consequences from contaminant exposure, decontamination (particularly external) is a critical step in disaster response activities on behalf of animals. This is also essential to the health and safety of humans who will be handling and caring for them, and for the prevention of contamination of their shelter and future home environments. It is important to identify the types of contaminants that may be involved. Hazardous Material specialists tasked to the deployment are excellent sources for guidance on decontamination approaches and requirements for personal protective equipment requirements. An additional resource is WebWiser©. WebWiser is a web-based program provided by the National Library of Medicine and is an excellent tool for identifying and finding out more information on chemical contaminants. It is available at https://webwiser.nlm.nih.gov/.

Decontamination is the process of removing contaminants from people, animals, equipment, structures, and the environment (Kumar et al, 2010). Decontamination protocols are devised to eliminate exposures to hazardous materials and reduce the spread of contamination. While decontamination is utilized to reduce human and animal exposure to surface (skin/coat) contaminants, there are many challenges associated including efficacy, safety, and methods of decontamination. There are anecdotal protocols that are designed for veterinary clinics and disaster situations based on a single contaminant incident. In current literature, animal decontamination protocols are based on the basic principles of leading animals through multiple stations that involve the removal of contaminated articles (collars, halters, other removable wearables), washing and rinsing the animal, and finally drying and performing a veterinary evaluation. These decontamination practices are the recommended practice for both large- and small-animal incidents for a vast range of chemical, biological, and radioactive exposures.

Decontamination procedures use both gross decontamination and technical decontamination techniques. It is important to recognize that harmful effects of some contaminants is exacerbated by water and dry contamination is required. When a wet decontamination is appropriate, gross decontamination removes the majority of surface contamination by using large amounts of water to rinse off loose particles from the animal's coat. This stage accounts for the bulk removal of the contamination. Technical decontamination is a multi-step process that encompasses a detailed removal of the hazardous material from all external aspects of the animal's body. Methods utilized include "brushing, vacuuming, and washing, to eliminate the contaminant from the animal;" however, in reality, washing remains the primary method by which materials are removed. In short, technical decontamination is an extensive process and may require repeating steps to ensure the complete removal of the hazardous materials or toxic agents. Historically, liquid dish soap has been the agent of choice for external technical decontamination. The physical properties found in liquid dish soap allow for binding and emulsification of particles and particularly oily substances that may bind or attach to the oils of the skin and hair follicles (Heyer, 2011). Other agents such as hypochlorite solutions and chlorhexidine solutions have been utilized for biological decontamination, but have the drawback of time dependency and inactivation. Hypochlorite solution typically requires 15 minutes and chlorhexidine requires 6 minutes of contact time with the skin to effectively denature biological agents (Heyer, 2011).

In addition, to the selection of soaps and setting up procedures for individual decontamination of horses rescued from a disaster environment, there is a critical need to consider the protection of the personnel performing the decon (personal protective equipment), protection of the environment from the contaminants (collection of waste water—itself a potentially massive volume), and need for a potentially very large number of personnel needed to complete the decon process (given a maximum time in personal protective equipment of 20 to 30 minutes in temperatures greater than 75°F, and a minimum of 3 personnel needed for each horse (1 person for restraint and 2 for washing, lathering, and rinsing). Finally, while data on water usage and time for decon procedures in horses is lacking, if one extrapolates from canine data, it will likely require more than 15 to 20 gal/horse and a minimum of 20 to 25 minutes per horse, thus making decontamination of a large number of horses in a disaster event extremely time consuming, personnel intensive, and require a large volume of fresh water (at least potable), which may be at a premium in a disaster. These data are not given to overwhelm, and it is recognized that veterinarians should not be the source of manpower for these procedures, but veterinarian oversight is critical, and the potential need for pharmaceutical restraint for those horses that are unruly or fearful, is a significant reality.

Triage in a Disaster Environment

Providing veterinary medical care during emergency or disaster situations is very different than the typical practice day for the following reasons:

- The number of injured or ill animals being brought to the veterinary medical facility may be much greater than the typical daily caseload.
- Animals will likely be presented by a rescuer rather than their owner.
- The owner may be unavailable to participate in decision making.
- The ownership status of the animal may often be unknown.
- Your facility may not be available or may be operating without the normal resources (power, water, ability to resupply, personnel shortages).
- Evacuation of animals to veterinary medical facilities capable of providing definitive care may be unavailable for many days or longer.
- Resources such as pharmaceuticals, supplies, and animal food may be scarce and difficult to replenish.

The issues identified above require that ground rules be set. In order to prevent a misunderstanding the veterinarians involved in the local animal disaster group (e.g., CART, VMRC, or other local group) need to know what the resources and expectations are for dealing with animal issues. For example, when the Texas A&M VET deploys into an area, county officials are asked how aggressive they want the veterinarians to be in providing veterinary medical care, develop the animal evacuation chain, and discuss with shelter partners the types and numbers of injuries they are prepared to provide continued care for. It has been the authors' experience that county officials understand the important role that animals play in their constituent's lives and that sheltering partners are prepared to provide substantial continued veterinary medical care. However, each disaster and local resources are different, requiring clear lines of communication and expectations that are set early.

It is also important to set the triage rules early in the deployment. Triage means literally "to sort" and is a critical process in the management of animals impacted by a disaster. An excellent discussion of triage is provided in "Veterinary Disaster Response" and is considered required reading for veterinarians and veterinary technicians wishing to participate in emergency response (Wingfield, 2009). The authors' team uses a slightly different system that is divided into field triage and veterinary med-

Table 1. Field Triage

Triage Category	Triage Color	Description
Immediate	Red	Immediate intervention required to preserve life or euthanasia is required
Delayed	Green	Likely to survive with or without intervention—may shelter in place
Carcass disposal	Black	Dead animals present

ical triage, and providing veterinary medical triage for injured or ill animals (whether they are large or small animals) is the focus.

In most circumstances, field triage will be provided by first responders deployed to the emergency or disaster—this may include law enforcement or animal control officers, but it also can consist of other search and rescue organizations or humane groups. This mix of professional responders results in a wide variation in accuracy of field triage categorization especially early in deployments. The system that the authors employ and recommend in field triage is very similar to that provided in Veterinary Disaster Response (Table 1).

5. Field Triage

The system that the Texas A&M VET has used is based on partnerships and the ability of the first responders to rescue animals requiring veterinary medical care or, in cases where first responders primary mission or animal temperament preclude rescue, reporting animal locations to animal control officers so that they can make the rescue. This system has generally worked very well, but, if rescues are made, it is critical that accurate rescue location be provided either in the form of a physical address, GPS coordinates, or both so that the animal has a greater chance of being reunited with its owners. In addition, it is imperative that the veterinary medical strike team recognizes the need for a short-term, finite response time and capacity so that the resources provided by local veterinarians do not impose an undue burden of time or expense on those businesses. In general, for planning and recovery purposes, the local animal response group (these groups are typically a combination of veterinarians, technicians, animal caretakers and others with animal handling experience) should only make plans for veterinary medical operations to last 48 to 72 hours. Local veterinary medical operations that exceed this time frame should trigger a discussion of the need for requests for additional assistance for the county, either in the form of requests for state veterinary medical assistance (e.g., other state-sponsored teams) or for 501c3 nonprofit agencies with animal issues/veterinary expertise.

6. Veterinary Medical Triage and Euthanasia

For most veterinarians and veterinary technicians, this aspect of emergency response is instinctive and natural—particularly for those who have worked in clinical practice and handled emergencies. However, while a practice may be well equipped and able to provide a high level of veterinary care to animals in a disaster, there are limits to what can be provided in a disaster setting that must be understood. These are limits in personnel, limits in resources (particularly drugs or other more expensive items), limits in time that can be devoted to an individual animal's plight, and limits in space (or ability to house, treat, or provide hospital care) for animals—each of these limits may require a triage decision that may not necessarily be considered ideal, but is essential for the greater good. For example, animals with severe lacerations that may be handled with wound management, antibiotics, and pain meds, can be successfully managed versus those that require an extensive surgical manipulation to repair. All members of the team must be able to discuss these decisions, and when disagreement is present, it is reasonable to have a hearing of all opinions, but ultimately, a final decision (triage) must be given. In all cases where euthanasia is recommended, a second confirmatory opinion must be agreed to— both for the health of the team and its cohesiveness, but also for the best interests of the animal's welfare, and the owner who may someday ask what happened. All euthanasia decisions and methods follow the AVMA Euthanasia Guidelines for euthanasia decision making as well as for methods. The latest version of the 2020 Euthanasia guidelines are currently available and are a key resource to keep close at hand: both for euthanasia decision making in a disaster setting for appropriate methods, but also for essential processes in situations where no owner is present.

There are several important aspects of medical triage, but key among them are good observation skills, excellent physical exam skills, and an ability to think and work quickly in an austere environment. The key to veterinary triage working well in a disaster setting is having cohesive, well-functioning teams. Strike teams of four or five individuals—typically a veterinarian, 1 to 2 technicians, and 1 to 2 assistants (often lay persons)—these teams are critical to a triage unit, as the veterinarian can move quickly from one animal to another, while technicians are able to perform necessary treatment tasks and assistants are available to restrain, record information in the medical record, or assist in other ways as needed. In a disaster, in order for the responding veterinary unit to be reimbursed for their supplies, drugs, and medical treatment given, there must be an excellent record of everything used. These records are as essential to the triage process as the act itself, as they will be necessary not only for helping to connect the animal back to its owner, but are absolutely essential for reimbursement process or in the situation of a euthanasia decision that must be made in the absence of owner consent.

7. Human Critical Incident Stress (HCIS)

What is critical incident stress? It is any event outside the usual realm of human experience that is markedly distressing and exceeds normal coping mechanisms. But, importantly, it is the individual that defines what "their" critical incident or event is. An incident that one may be able to easily cope with may noticeably affect another individual. All responders are exposed to critical incidents or stressors during deployments or while responding to disasters, so it is important to recognize and develop team and individual support systems and coping mechanisms for any and all people involved in disaster response. This is a key reason for team based response, as individuals who are self-deployed volunteers or those who do not have a team of people around them can be particularly vulnerable or have no support structures around them.

Critical incidents can range from any serious injury, death, or illness seen by a responder, whether it is someone they know or not, but it is absolutely not necessary that situation be personal—being involved in terrorism, responding to incidents with many affected animals or people, or both, and situations where there is a personal connection (location, situation involving people of similar ages or with children, responding when personally impacted by the event, etc). The bottom line is this: any event can trigger an emotional or stress response, even when prepared for it.

There are many types of symptoms such as physical, cognitive, behavioral, and emotional that can vary widely in severity from mild to extreme debilitation or dysfunction. The most common cognitive symptoms are nightmares, poor attention or problem solving/concentration, intrusive images, but any new or unusual symptoms may occur. Emotional and behavioral symptoms can range from fear, guilt, and grief to irritability, anger, depression or emotional outbursts—to withdrawal, inability to rest, increased use of alcohol or changes in social behavior—and each of these may occur immediately after the event to weeks or months later. The key is to understand and recognize that these are NORMAL people having NORMAL responses to a very ABNORMAL situation. It is also important to recognize that HCIS is NOT: 1) for those who "can't take it", 2) a sign of weakness, 3) counseling or psychotherapy, or 4) a critique of the response to the event. The approach to management of HCIS is education in awareness of this type of stress response, the importance of debriefing after an event, understanding how to defuse the feelings and where to find the support needed, such as friends, clergy, fellow responders, family, and professional CISM personnel. Defusing and debriefing through the use of peer counselors and mental health specialists, people who understand this work and what the veterinarian is experiencing, in any response are a key first step in the transition from being a first responder in action and returning to normal activities. This is particularly important for those who don't respond daily or weekly, such as veterinarians who leave their practice life to respond to a disaster on an occasional basis. Without exception, debriefing and defusing should only include those directly involved in the incident, are confidential, are safe (people who responders trust) and nonjudgmental. Defusing, which occurs immediately post event (12 to 24 hours) allows for symptom mitigation and debriefing, which occurs 24 hours to 4 weeks post event to facilitate psychologic closure, mitigation, and identification of those needing intervention following an event are the bandages that stop the psyche from bleeding. They are emotional first aid after a traumatic event or sequence of events. The process is designed to provide opportunities to vent the trauma and learn ways to cope, while also providing follow-up and help if needed.

Self care is a very important part of developing skills to help survive critical incidents and the stress they bring. It is crucial to keep work, play, and stress balanced and in control. It is also important to be aware of HCIS symptoms. Other helpful keys are to maintain good nutrition and schedules, including exercising regularly and getting rest. One of the most important things to remember is that it is each person's responsibility to themselves, their family, and the people and animals that are being helped to "remain in the game" by staying healthy. In addition, it is also as important to look out for partners and other team members ("battle buddies") and help point them toward help when needed.

8. Developing an Emergency Plan for Your Practice: The Importance of Personal, Practice, and Local Preparedness

Supplemental Information and Details on Planning

The Texas A&M VET has been involved in emergency preparedness and response since 2009 and has deployed to most of the disasters that have occurred in the state of Texas since that time. Each deployment has provided real-life examples of how veterinary practices and hospitals are threatened by one of the following:

- Direct damage to hospital or clinic with potential for injuries to patients, clients, or staff.
- Financial losses associated with non-reimbursement of response associated costs.
- Reduced future income potential associated with loss of client base. Future client base may be also be lost due to client fatalities, victims moving out of the impact area, or changes in client's financial status in the post-disaster environment.

The key to successfully navigating a disaster that impacts the practice or community is to commit to developing a practice or hospital emergency and continuity of operations plan. This is a deliberate process that should consider the types of disasters that occur, and the variety of hazards present in each practice and the community. It is helpful to separate the types of disasters into no-notice versus those incidents in which advance notice of an impending event is provided.

- No-notice event: These can be separated into those incidents that are clinic-centric and incidents in which the incident is external to the clinic or practice.
  —Clinic-centric: The best example of a clinic-centric incident is a fire involving a practice's structure.
  —External to clinic: Examples include flash-flooding, explosions, wildfires, and tornadoes. The Texas A&M VET has been involved in responses to each of these types of incidents.
- Advance-notice event: The best example of an advance notice event is a hurricane or winter storm. Weather forecasters monitor for these systems and provide advance warning for a significant amount of time prior to arrival. This provides the opportunity to mitigate risks associated with the impending incident.

Developing a Clinic or Hospital Emergency Plan

The following discussion will provide an overview of the process for developing an emergency plan for veterinary medical practices or hospitals. This is a complex process and a full discussion is beyond the scope of what can be provided in these proceedings. There are multiple resources available to provide guidance you through the process.[8–12]

Define Your Practice

The initial step in developing an emergency practice plan is to fully define the practice. This may seem counterintuitive, but it is easy to overlook key issues. Addressing the following issues or areas will allow you to have an accurate representation of the practice.

- Personnel and clients: Identifying these two populations will identify the number of people who may respond on behalf of the practice and the number of non-employees for whom the practoce has the responsibility of providing for their safety. A third population to consider incorporating into the planning process is external contractors who provide specific services for the practice on a contractual or as-needed basis.
- Patients: The number of out-patient and hospitalized animals should be calculated. The authors prefer basing this on maximum capacity as it prepares the practice to deal with the worst-case scenario.
- Data information system: Identify the systems used for management of patient records, financial accountability, and maintaining other important information such as employee records and insurance papers. The authors prefer electronic systems that are either cloud based or have an automated off-site backup feature.
- Equipment: Develop a list of all equipment and include brand, serial numbers, date of purchase, purchase price, and place of purchase. It can be helpful to keep photographs of equipment as well.
- List of resources that are available to be used as emergency response assets. This particular point is inward facing and intended to identify resources that may be used to respond on behalf of the practice rather than resources that may be used to respond as an agent of a local jurisdiction.
- Pharmaceutical and medical supply inventory: This inventory is rarely static and varies day to day. Electronic inventory systems provide the ability to maintain inventory awareness on a "real-time" basis, particularly when they are part of the medical records system.
- Contact information: Maintain a current list of emergency and service provider numbers. This should include law-enforcement agencies, regulatory agencies, and the Office of Emergency Management.
- As-built drawings for owned buildings: These will be helpful if a practice is damaged or destroyed because of an emergency or disaster incident.
- Financial projections for maintaining the liquidity of the practice based on pre-incident conditions.

Identify Risks

Risk identification or hazards analysis is a key component to developing an emergency plan for veterinary practices. It involves identifying those risks that are inherent in the vicinity of the practice. This process should include man-made and natural disasters, with infectious disease incidents being included under natural disasters. Man-made events may be classified as technological (power outages, chemical releases) or intentional (Terror attacks, mass shootings and other deliberate actions). It is important to include transportation accidents given the number of animals and volume of hazardous materials that are transported on highway and rail systems. It is also advisable to contact local jurisdiction's Office of Emergency Management as they will know of hazards that many may not be aware of. It may also be helpful to separate the risks into the following categories; those that are limited to the practice (e.g., structure fires) and those that have a broader distribution (e.g., wildfire, tornado, hurricane, winter weather, flooding).

Communications Plan

This plan should be separated into two areas, internal and external. Internal communications planning will involve detailing how all owners, employees, and other identified human resources may be quickly contacted when there is an impending incident or one that has just occurred. This can take a variety of different forms from a telephone calling tree to a group text message. The desired outcome is to have everyone communicated within a manner that gets everyone on scene or evacuated quickly without individually tying up key personnel that may be needed for other purposes.

There should also be a plan for communicating with animal owners. It is often preferable to discharge patients that can be safely discharged to their owners in cases of advance-notice events. No-notice events, particularly those that directly impact the practice, will typically result in heightened concern in owners of hospitalized patients. Consider the role of social media and how it may be used to broadly broadcast a message on the status of your clinic, employees, and patients. It is also important to have a plan on how the practice will monitor for and respond to negative or inaccurate social media posts.

Identify Goals and How They Will Be Accomplished

This will be the lengthiest section of the emergency plan. A full discussion of all the goals is beyond the scope of what can be provided in these proceedings and the following are provided as a starting point for the emergency planning process.

Life safety of employees and clients: This section should be given the highest priority and include plans for performing an immediate evacuation of the practice when the practice is threatened by incidents that are internal to the practice. Structure fires are an example of these types of incidents. It should include information on how the evacuation process will be initiated and communicated to all occupants. Primary and secondary meeting places will need to be identified so that all employees and clients can be accounted for immediately after evacuation.

Life safety should also be considered in longer-term events. One of the best examples is provided when veterinary practices continue to operate in the post-disaster phase in the absence of normal supporting infrastructure. The post-hurricane environment provides a good example. Many hazards can be part of the post-landfall timeframe including down trees, lack of electrical service, and structural damage. Protecting the health and wellbeing of staff and people that may come to a practice should be planned for in an attempt to mitigate any risks that may be present.

Life safety of patients: This will receive the second highest priority. This section should be separated into no-notice and advance-notice events. Providing for the life-safety of patients in no-notice events is focused on getting patients out of the facility as quickly as can be accomplished without introducing unmitigated risks to human resources.

Incidents for which advance notice is typically available provides more options. Discharging patients whose condition allows will typically result in reduction of care provided by clinic personnel. Patients that are not medically stable will require more advanced planning. It is appropriate to identify colleagues that may be able to receive those patients that cannot be discharged. Owners should be provided the opportunity to approve what cases they will be transferred to. If they do not wish for their animals to be transferred to those identified as receiving practices, then plans will need to be made on how animals will be transferred to other points of care.

No-notice events provide a different challenge than that discussed above in that patients may need to be evacuated at a moment's notice. The structure fire again provides the best example. Planning includes accounting for the safety of personnel that are evacuating patients, location to which patients will be evacuated, and how they will be contained after evacuation. As in the discussion above, thought needs to be invested in planning for where those patients requiring continued veterinary medical care will go assuming the practice being evacuated is no longer viable.

Pharmaceuticals, medical supplies, and equipment represent a significant investment and are critical to the ability of a practice to continue operations after disaster strikes. An evacuation plan and storage plan for supplies and equipment needs to be developed in addition to the documentation discussed earlier in this paper.

Preservation of important documents: This includes medical records, financial instruments, employee records, inventory information, and insurance policies. Electronic storage of these documents in a cloud-based system or off-site server can simplify this process.

Continuity of Operations

This is an exceptionally important area given the role veterinary practices play in providing employment and service to communities. The reality is that disaster scenarios typically cause negative consequences on a practice's business model. These consequences include but are not limited to the following:

- Direct damage to the veterinary practice structure.
- Loss of key personnel.
- Reduced future client base.

- Reduced disposable income for remaining clients.

Some of these risks can be mitigated by hardening the practice when there is advanced notice of a severe-weather event and investing in emergency electrical generators. It will also be helpful to consider where a practice may be relocated if the current structure is destroyed or requires significant repairs. Monitoring of available lease space and having an established relationship with a real estate professional will provide the best opportunity for quickly relocating the practice. It is also good business to understand cash-flow requirements for maintaining current staffing levels. Disasters are anticipated to cause at least a temporary decline in cash flow. It will be important to understand when to lower expenses so as to maintain the long-term practice viability.

An area that is often overlooked is planning for infectious disease. Infectious diseases that can disrupt practice activity are typically considered to be in the livestock realm given the number of regulated diseases. The reality is that viruses and bacteria are continuing to adapt and the appearance of a novel strain that potentially impacts other species and may be zoonotic are always possible. Canine influenza has, as of this writing, not been shown to cause clinical illness in people, but given the potential for reassortments and genetic shifts or drifts, this is not outside of the realm of possibility. Plans identifying how animals and people may be moved on and off the property without resulting in the spread of the disease in question can be developed. These must be developed in conjunction with the USDA and state-level animal health regulatory organizations. It is also helpful to define how personnel will be protected in cases where the disease in question is impacting human populations.

Participating in Organized Emergency Response

Planning for animals in disasters is still not where it needs to be. The authors have worked with some communities that plan for the local veterinarians to play a major role. This is something the authors support, but the reality is that most jurisdictions cannot pay for these services. This places the local veterinarian in the position of performing work for free when there are no owners present and deciding if they will charge when an owner is available. It is recommended that practices define how they will participate and include financial aspects in this decision. This should be discussed with the local jurisdiction. It is appropriate to define the length of time to respond, financial limits, and what the jurisdiction will do when these are exceeded.

Conclusion

Practice planning is beyond what can be fully discussed in these proceedings. It is a complicated process but fortunately, there are resources available. The template available at the link in the fourth reference is excellent. The Texas A&M VET, first reference, also has templates available. The VET can also bring instructor-student teams to assist in the process. This service is available at no to minimal costs.

9. Developing Emergency Plans for Animals at the Local Level

Introduction

As noted in earlier discussions, it appears that adverse weather conditions are occurring more frequently and becoming more severe. The last 2 years have seen 800- and 1,000-year floods, landfall of a Category IV hurricane, and historic flooding from Wharton County, Texas, to the Louisiana Border. Northern California has recently experienced devastating wildfires. There has been an active volcano in Hawaii that destroyed homes and impacted rural areas. Numerous wildfires in New Mexico, Colorado, and California, and flooding in the Northeast and Northwest have occurred as these proceedings were being crafted. Each of these disasters are impacting thousands of people and animals. Some of these communities have robust animal-focused plans while others do not. Planning for and responding on behalf of animals is always a secondary priority at the local, state, and national level with protection of human life and safety appropriately receiving the highest priority. The two things learned from the numerous deployments of the Texas A&M VET is that robust and well-thought-out animal-focused tactical plans make a significant difference in the efficiency and effectiveness of animal-focused response efforts and that the highest-priority mission, providing for the human condition, cannot be fully accomplished without providing for their animals.

Emergency Preparedness Overview

Emergency management consists of multiple phases including mitigation, preparedness, response, and recovery.[13] This presentation is focused on the preparedness or planning phase and how the veterinary medical professional is critical to successfully achieving the desired outcome. FEMA has developed the *Developing and Maintaining Emergency Operations Plans Comprehensive Preparedness Guide (CPG) 101* to guide communities through the planning process.[14] This document provides basic principles, discussed below, that are broadly applicable to all communities across the United States.

- *"Planning must be community-based representing the whole population and its needs."* Prior to Hurricanes Katrina and Rita, animals were not a legislatively mandated target of emergency planning. These two storms demonstrated the need for emergency planning for animals and federal legislation requiring inclusion of animals in emergency efforts passed.[3]

- *"Planning must include participation from all stakeholders in the community."* The stakeholder community for animal-related planning is an exceptionally diverse community ranging from pet owners, agriculturally based industries, animal control officers, livestock officers, animal welfare groups, extension agents, and veterinary medical professionals. The level of diversity in this stakeholder group is increased as compared to other planning areas. An additional complication is that some of the different stakeholder groups have diametrically opposed thoughts and goals.
- *"Planning uses a logical and analytical problem-solving process to help address complexity and uncertainty in potential hazards and threats."* The clinical problem-solving approach employed by veterinary medical professionals is ideally suited for emergency planning.
- *"Planning considers all hazards and threats."* While the causes of emergencies can vary greatly, many of the effects do not.
- *"Planning should be flexible enough to address both traditional and catastrophic incidents."*
- *"Plans must clearly identify the mission and support goals (with desired results.)"*
- *"Planning depicts the anticipated environment for actions."* The environment in which emergency and disaster operations occurs is markedly different than that encountered on a typical day. Accounting for this difference is critical in accounting for the safety of first responders and understanding what resources will likely be available.
- *"Planning does not need to start from scratch."* Each stakeholder brings different skills and protocols into the planning process. These represent a starting point that allow planners to not have to recreate the wheel.
- *"Planning identifies tasks, allocates resources to accomplish those tasks, and establishes accountability."* The important point here is that during a response, the animal-focused tasks primarily focused on preserving the health and well-being of animals and maintaining their normal relationship with their owners, is not that different from what practitioners do daily. The environment in which one performs, however, can be vastly different.
- *"Planning includes senior officials throughout the process to ensure both understanding and approval."* This is a critically important point. The reality is that a veterinary medical professional may be engaged under the typical veterinarian: client relationship or acting as an "agent" of the jurisdiction. Acting as an agent of the jurisdiction requires an understanding that actions are being performed to accomplish the goals of the jurisdiction in a manner that they approve of.
- *"Time, uncertainty, risk, and experience influence planning."* The Texas A&M VET has been actively engaged in the planning process from the time of it's inception. The multiple deployments and joint planning efforts with jurisdictions have influenced the planning process. Being a responder makes for better planners and being a planner makes for better responders.
- *"Effective plans tell those with operational responsibilities what to do and why to do it, and they instruct those outside the jurisdiction in how to provide support and what to expect."*
- *"Planning is fundamentally a process to manage risk."*
- *"Planning is one of the key components of the preparedness cycle."*

Acknowledgments

Declaration of Ethics

The Authors have adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Authors have no conflicts of interest.

References

1. Blake ES, Zelinsky DA. National hurricane center tropical cyclone report (AL092017). National Oceanic and Atmospheric Administration. May 9, 2018. Available from: https://www.nhc.noaa.gov/data/tcr/AL092017_Harvey.pdf.
2. National Weather Service. NWS weather fatality, injury and damage statistics. 2017. Available from: . Accessed October 11, 2017.
3. NOAA National Centers for Environmental Information. Billion dollar weather and climate disasters: Table of events. 2017. Available from: https://www.ncdc.noaa.gov/billions/events/US/2007-2016. October 11, 2017.
4. U.S. Fire Administration, Federal Emergency Management Agency. Operational lessons learned in disaster response. 2015. Available from: https://www.usfa.fema.gov/downloads/pdf/publications/operational_lessons_learned_in_disaster_response.pdf.
5. National Fire Protection Association. Codes and standards. Available from: https://www.nfpa.org/Codes-and-Standards/All-Codes-and-Standards/List-of-Codes-and-Standards. Accessed May 23, 2018.
6. Texas Commission on Law Enforcement. Available from: https://www.tcole.texas.gov/. Accessed May 24, 2018.
7. Federal Emergency Management Agency. National incident management system. May 15, 2018. Available from:
8. Federal Emergency Management Agency. Incident command system resources. November 15, 2017. Available from:
9. Federal Emergency Management Agency. National incident management system (NIMS). Available from: https://training.fema.gov/nims/. October 10, 2015.
10. Texas A&M Veterinary Emergency Team/VET. Plans and standard operating guidelines. Available from: http://vetmed.tamu.edu/VET. 2018.
11. AVMA. Emergency planning resources for veterinary practices. Available from: https://www.avma.org/KB/Resources/Reference/disaster/Pages/Emergency-Planning-Resources-for-Veterinary-Practices-Disaster-Preparedness.aspx. Accessed May 31, 2018.

12. AVMA. CD-Rom emergency preparedness and response guide. 2018. Available from: https://ebusiness.avma.org/ProductCatalog/product.aspx?ID=193.
13. AVMA. Guide to writing a veterinary medical practice emergency plan. Available from: https://www.avma.org/KB/Resources/Reference/Documents/AVMA_Guide_to_Writing_a_Veterinary_Practice_Emergency_Plan.pdf. Accessed May 29, 2018.
14. FEMA. Animals in disaster/module A. Unit 3. The four phases of emergency management. Available from: https://training.fema.gov/emiweb/downloads/is10_unit3.doc. Accessed May 31, 2018.
15. FEMA. Developing and maintaining emergency operations plans, Comprehensive Preparedness Guide (CPG) 101. Version 2.0. November 2010.
16. Robert T. Stafford Disaster Relief and Emergency Assistance Act, Public Law 93–288, as amended, 42 U.S.C. 5121 et seq., and Related Authorities. *United States Code, Title 42, The Public Health and Welfare, Chapter 68. Disaster Relief.*
17. AVMA. Pet ownership calculator. Available from: https://www.avma.org/KB/Resources/Statistics/Pages/US-pet-ownership-calculator.aspx. Accessed May 31, 2018.
18. Texas A&M VET. Plans and standard operating guidelines. 2016. Available from: http://vetmed.tamu.edu/VET.
19. Creating a community animal disaster plan: A step-by-step guide to building an animal disaster plan and developing the necessary response capacity for your community. Available from: http://veterinaryextension.colostate.edu/menu1/disaster/animal-disaster-toolkit.pdf.
20. FEMA. Disaster Assistance Policy 9523.19. Available from: http://www.tahc.state.tx.us/emergency/FEMA_DAP9523.19_PetsRecovery.pdf.
21. Texas Agriculture Code. Available from: https://statutes.capitol.texas.gov/Docs/SDocs/AGRICULTURECODE.pdf.

Significance of Radiographic Findings in Racehorses

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1. Introduction

Radiography is a widely available diagnostic tool useful for assessing skeletal features associated with fractures, osteochondral fragmentation, osteoarthritis, subchondral stress remodeling, stress fractures, and less common bone pathologies (infection, neoplasia). High-quality radiographs provide substantial skeletal information for the monetary and time investments. However, it is important to remember that radiographs are static images that convey morphologic but not functional (metabolic) information. Bone tissues are changing dynamically in response to mechanical and metabolic loads. The initial stage of injuries associated with repetitive activities is bone microdamage, which alone is not visible on radiographs. Consequently, bone tissue can be compromised without detectable radiographic abnormalities. Further, bone density must change considerably to be visible radiographically. Serial images or other image modalities (e.g., magnetic resonance imaging [MRI]) may be needed to identify developing lesions and assess the progression of lesions (quiet, exacerbating, or resolving). It is acknowledged that published evidence on which to base interpretation of the clinical significance of many abnormalities is incomplete.[1] However, given these caveats, abnormalities visible on radiographs are often useful for diagnostic, treatment planning, and prognostic purposes.

2. Changes Associated with Skeletal Adaptation and Injury

In order to understand the usefulness and limitations of imaging techniques in racehorses, it is important to have perspective on the skeletal adaptive and pathologic processes and their manifestations for recognition in racehorses. Bones are heavy and energetically expensive during locomotion. Consequently, the skeleton is highly dynamic, continuously adding, removing, or replacing bone tissue for healthy skeletal function while minimizing energy expenditure. Specifically, the skeleton strategically places mineralized tissue in mechanically advantageous positions depending on the most recent mechanical loading experiences. Essentially, horses are not born with racehorse skeletons. Training makes racehorse skeletons, ideally by causing skeletal adaptation to meet competition needs without sustaining injury.

Skeletal adaptation occurs in response to increasing and/or altered loads associated with race training and race training circumstances. Increases in factors such as horse speed and racetrack surface hardness increase loads and stresses on the skeleton. To accommodate greater loads the skeleton must lay down

NOTES

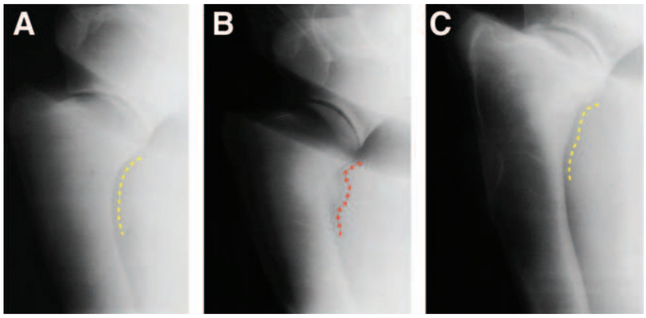

Fig. 1. Lateromedial radiographs of a developing and resolved stress fracture at the humeral neck. A, Early clinical signs-no abnormalities. B, 1-month later – focal periosteal woven bone callus. C, 3-months later – lamellar cortical expansion. Courtesy of Dr. Rick Arthur.

additional bone material. For long bones, this process is associated with deposition of bone on outer cortical surfaces to enlarge bone cross-sectional area.[2,3] The enlarged cross-sectional area reduces bone stresses and strains to within physiological limits. Further, the deposition of bone material on the periphery of bones is mechanically advantageous for sustaining bending and torsional loads.[4]

The rate of increasing exercise intensity (rate that increasing loads are applied to the skeleton over days/weeks) affects the rate that the bone needs to adapt to the new circumstances. Ideally the rate of increasing exercise intensity is within the limits that stimulate bone formation with minimal bone perturbation. Under these circumstances high-quality lamellar bone tissue has time to be applied to bone surfaces. If the rate of increasing exercise intensity exceeds the level bones can sustain, substantive bone damage is created. A rapid response to attempt to buttress a weakened bone structure caused by substantive bone damage results in lesser quality woven bone tissue, which can be formed rapidly, to be deposited on bone surfaces. Ultimately, woven bone is replaced by lamellar bone tissue when time and loading circumstances allow. These different responses are indicators of bone health and bone disturbance—and have distinguishing features on images. Specifically, lamellar bone is dense, homogeneous, and has a smooth surface. Woven bone is porous, heterogeneous, and has an irregular surface (Fig. 1).

Bone adaptation and bone injury are at the separate ends of an analog scale. Submicroscopic and microscopic level bone perturbation stimulate bone adaptation, and is resolved with changes in bone geometry consistent with bone adaptation. Microdamage that causes local bone tissue injury stimulates bone repair in addition to bone deposition. The focus of microdamage is first resorbed by osteoclasts, which transiently weakens the bone material. However, given appropriate (reduced) exercise intensity to prevent further damage on a weakened structure, osteoblasts refill the resorption spaces with secondary osteons. Secondary osteons not only replace damaged bone tissue, but enhance properties that resist crack propagation in bone material. Several features of these processes are relevant to image interpretation. Focal regions of osteopenia are related to intermediary steps in the process of repairing a burden of microdamage in tissue. These regions are weakened bone tissue, which can serve as sites of fracture initiation under otherwise normal training and racing circumstances. These focal osteopenic sites can be observed on morphologic images as incomplete cortical stress fractures or as subchondral lesions. Because bone tissue is capable of regeneration, after rehabilitation the prognosis for return to performance is excellent given that there are no adverse sequelae such as collapse of articular cartilage over a subchondral osteopenic lesion.

Equine athletes in the occupation of racing are susceptible to incurring substantive bone damage in the form of overuse injuries. Racing related overuse injuries are due to the repetitive motions incurred during training- and race-specific loading conditions. These specific loading conditions result in predictable sites, natures, and configurations of injuries in racehorses. Knowledge of the sites and features of common, typical injuries aids in the selection of clinical diagnostic and imaging techniques.

3. Stress Fractures

Radiographs are useful for stress fractures in the distal portion of the limb because of the relatively scant soft tissue relative to bone tissues. Stress fractures are associated with the intracortical remodeling of microdamaged bone material. When damage resorption exceeds bone tissue replacement during the process of healing, the affected region becomes osteopenic—and may be recognized on radiographs. Focal periosteal woven bone callus and endosteal sclerosis serve to buttress the underlying weakness. The visualization of these features, regardless of the presence or absence of a radiolucent incomplete fracture line are indicative of an underlying stress fracture. With progression of intracortical healing, the size of the callus diminishes and the callus surface becomes smoother with conversion of woven bone to lamellar bone through the remodeling process. A residual increase in bone diameter at this location reflects skeletal adaptation to the new loading conditions (Fig. 1). The most common sites for radiographic detection of cortical stress fractures are the third metacarpal bone, tibia, and proximal phalanx. Some stress fractures can be detected in the humerus.

4. Stress Remodeling

Stress remodeling occurs in subchondral bone sites. The features of stress remodeling are similar to those of stress fractures with the exception of the lack of a periosteal response due to the overlying

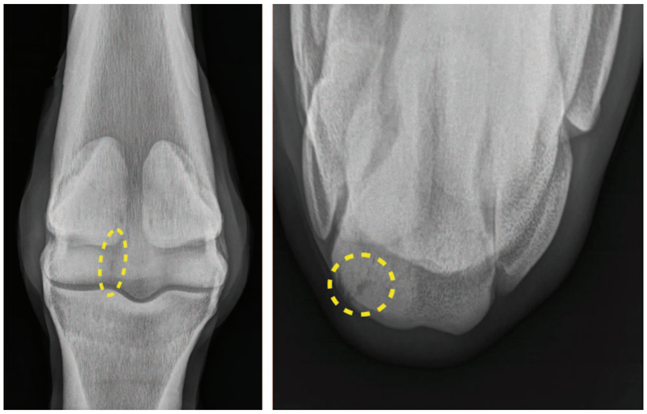

Fig. 2. Subchondral lucency in the third metacarpal bone (left) and third carpal bone (right). Courtesy of Dr. Ryan Carpenter.

articular cartilage. Accumulation of microdamage in regions of high stress devitalizes bone material. The devitalized bone material must first be removed before it can be replaced with new healthy bone material. During this process, the microdamage and focal osteopenia weaken the bone substance. Given time and early recognition, the lesion can heal. Continued exercise on the weakened tissue can culminate in articular cartilage collapse. Recognition of the subchondral lucency before articular fracture or cartilage collapse is most commonly observed in the third metacarpal and carpal bones (Fig. 2).

5. Complete Bone Fractures

The most straightforward diagnoses involve complete, displaced fractures. Indications for repair and prognoses for healing and return to performance are related to the presence/reconstruction of a weight-bearing bone column and articular involvement/reconstruction. Relatively few complete long bone diaphyseal fractures that completely separate the proximal and distal portions of the bone column are amenable to successful repair. The likelihood of success increases when implants reconstruct the bone column so that the bones can sustain loads. The likelihood of return to performance is higher with non-articular fractures and with anatomically reduced articular fractures without associated subchondral bone pathology.

6. Third Metacarpal/Metatarsal Condylar Fractures

Complete, displaced or non-displaced articular fractures commonly affect the third metacarpal/metatarsal condyle and the third carpal bone. Condylar fractures more commonly affect the lateral than the medial condyle. Complete lateral condylar fractures usually exit the lateral side of the metacarpal cortex, thus leaving intact a column of bone from the proximal to distal articular surfaces. Medial condylar fractures have a higher likelihood of progressing proximally, resulting in complete, comminuted metacarpal/metatarsal fractures; however, successful repair can return horses to racing performance.[5]

Condylar fracture initiation occurs in the subchondral bone of the articular surface.[6] The fracture propagates a variable amount proximally, resulting in incomplete and complete fractures, nondisplaced and displaced configurations. Consequently, all condylar fractures will have an articular component, and incomplete fractures will be present in the subchondral bone. Condylar fractures are commonly associated with subchondral bone pathology that can manifest as a focal subchondral radiolucency or as an osteochondral fracture fragment (articular comminution) at the distal aspect of the fracture on the palmar aspect of the condyle (Fig. 2). Prognosis for return to racing performance is better for nondisplaced fractures than displaced fractures.[7] Prognosis of incomplete fractures for return to racing performance is good with conservative or surgical treatment; 87% of conservative, 74% of surgical returned to racing performance.[5] Sixty-three percent (63%) of all condylar fractures treated surgically returned to racing performance, including successfully repaired medial condylar fractures. Prognosis for return to racing was adversely affected by severe joint injury, articular comminution,[6] and less than optimal surgical repair.[5]

High-quality radiographs are critical for detecting incomplete lateral condylar fractures, articular comminution, and evidence of subchondral bone abnormalities that portend impending lateral condylar fracture. Key views include the flexed dorsodistal to palmaroproximal oblique radiographic projection which superimposes the distal aspect of the condyle on the proximopalmar aspect of the proximal phalanx,[8,9] and the 125° dorsopalmar metacarpal skyline projection (D35°Di-PaPr).[10] Unicortical (incomplete) fracture is characterized by uniaxial parasagittal lucency to clear linear radiolucency (Fig. 2).[9] However, in one report, radiography was only 78% sensitive for picking up unicortical lateral condylar fractures, the remaining detected on low field MRI examination.[9]

7. Palmar/Plantar Osteochondral Disease

Palmar/plantar osteochondral disease (POD) is very common in racehorses that have died or were euthanized during racing or training. POD lesions have been observed during postmortem examination in 44% to 67% of racehorse limbs.[11–13] These lesions have been associated with a history of greater number of lifetime races and shorter inter-race intervals, typical of cumulative race exposure and training intensity.[14] POD lesions have been associated with other pathologies within the fetlock joint; increasing severity of POD is associated with increasing prevalence/severity of other lesions.[12,15] POD is considered a fatigue injury of subchondral bone that is recoverable in early stages of disease, but can progress to articular cartilage collapse and irreversible degenerative joint disease. Affected 3-year-old racehorses given free-choice exercise had a favorable prognosis for return to racing with similar post-injury performance to pre-injury performance.[16]

8. Proximal Sesamoid Bone Pathology

Medial proximal sesamoid bone (PSB) and apical PSB fractures observed in 2-year-old training sale Thoroughbred racehorses were less likely to race and earn money.[17] Removal of apical fractures in horses is associated with good return to racing and career longevity, however, there is a better prognosis for hindlimb (86%) than forelimb (55%) fractures, and a poorer prognosis for medial PSB fractures (44% to 47% raced postoperatively).[18,19] Size of the apical fracture fragment was not observed to affect racing prognosis.[20] Uniaxial transverse PSB fracture repaired with lag screws resulted in 5 of 8 horses without concurrent degenerative joint disease returning to racing.[21]

9. Sesamoiditis

Evidence for significance of sesamoiditis relative to racing performance is controversial. Whereas some studies observed that enlarged vascular channels with non-parallel borders adversely affected racing performance, others using different criteria for sesamoiditis found no relationship.[17,22,23] The observed relationships characterized sesamoiditis as the presence of vascular channels > 2 mm width and abnormal or non-parallel sides. Thirty percent (30%) of severely affected horses raced at 2 years of age and 70% at 3 years of age compared to 51% and 79% of non-affected horses racing at 2 and 3 years of age respectively.

Forelimb proximal sesamoid bone enthesophyte in yearlings and medial proximal sesamoid bone fracture in 2-year-old in training sales were associated with a lower proportion of horses starting a race (57% affected vs 82% non-affected; 71% vs 91%, respectively); however, if yearling horses started in a race there were no differences in places, money earned, or money earned per start.[22]

10. Proximal Phalanx (P1)

The presence of a forelimb and fore- or hind-limb articular margin osteochondral fragment was associated with a lower likelihood of starting in a race (38% and 76% vs 91% without the lesion) and a lower proportion who earned money.[17] Arthroscopic removal of dorsoproximal osteochondral fragments resulted in 89% to 92% of horses racing after surgery; 71% to 87% at the same or higher level, more commonly with lower earnings.[24–27]

Non-displaced fractures have been treated conservatively with 4 of 6 returning to racing performance.[28] Displaced fractures have been treated successfully with screw fixation. Short, non-displaced dorsal fractures of the proximal articular margin (most commonly of the medial eminence) treated by arthroscopic debridement resulted in 91% return to racing.[29] Length of career and earnings were not different between cases and controls although injured horses had fewer post-operative starts.

Eleven of 21 (52%) Thoroughbred horses with a non-comminuted P1 fracture (sagittal, dorsal frontal, oblique, physeal, and palmar process) returned to racing performance, 65% to a higher level.[28] While moderately comminuted P1 fractures in Thoroughbreds have been successfully repaired (92% positive outcome), none reported returned to racing.[30] Prognosis for survival was fair for severely comminuted fractures.

11. Carpus

Radiographic visualization of lucencies in the radial facet of the third carpal bone can be indicative of incomplete fracture or articular cartilage damage (Fig. 2).[31,32] Similarly, lucencies in the distal aspect of the radial carpal bone were associated with osteochondral or cartilage fragmentation in 71 horses. Eighty percent (80%) of the 55 surgically treated horses returned to racing, 63% of these at the same or better level. Only 42% of non-surgically treated horses returned to racing, 14% at the same or better level.[33]

A recent comprehensive study of 828 Quarter Horse and Thoroughbred racehorse with arthroscopic removal of osteochondral fragments in the carpus found that 82% of horses raced after surgery, with 70% performing at the same or higher level than before surgery.[34] Likelihood of racing after surgery was increased if horses had raced before surgery, and decreased with increasing horse age, being female, and having a severe lesion with substantive subchondral bone removed. Similar findings have been reported in other studies.[35,36] Whereas most studies compare pre- and post-surgery racing performance of affected horses, a comparison of the performance of horses surgically treated for carpal osteochondral fragments with unaffected control horses found better racing performance in the affected treated horses.[37] Of those control horses that raced, a lower percentage of control racehorses (59%) won races than affected, surgically treated racehorses (75%).

Palmar osteochondral fragments were removed in 31 horses, many that also had dorsal fragments. Fifty-two percent (52%) returned to racing, 48% earned money, and 32% had 5 or more starts.[38] Performance decreased with increasing number of palmar fragments. Similar findings were observed in a study of horses of varied disciplines, 76% returned to intended use.[39]

Yearlings with evidence of dorsal medial intercarpal joint disease are less likely to start in a race (63% affected vs 82% non-affected); however, for horses that started in a race there were no differences in places, money earned, or money earned per start.[22] No differences in race performance of sale yearlings was associated with accessory carpal bone osteochondral fragmentation.[40]

Complete, displaced or non-displaced articular fractures commonly affect the third carpal bone. Return to racing after lag screw fixation of dorsal (frontal) slab fractures varied from 35% to 72%, 85% for incomplete dorsal slab fractures, and 63% to 72% for sagittal slab fractures.[41–45] Fracture displacement, third carpal bone lysis, and cartilage damage lessened the likelihood of racing. Surgical management of sagittal slab fractures had a better return to racing than conservative management.[35]

12. Tarsus

Yearlings with an osteophyte/enthesophyte in the distal intertarsal or tarsometatarsal joints were less likely to start in a race than horses without the lesion (76% vs 82%); however, for horses that started in a race there were no differences in places, money earned, or money earned per start.[22] The presence of wedging of the central or third tarsal bones in horses at 2-year-old in training sales was associated with a lower proportion of horses that raced (60% vs 91%) and a lower proportion of earned money.[17] For horses surgically treated for tarsocrural osteochondrosis before 2 years of age, 43% and 78% raced as 2- and 3-year-olds, respectively; compared to 48% and 73% of siblings.[46]

13. Stifle

Flattening of the medial femoral condyle in horses at 2-years-old in training sales was associated with fewer 3-year-old racing starts, compared with values for horses that had no lesion.[17] Weanlings and yearlings at sales that had a medial femoral condylar lucency < 3 mm in depth or a cyst were less likely to start a race as a 2-year-old but only horses with a cyst were less likely to start a race as a 3-year-old compared to maternal siblings.[47] Whereas 41% of lucencies remained the same size between weanling and yearling radiographs, similar proportions of horses had lesions that decreased or increased in size. Arthroscopic debridement of medial femoral condylar cysts resulted in 64% of horses that raced compared with 77% of maternal siblings.[48] The extent of articular surface debridement was adversely related to the likelihood of participating in a race.

14. Summary

Racehorses are elite athletes that must adapt their skeleton to the increased stresses associated with training and racing. Bones undergo predictable changes in the course of adaptation and repair. Radiographically, medullary sclerosis and smooth periosteal expansion reflect mechanisms for adapting to increasing stresses with progression of race training. The nature of the repetitive motions associated with training and racing result in typical locations and morphologic changes when injuries occur. Given time (recovery), bones are capable of repair and regeneration. Woven bone callus reflects an attempt to buttress an underlying weakness. Focal osteolysis can reflect resorption of damaged bone tissue, structural weakness, and risk for greater injury—until the osteolysis dissipates when healthy bone replaces damaged tissue. It is apparent that many horses with a radiographic abnormality subsequently perform in a race, although the proportion of horses capable of doing so can be less than unaffected horses, depending on the nature of the abnormality.

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Declaration of Ethics

The Author has adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Author has no conflicts of interest.

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References

1. Colgate VA, Group F, Marr CM. Science-in-brief: Risk assessment for reducing injuries of the fetlock bones in Thoroughbred racehorses. *Equine Vet J* 2020;52:482–488.
2. Nunamaker DM, Butterweck DM, Provost MT. Some geometric properties of the third metacarpal bone: A comparison between the Thoroughbred and Standardbred racehorse. *J Biomech* 1989;22:129–134.
3. Stover SM, Pool RR, Martin RB, et al. Histological features of the dorsal cortex of the third metacarpal bone mid-diaphysis during postnatal growth in Thoroughbred horses. *J Anat* 1992;181:455–469.
4. Martin RB, Burr DB, Sharkey NA, et al. Mechanical properties of bone. *Skeletal Tissue Mechanics*. 2nd ed. New York, NY: Springer; 2015; 355–422.
5. Zekas LJ, Bramlage LR, Embertson RM, et al. Results of treatment of 145 fractures of the third metacarpal/metatarsal condyles in 135 horses (1986–1994). *Equine Vet J* 1999;31: 309–313.
6. Rick MC, O'Brien TR, Pool RR, et al. Condylar fractures of the third metacarpal bone and third metatarsal bone in 75 horses: Radiographic features, treatments, and outcome. *J Am Vet Med Assoc* 1983;183:287–296.
7. Martin GS. Factors associated with racing performance of Thoroughbreds undergoing lag screw repair of condylar fractures of the third metacarpal or metatarsal bone. *J Am Vet Med Assoc* 2000;217:1870–1877.
8. Pilsworth RC, Hopes R, Greet TR. A flexed dorso-palmar projection of the equine fetlock in demonstrating lesions of the distal third metacarpus. *Vet Rec* 1988;122:332–333.
9. Ramzan PH, Palmer L, Powell SE. Unicortical condylar fracture of the Thoroughbred fetlock: 45 cases (2006–2013). *Equine Vet J* 2015;47:680–683.
10. Hornof WJ, O'Brien TR. Radiographic evaluation of the palmar aspect of the equine metacarpal condyles: A new projection. *Vet Radiol* 1980;21:161–167.

11. Bani Hassan E, Mirams M, Mackie EJ, et al. Prevalence of subchondral bone pathological changes in the distal metacarpi/metatarsi of racing Thoroughbred horses. *Aust Vet J* 2017;95:362–369.
12. Pinchbeck GL, Clegg PD, Boyde A, et al. Pathological and clinical features associated with palmar/plantar osteochondral disease of the metacarpo/metatarsophalangeal joint in Thoroughbred racehorses. *Equine Vet J* 2013;45:587–592.
13. Barr ED, Pinchbeck GL, Clegg PD, et al. Post mortem evaluation of palmar osteochondral disease (traumatic osteochondrosis) of the metacarpo/metatarsophalangeal joint in Thoroughbred racehorses. *Equine Vet J* 2009;41:366–371.
14. Pinchbeck GL, Clegg PD, Boyde A, et al. Horse-, training- and race-level risk factors for palmar/plantar osteochondral disease in the racing Thoroughbred. *Equine Vet J* 2013;45: 582–586.
15. Peloso JG, Vogler JB 3rd, Cohen ND, et al. Association of catastrophic biaxial fracture of the proximal sesamoid bones with bony changes of the metacarpophalangeal joint identified by standing magnetic resonance imaging in cadaveric forelimbs of Thoroughbred racehorses. *J Am Vet Med Assoc* 2015;246:661–673.
16. Tull TM, Bramlage LR. Racing prognosis after cumulative stress-induced injury of the distal portion of the third metacarpal and third metatarsal bones in Thoroughbred racehorses: 55 cases (2000–2009). *J Am Vet Med Assoc* 2011; 238:1316–1322.
17. Meagher DM, Bromberek JL, Meagher DT, et al. Prevalence of abnormal radiographic findings in 2-year-old Thoroughbreds at in-training sales and associations with racing performance. *J Am Vet Med Assoc* 2013;242:969–976.
18. Schnabel LV, Bramlage LR, Mohammed HO, et al. Racing performance after arthroscopic removal of apical sesamoid fracture fragments in Thoroughbred horses age < 2 years: 151 cases (1989–2002). *Equine Vet J* 2007;39:64–68.
19. Schnabel LV, Bramlage LR, Mohammed HO, et al. Racing performance after arthroscopic removal of apical sesamoid fracture fragments in Thoroughbred horses age > or = 2 years: 84 cases (1989–2002). *Equine Vet J* 2006;38:446–451.
20. Kamm JL, Bramlage LR, Schnabel LV, et al. Size and geometry of apical sesamoid fracture fragments as a determinant of prognosis in Thoroughbred racehorses. *Equine Vet J* 2011;43:412–417.
21. Henninger RW, Bramlage LR, Schneider RK, et al. Lag screw and cancellous bone graft fixation of transverse proximal sesamoid bone fractures in horses: 25 cases (1983–1989). *J Am Vet Med Assoc* 1991;199:606–612.
22. Kane AJ, McIlwraith CW, Park RD, et al. Radiographic changes in Thoroughbred yearlings. Part 2: associations with racing performance. *Equine Vet J* 2003;35:366–374.
23. Spike-Pierce DL, Bramlage LR. Correlation of racing performance with radiographic changes in the proximal sesamoid bones of 487 Thoroughbred yearlings. *Equine Vet J* 2003;35:350–353.
24. Colon JL, Bramlage LR, Hance SR, et al. Qualitative and quantitative documentation of the racing performance of 461 Thoroughbred racehorses after arthroscopic removal of dorsoproximal first phalanx osteochondral fractures (1986–1995). *Equine Vet J* 2000;32:475–481.
25. Elce YA, Richardson DW. Arthroscopic removal of dorsoproximal chip fractures of the proximal phalanx in standing horses. *Vet Surg* 2002;31:195–200.
26. Kawcak CE, McIlwraith CW. Proximodorsal first phalanx osteochondral chip fragmentation in 336 horses. *Equine Vet J* 1994;26:392–396.
27. Yovich JV, McIlwraith CW. Arthroscopic surgery for osteochondral fractures of the proximal phalanx of the metacarpophalangeal and metatarsophalangeal (fetlock) joints in horses. *J Am Vet Med Assoc* 1986;188:273–279.
28. Markel MD, Richardson DW. Noncomminuted fractures of the proximal phalanx in 69 horses. *J Am Vet Med Assoc* 1985;186:573–579.
29. Elzer EJ, Bramlage LR. Arthroscopic debridement of short frontal plane proximal phalanx fractures preserves racing performance. *Equine Vet J* 2020 [Online ahead of print].
30. Kraus BM, Richardson DW, Nunamaker DM, et al. Management of comminuted fractures of the proximal phalanx in horses: 64 cases (1983–2001). *J Am Vet Med Assoc* 2004; 224:254–263.
31. Moore RM, Schneider RK. Arthroscopic findings in the carpal joints of lame horses without radiographically visible abnormalities: 41 cases (1986–1991). *J Am Vet Med Assoc* 1995;206:1741–1746.
32. Ross MW, Richardson DW, Beroza GA. Subchondral lucency of the third carpal bone in Standardbred racehorses: 13 cases (1982–1988). *J Am Vet Med Assoc* 1989;195:789–794.
33. Dabareiner RM, White NA, Sullins KE. Radiographic and arthroscopic findings associated with subchondral lucency of the distal radial carpal bone in 71 horses. *Equine Vet J* 1996;28:93–97.
34. Graham R, Rosanowski SM, McIlwraith CW. A 10-year study of arthroscopic surgery in racing Thoroughbreds and Quarter Horses with osteochondral fragmentation of the carpus. *Equine Vet J* 2020;52:225–231.
35. Kannegieter NJ, Ryan N. Racing performance of Thoroughbred horses after arthroscopic surgery of the carpus. *Aust Vet J* 1991;68:258–260.
36. Shimozawa K, Ueno Y, Ushiya S, et al. Survey of arthroscopic surgery for carpal chip fractures in Thoroughbred racehorses in Japan. *J Vet Med Sci* 2001;63:329–331.
37. Raidal SL, Wright JD. A retrospective evaluation of the surgical management of equine carpal injury. *Aust Vet J* 1996;74:198–202.
38. Getman LM, Southwood LL, Richardson DW. Palmar carpal osteochondral fragments in racehorses: 31 cases (1994–2004). *J Am Vet Med Assoc* 2006;228:1551–1558.
39. Lang HM, Nixon AJ. Arthroscopic removal of discrete palmar carpal osteochondral fragments in horses: 25 cases (1999–2013). *J Am Vet Med Assoc* 2015;246:998–1004.
40. Davern AJ, Peloso JG, Hawkins JF, et al. Comparison of the racing performance of Thoroughbreds with versus without osteochondral fragmentation of the accessory carpal bone identified on yearling sales repository radiographs. *J Am Vet Med Assoc* 2019;254:501–507.
41. Doering AK, Reesink HL, Luedke LK, et al. Return to racing after surgical management of third carpal bone slab fractures in Thoroughbred and Standardbred racehorses. *Vet Surg* 2019;48:513–523.
42. Kraus BM, Ross MW, Boston RC. Surgical and nonsurgical management of sagittal slab fractures of the third carpal bone in racehorses: 32 cases (1991–2001). *J Am Vet Med Assoc* 2005;226:945–950.
43. Martin GS, Haynes PF, McClure JR. Effect of third carpal slab fracture and repair on racing performance in Thoroughbred horses: 31 cases (1977–1984). *J Am Vet Med Assoc* 1988;193:107–110.
44. Rutherford DJ, Bladon B, Rogers CW. Outcome of lag-screw treatment of incomplete fractures of the frontal plane of the radial facet of the third carpal bone in horses. *N Z Vet J* 2007;55:94–99.
45. Stephens PR, Richardson DW, Spencer PA. Slab fractures of the third carpal bone in Standardbreds and Thoroughbreds: 155 cases (1977–1984). *J Am Vet Med Assoc* 1988; 193:353–358.
46. Beard WL, Bramlage LR, Schneider RK, et al. Postoperative racing performance in Standardbreds and Thoroughbreds with osteochondrosis of the tarsocrural joint: 109 cases (1984–1990). *J Am Vet Med Assoc* 1994;204:1655–1659.
47. Perez-Nogues M, Derham A, Marmion J, et al. Progression of shallow medial femoral condyle radiographic lucencies in Thoroughbred repository radiographs and their influence on future racing careers. *Equine Vet J* 2020 [Online ahead of print].
48. Sandler EA, Bramlage LR, Embertson RM, et al. Correlation of lesion size with racing performance in Thoroughbreds after arthroscopic surgical treatment of subchondral cystic lesions of the medial femoral condyle: 150 cases (1989–2000), in *Proceedings*. Am Assoc Equine Pract 2002;48:255–256.

Diagnostic Imaging Findings in English Sport Horses in Relation to Performance and Lameness

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As knowledge of equine sports medicine advances, the list of differential diagnoses causing performance problems lengthens. The clinical examination is a critical component and its findings must be considered in conjunction with imaging findings. Careful physical examination including detailed palpation, manipulation, examination of the horse in motion, quantitative gait assessment tools, and diagnostic anesthesia are important parameters. More often than not, the adult sport horse is a complicated interaction of different problems of variable importance. These abnormalities may even arise from different body systems. For example, many sport horses will have lameness in more than one limb, or lameness in one limb in addition to axial skeleton dysfunction. Diagnostic imaging, in all of its many forms, is an important piece of a complete work up that requires careful integration into the overall clinical assessment. Author's address: 911 Mustang Court, Petaluma, CA 94954; e-mail: smpuchalski@gmail.com.

1. Introduction

The clinical assessment of an equine athlete is critically important to that athlete's career longevity, acute injury diagnosis, and chronic injury management. The clinical assessment, performance history, and anamnesis should lead the clinician toward a diagnostic imaging modality or several imaging modalities in order to fully characterize the perceived problem. Choosing the optimal diagnostic imaging modality is not always easy. In most instances, the clinician will start with the readily accessible modalities of radiographs and ultrasound with an eye toward what more can be done with different equipment. The clinician must first acquire and accurately interpret the radiographic and ultrasonographic images. They should also understand the strengths and weaknesses of each of the additional diagnostic imaging modalities in addition to having some concept of what they are expecting to find. In many instances, a given horse, for a given problem may have numerous modalities applied. Whenever possible, a discussion regarding additional imaging is best done in advance of ordering the additional test and after interpretation of the readily available techniques.

Multiple steps are incorporated into the evaluation of any diagnostic imaging results. An accurate diagnosis should be the ultimate goal of any diagnostic imaging study. Accuracy must include the identification of both true-positive and true-negative studies, not just the identification of lesions. Simply identifying a lesion is only a small, albeit critical, part of the entire process. Correct interpretation of images depends on many factors starting at image acquisition (optimized for high-quality images with few artifacts) and ending with decision making (where the observer both recognizes and interprets imaging findings correctly). The findings must

NOTES

then be synthesized with the clinical exam and considered in relation to the horse's discipline and performance level.

Certain radiographic findings such as bone fragments, osteophytes, and developmental lesions are common findings in sport horse practice. Horses with these problems will present in a variety of ways. The easiest situation to interpret is when these findings are limited to the lame leg, in the site localized via examination or diagnostic analgesia. More often, this is not the case. Often these abnormalities are seen in sound horses presenting for pre-purchase or sales evaluation, or as bilateral lesions in horses with unilateral lameness. Veterinarians must make an educated guess regarding the impact on performance and long-term outcome.

2. Performance

Equine performance outcomes are difficult to measure. The lack of objective data for comparison between horses with and without lesions makes scientific study design challenging. Multiple research groups have evaluated radiographic lesions and performance outcomes in Thoroughbred (TB),[1–6] Standardbred,[7,8] and French Trotter[1,9,10] racehorses using racing outcomes such as total career earnings, earnings per start, and total career starts. Only a limited number of studies have evaluated horses used for sports other than racing.[11–13] These studies have produced good guidelines for many commonly encountered lesions. However, it remains that veterinarians must make decisions based on the individual horse at hand, and each clinical scenario is almost always different.

Equestrian sports all have different demands. It is clear that a 2-year-old TB flat racing horse has different stressors placed on its cardiovascular and musculoskeletal systems than a 12-year-old Warmblood show jumper. With growing popularity of amateur involvement in many equestrian sports (e.g., cutting, reining, dressage, show jumping, eventing, endurance), it is important to also understand the variability of demands within a sport at different levels. In racing and some Western performance sports, heavy emphasis is placed on a short, intense career with some of the largest purses being available to younger horses. Whereas, in other equestrian sports (e.g., dressage), it may take many years of training for a horse and rider combination to acquire the skills necessary to compete at the highest level. Furthermore, the influence of specific trainers or training programs remains a substantial and often unrevealed factor in career longevity in horses—regardless of discipline. These factors should all be considered when deciding about the significance or future influence that a particular radiographic lesion may have on performance.

Many factors beyond musculoskeletal health influence performance in sport horses: talent and ability, training program, opportunity, rider/jockey ability, goals of the owner(s) or trainer(s), and the intangible factors of horse toughness or "heart." These factors most likely have unequal and variable weighting on a horse's career, cannot be measured and confound direct evaluation of performance outcome in studies evaluating imaging versus performance.

3. Bone Fragments

Not all osteochondral fragments are the same. Fragment imaging characteristics, which may also correlate with breed and use, are an important consideration for impact on performance. Consider the fetlock joint, where fragments occur in association with the dorsal, proximal aspect of the proximal phalanx (P1), the dorsal proximal aspect of the sagittal ridge of the third metacarpal (-metatarsal) condyle, and the palmar (plantar) processes of the proximal phalanx. Dorsal, proximal P1 fragments in Thoroughbreds are most often fractures secondary to repetitive trauma; however,[14] certain types of fragments in Warmblood and Standardbred horses are of uncertain origin.[15] Evaluation of the clinical signs and imaging characteristics can lead to conclusions regarding etiology, chronicity, and related signs. In general, dorsoproximal P1 chip fractures reduce performance,[2] an effect that may be mitigated with surgical intervention. More confusing are horses with smooth-margined, round lesions associated with dorsoproximal P1. Yearling TB horses with this finding are less likely to start.[5] In Warmblood horses with this finding, increasing age of the horse and increasing number of fragments is associated with increasing odds ratio for lameness.[15] Furthermore, in this study, older horses were more likely to have other associated joint abnormalities such as synovitis, cartilage wear lines, erosions, and fibrillation.[15] Plantar, proximal P1 fragments are less well understood. These are probably more common in certain breeds of horses including Standardbreds, Trotters, and Warmbloods.[10,16,17] These fragments are reported to have a relatively high incidence and influence on measures of performance in trotters.[10] In Warmblood horses, the influence of this lesion is not well understood.

In general, identifying a lesion is the first step. Characterizing the lesion fully using other imaging findings and the presence or absence of concomitant lesions most likely yields a more complete assessment of any given lesion. Furthermore, assessment of the whole horse may also be an important factor in overall performance outcomes with many reports showing that increased number (and severity) of lesions is associated with decreased performance.[1,9]

4. Periarticular New Bone Formation

Osteophytes and enthesophytes occur in numerous locations. Osteophytes provide clear evidence of joint disease in most locations. However, specific sites, such as the proximal third metatarsal bone[18] and the proximomedial tibia at the medial femorotibial joint, are often identified in sound horses. Furthermore, studying the influence of these changes on performance is difficult. Qualitative imaging features in addition to clinical information should be utilized to assess the finding(s). For example, proximal third metatarsal osteoproliferation may be at the joint margin (e.g., osteophyte), slightly distant from the joint margin (likely associated with the dorsal tarsometatarsal ligament), or more distant from the joint margin (likely associated with the cranial tibial tendon and/or peroneus tertius insertion). If the osseous proliferation is present at the joint margin, close evaluation for subchondral bone change (irregularity or change in opacity) or other evidence of joint disease should be undertaken. Additional abnormalities will lead to a stronger conclusion of the significance of the finding. Marginal proliferation on the proximal, medial tibia may provide evidence of joint disease. This can prompt the observer to closely inspect the medial femoral condyle for shape change or alteration in structure, the attachment sites of the menisco-tibial or cruciate ligaments, or prompt further investigation with additional radiographic projections (e.g., flexed lateral oblique [cranio 5 disto 10 lateral-caudoproximomedial oblique] to highlight the medial femoral condyle) or ultrasound. Enthesophytes provide clear evidence of chronic pathologic change at the bone/soft tissue interface. Certain locations are very frequently identified and likely carry limited significance, for example the oblique sesamoidean ligaments or the proximal attachment of the distal digital annular ligament. Because these findings can occur at such a wide variety of locations for a wide variety of reasons, each case should be evaluated on an individual basis.

When a bone spur is identified, it should be carefully categorized as an osteophyte distant from the joint surface, periarticular (joint margin) osteophyte, or enthesophyte (tendon/ligament/joint capsule insertion). The categorization of the lesion will then prompt either active dismissal of the lesion as insignificant, further investigation of the lesion, or allow the observer to make a diagnosis.

5. Osteochondrosis

Osteochondrosis lesions come in all shapes and sizes, and should include lesions of endochondral ossification that develop in juvenile horses. A more inclusive term of juvenile osteochondral conditions[19] has been proposed to include osteochondrosis, juvenile subchondral osseous cyst-like lesions, physitis, and avulsion lesions of epiphyseal or apophyseal bone. Many studies evaluate the influence of lesion size, location, surgical versus medical management and the influence on outcome.[1,20–26] Overall, the understanding of these conditions is much greater in horses used for racing than other non-racing disciplines.

In general, osteochondrosis increases the likelihood of untoward downstream effects including synovitis and osteoarthritis. The identification of an osteochondrosis lesion should prompt an immediate assessment of multiple factors that include the lesion size and depth, the relationship to the weight bearing surface and/or other articular components, the presence of other associated joint abnormalities such as soft-tissue swelling or osteophyte formation, and surgical accessibility. The identification of additional, related lesions or contralateral lesions likely increases the clinical significance of lesions in the individual animal.

6. Cervical Spine

High-quality radiographs of the cervical vertebrae provide a wealth of information about vertebral morphology.[27,28] Quality assessment should be performed by the operator at the time of image acquisition. Patient positioning and preparation, beam angle, film focal distance, exposure, and motion all play a role in image quality that can significantly detract from the clinical utility of radiographs. Latero-lateral radiographs have several limitations including superimposition of the bone over the soft tissues of the spinal cord and articular process joints, a lack of orthogonal projections, and that they are generally taken with a fixed or stationary head position. These limitations can be partially alleviated through quantification of the sagittal diameter ratios, the use of oblique and/or positional projections and complementary imaging techniques such as ultrasound, and the use of contrast media (myelography). Thoughtful consideration of the limitations and their respective solutions should enter into the clinicians' rationale early in the discourse. When quantification of sagittal diameter ratios and myelography are employed, it is important to remember that even these techniques are faulted. Inter- and intra-observer variability in ratio measurement make the use of this technique somewhat questionable except in very positive or very negative cases.[3] Similarly, myelography, though for a time considered to be the gold standard for the identification of spinal cord compression, is fraught with false-negative and false-positive results. Even with these limitations, radiographs are still useful for the evaluation of the shape, size, alignment, symmetry, opacity, and number of vertebrae giving good information about many disease processes.

Ultrasound is invaluable for the assessment of the vertebral surfaces and associated soft tissues, and for its role in ultrasound-guided or ultrasound-assisted interventions. In general, ultrasound does not provide useful information for the assessment of the central nervous system. Nerve-root evaluation can be performed when the nerve roots or lower motor neurons exit the vertebral canal. Evaluation of the nerve roots can be performed in the lumbosacral region on per-rectal ultrasound examination providing some information about these structures. Ultrasound is complementary to radiographs for evaluation of the nuchal ligament and bursa, artic-

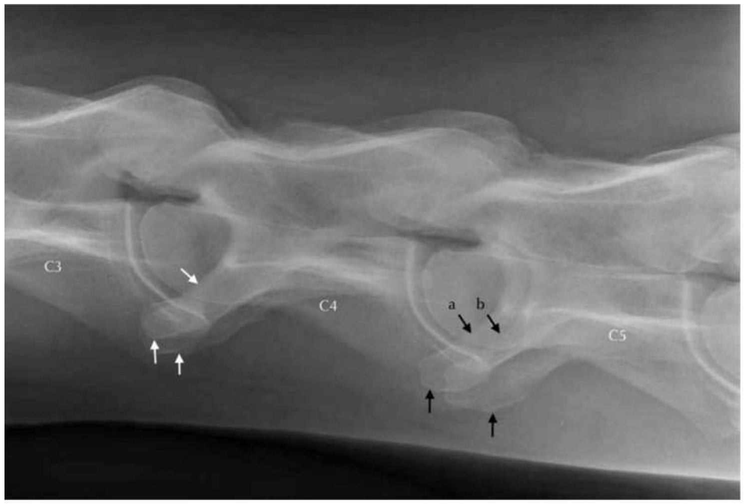

Fig. 1. Laterolateral radiograph of the mid-cervical spine. C3, C4, and C5 have indistinguishable anatomic features and external markers in this region can be helpful, particularly when using a small size (portable) radiograph detector (plate). Note that the transverse processes of C4 are well positioned with near-perfect superimposition (white arrows) but the transverse processes of C5 (black arrows) have discrepant cranial margins (A and B). The most likely cause of this is lateroflexion of the neck at the time of radiographic acquisition.

ular processes and joints of the cervical, thoracic and thoracolumbar spine, the supraspinous ligament, the interspinous ligaments and spacing of the thoracic and lumbar dorsal processes. In the thoracic and thoracolumbar spine, ultrasound of the dorsal aspect of the spinous processes and supraspinous ligament can be very misleading for the diagnosis of spinous process impingement and should always be used in concert with radiographs. Ultrasound alone can be used for evaluation of the pelvis and sacroiliac region including the associated soft tissues, but is often more useful when used in conjunction with nuclear scintigraphy. Ultrasound is often used to guide intra- or peri-articular injections of the intervertebral joints or sacro-iliac regions, or to sample cerebrospinal fluid (CSF) from various locations.

Diagnostic imaging, featuring the novel techniques, has allowed for great leaps forward in our understanding of pathology of the cervical vertebrae. Even the common usage of modern radiography equipment with good quality image processing has allowed great leaps forward in the ability to make diagnoses pertaining to the cervical vertebrae. Any differential diagnosis impacting the cervical

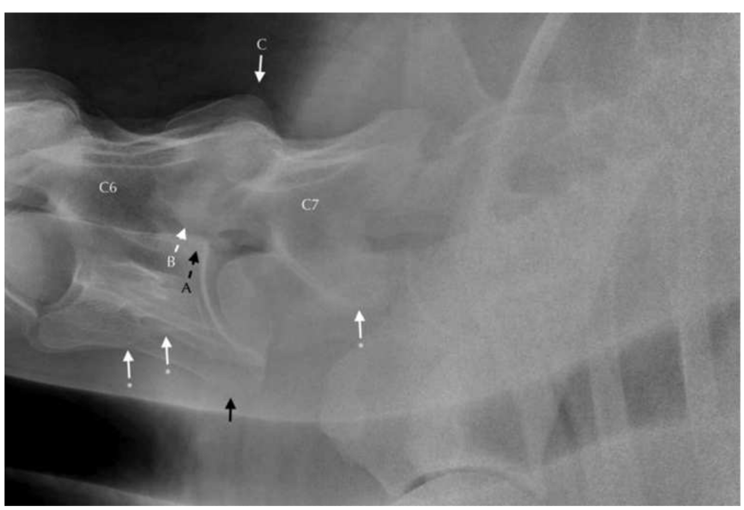

Fig. 2. Laterolateral radiograph of the caudal cervical spine. There is transposition of the caudal tubercle of one transverse process of C6 to C7 (*) with a normal transverse process on the other side (black arrow). Moderate periarticular new bone production is present on the ventral margins of the articular processes of C6 to C7 (arrows, A and B). The spinous process of C7 (C) is superimposed over the dorsal margin of the articular processes. This is frequently misinterpreted as new bone formation.

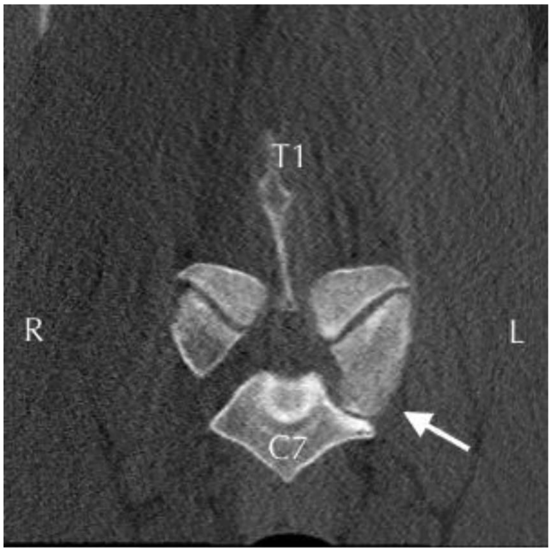

Fig. 3. Transverse CT image through the C7 to T1 articular process joints. There is marked asymmetry of the articular processes that is most likely anomalous development. This causes marked, asymmetric stenosis of the intervertebral foramen (white arrow) in a horse with unilateral, intermittent forelimb lameness.

vertebrae and/or spinal cord and/or nerve roots can manifest as cervical region pain.

Cervical articular process joint disease (osteoarthritis) with or without malformation or developmental orthopedic disease (osteochondrosis) of the vertebrae is a common diagnosis in equine sports medicine practice for horses with clinical signs ranging from stiffness and inability or unwillingness to flex (sometimes one direction more than another), forelimb lameness to fixed neck position. Critical assessment of radiographic quality is very important as marginal quality radiographs can both overestimate and underestimate abnormalities of this region (Fig. 1). More research is needed to understand the relationship between radiographic abnormalities and clinical signs as mild radiographic abnormalities can be clinically silent. Nuclear scintigraphy and ultrasound are frequently used in conjunction with radiographs to further characterize this problem. Important radiographic findings include periarticular new bone, irregular margination of the articular surfaces, regional sclerosis and enlargement of the articular processes, and asymmetry of the articular processes (Fig. 2). These findings are much better appreciated on cross-sectional imaging modalities (computed tomography [CT]), and can be more fully characterized with respect to the intervertebral foramina and dura mater. Anomalous vertebral developmental can be an important underlying cause of osteoarthritis that is often not diagnosed on plain radiographs (Fig. 3).

Nuchal desmopathy/enthesopathy, as identified on radiographs, is a common finding in sport horses with variable clinical significance. Nuchal bursitis is invariably clinically significant, particularly when it is associated with a septic etiology. Clinical signs relating to nuchal ligament pain range from inability or unwillingness to flex at the poll, extreme pain on palpation or when placing a halter or bridle, or this can be a radiographic finding with no clinical relevance. This imaging diagnosis must always be interpreted with clinical examination findings.

Intervertebral disc disease is uncommon in horses. When intervertebral disc space collapse is identified, it is important to evaluate the horse and radiographs for other evidence relating to the potential etiology. Possibilities include previous trauma, discospondylitis, neoplasia, and degeneration. Disc-space narrowing

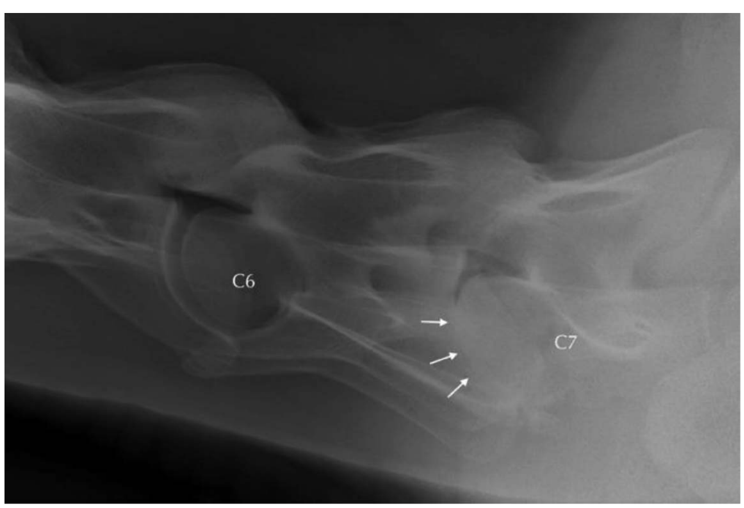

Fig. 4. Laterolateral radiograph of the caudal cervical spine in a 15-year-old warmblood dressage horse with inability or unwillingness to do collected dressage movements. The intervertebral disc space is nearly completely collapsed at C6 to C7 (white arrows) with a step defect between the ventral lamina of C6.

can be associated with soft tissue, presumably intervertebral disc material, specifically annulus fibrosus, extending into the ventral vertebral canal and causing extra-dural spinal cord compression that may be identified with myelography (CT or radiographic). Critical assessment of end plate morphology is needed to differentiate between aggressive and non-aggressive causes of intervertebral disc-space collapse (Fig. 4).

In summary, bone chips, bone spurs and osteochondrosis, and cervical changes occur commonly in performance horses. The identification of lesions must be accompanied with an understanding of the demands placed on the horse for its given sport, and a search for additional, related lesions. Broad guidelines provide some information for the interpretation of these lesions, but each individual case should be contemplated separately. Exceptions to every rule exist with a rare horse having an exceptional performance career with major radiographic findings and other horses having poor performance as a result of minor findings. A direct correlation between radiographic lesion presence and performance will remain elusive and good clinical judgment will always be necessary.

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Declaration of Ethics

The Author has adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Author has no conflicts of interest.

References

1. Robert C, Valette JP, Jacquet S, et al. Influence of juvenile osteochondral conditions on racing performance in Thoroughbreds born in Normandy. *Vet J* 2013;197:83–89.
2. Meagher DM, Bromberek JL, Meagher DT, et al. Prevalence of abnormal radiographic findings in 2-year-old Thoroughbreds at in-training sales and associations with racing performance. *J Am Vet Med Assoc* 2013;242:969–976.
3. Preston SA, Brown MP, Trumble TN, et al. Effects of various presale radiographic findings for yearling Thoroughbreds on 2-year-old racing performance. *J Am Vet Med Assoc* 2012;241:1505–1513.
4. Kane AJ, Park RD, McIlwraith CW, et al. Radiographic changes in Thoroughbred yearlings. Part 1: prevalence at the time of the yearling sales. *Equine Vet J* 2003;35:354–365.
5. Kane AJ, McIlwraith CW, Park RD, et al. Radiographic changes in Thoroughbred yearlings. Part 2: associations with racing performance. *Equine Vet J* 2003;35:366–374.
6. Spike-Pierce DL, Bramlage LR. Correlation of racing performance with radiographic changes in the proximal sesamoid bones of 487 Thoroughbred yearlings. *Equine Vet J* 2003;35:350–353.
7. Jorgensen HS, Proschowsky H, Falk-Ronne J, et al. The significance of routine radiographic findings with respect to subsequent racing performance and longevity in standardbred trotters. *Equine Vet J* 1997;29:55–59.
8. Grondahl AM, Gaustad G, Engeland A. Progression and association with lameness and racing performance of radiographic changes in the proximal sesamoid bones of young standardbred trotters. *Equine Vet J* 1994;26:152–155.
9. Robert C, Valette JP, Denoix JM. Correlation between routine radiographic findings and early racing career in French trotters. *Equine Vet J Suppl* 2006:473–478.
10. Courouce-Malblanc A, Leleu C, Bouchilloux M, et al. Abnormal radiographic findings in 865 French standardbred trotters and their relationship to racing performance. *Equine Vet J Suppl* 2006:417–422.
11. Verwilghen DR, Janssens S, Busoni V, et al. Do developmental orthopaedic disorders influence future jumping performances in Warmblood stallions? *Equine Vet J* 2013;45:578–581.
12. Puchalski SM, Peters DF, Tenney W, et al. Radiographic survey of elite show jumpers competing successfully in the United States, in *Proceedings.* Am Assoc Equine Pract 2011;57:456.
13. van Hoogmoed LM, Snyder JR, Thomas HL, et al. Retrospective evaluation of equine prepurchase examinations performed 1991–2000. *Equine Vet J* 2003;35:375–381.
14. Kawcak CE, McIlwraith CW. Proximodorsal first phalanx osteochondral chip fragmentation in 336 horses. *Equine Vet J* 1994;26:392–396.
15. Declercq J, Martens A, Maes D, et al. Dorsoproximal proximal phalanx osteochondral fragmentation in 117 Warmblood horses. *Vet Comp Orthop Traumatol* 2009;22:1–6.
16. Lykkjen S, Dolvik NI, McCue ME, et al. Equine developmental orthopaedic diseases—A genome-wide association study of first phalanx plantar osteochondral fragments in Standardbred trotters. *Anim Genet* 2013;44:766–769.
17. Fortier LA, Foerner JJ, Nixon AJ. Arthroscopic removal of axial osteochondral fragments of the plantar/palmar proximal aspect of the proximal phalanx in horses: 119 cases (1988–1992). *J Am Vet Med Assoc* 1995;206:71–74.
18. Fairburn A, Dyson S, Murray R. Clinical significance of osseous spurs on the dorsoproximal aspect of the third metatarsal bone. *Equine Vet J* 2010;42:591–599.
19. Denoix JM, Jeffcott LB, McIlwraith CW, et al. A review of terminology for equine juvenile osteochondral conditions (JOCC) based on anatomical and functional considerations. *Vet J* 2013;197:29–35.
20. McCoy AM, Ralston SL, McCue ME. Short- and long-term racing performance of Standardbred pacers and trotters after early surgical intervention for tarsal osteochondrosis. *Equine Vet J* 2015;47:438–444.
21. Clarke KL, Reardon R, Russell T. Treatment of osteochondrosis dissecans in the stifle and tarsus of juvenile Thoroughbred horses. *Vet Surg* 2015;44:297–303.
22. van Weeren PR, Jeffcott LB. Problems and pointers in osteochondrosis: Twenty years on. *Vet J* 2013;197:96–102.
23. McIlwraith CW. Surgical versus conservative management of osteochondrosis. *Vet J* 2013;197:19–28.
24. van Weeren PR, Denoix JM. The Normandy field study on juvenile osteochondral conditions: Conclusions regarding the influence of genetics, environmental conditions and management, and the effect on performance. *Vet J* 2013;197:90–95.
25. Beard WL, Bramlage LR, Schneider RK, et al. Postoperative racing performance in standardbreds and Thoroughbreds with osteochondrosis of the tarsocrural joint: 109 cases (1984–1990). *J Am Vet Med Assoc* 1994;204:1655–1659.
26. Laws EG, Richardson DW, Ross MW, et al. Racing performance of standardbreds after conservative and surgical treatment for tarsocrural osteochondrosis. *Equine Vet J* 1993;25:199–202.
27. DeRouen A, Spriet M, Aleman M. Prevalence of anatomical variation of the sixth cervical vertebra and association with vertebral canal stenosis and articular process osteoarthritis in the horse. *Vet Radiol Ultrasound* 2016;57:253–258.
28. Santinelli I, Beccati F, Arcelli R, et al. Anatomical variation of the spinous and transverse processes in the caudal cervical vertebrae and the first thoracic vertebra in horses. *Equine Vet J* 2016;48:45–49.

How Imaging Correlates to Prognosis, Rehabilitation, and Return to Work

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1. Introduction

Advanced imaging modalities are now routinely used in equine practice and the technology involved continues to advance at a fairly rapid pace. It can be difficult for practitioners to decide which modalities to choose for both diagnosis and re-evaluation, particularly in light of some modalities requiring referral and/or general anesthesia, notably high-field magnetic resonance images (MRIs). The purpose of this paper is to provide an overview of how certain imaging modalities can be used alone or in combination to guide rehabilitation protocols and decision making such as return to performance as well as prognosis following musculoskeletal injury. The accuracy of certain imaging techniques for diagnosing specific injuries in combination with localizing blocks is beyond the scope of this paper and is presented in other papers within this session.

2. Imaging Modalities

Ultrasonography

Traditional B-mode gray-scale ultrasound examination in both the transverse and longitudinal planes has been used for decades to diagnose and monitor tendon and ligament injuries.[1,2] A typical examination involves measurement of the overall tendon or ligament cross-sectional area, lesion cross-sectional area, and total proximal-to-distal length of the lesion in the transverse plane as well as subjective assessment of the lesion echogenicity on a grading scale. In the longitudinal plane, loss of linear fiber pattern is either subjectively reported as a percentage or using a grading system. Decreases in lesion and overall tendon/ligament size correlated with improvements in echogenicity and linear fiber pattern are indicative of healing and used to guide rehabilitation protocols.[1] It is well known, however, that flexor tendons in particular appear well healed on gray-scale ultrasound examination long before they are histologically healed and biomechanically stable.[3,4] For this reason, ultrasound techniques that allow for more in-depth interrogation of tendon healing have been explored and are now being used to monitor the healing of both tendon and ligament injuries in horses as well as in humans.

Color or Power Doppler, as originally described for use in the cardiology field, uses high-frequency sound waves to measure blood flow and is now used broadly in both equine and human sports medicine

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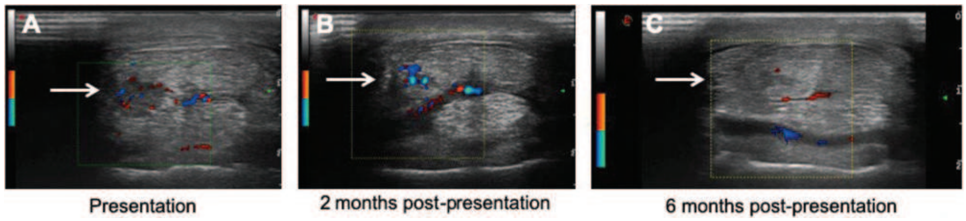

Fig. 1. Doppler ultrasound examination of a substantial lesion of the dorsal aspect of the lateral lobe of the deep digital flexor tendon at level B in the pastern. Examination at the time of presentation and 2 months after presentation revealed increased vascularity of the lesion (white arrow) as expected during the proliferation and reparative phases of healing (A and B) which was resolved by 6 months post-presentation (C). For all images, lateral is on the left side of the image. Red represents blood flow toward the ultrasound probe while blue represents blood flow away from the ultrasound probe.

for the differentiation of active versus inactive tendon and ligament injuries.[5–11] In terms of monitoring tendon healing, Doppler is especially useful for identifying the progression of a tendon lesion out of the inflammation and proliferation/reparative phases in which hypervascular granulation tissue exists (Fig. 1, A and B) and into the remodeling phase in which hypovascular scar tissue predominates (Fig. 1C). Such information is helpful for determining lesion resolution, or lack thereof in some cases, and for appropriately guiding increases in levels of controlled exercise. Doppler is also very useful for assessing re-injury or even setbacks during the initial rehabilitation period in which a lesion that was hypovascular on a previous examination suddenly becomes vascular again. While little information is available regarding the use of Doppler for assessing ligament healing, a descriptive study examining the suspensory branches of 13 horses did find Doppler signal in all branches that were abnormal on gray-scale ultrasound and did not find Doppler signal in any branches that were normal on gray-scale ultrasound.[10] While these results were not able to be correlated to soundness, they provide justification for further investigation of the use of Doppler for the assessment of ligament injuries.[10]

Elastography is another ultrasound technique now used in both equine and human sports medicine to assess the quality of healing tendon tissue.[3,12–14] Elastography allows for determination of tissue stiffness through application of compression with the ultrasound probe which results in tissue deformation (strain) and alteration of sound waves as they travel through that tissue. Normal tendon tissue is stiffer than injured tendon and therefore elastography can be used to monitor tendon healing over time from "soft" to "hard" tissue as commonly reported with a color scale on most ultrasound programs (Fig. 2). In a prospective longitudinal study on the healing of naturally occurring superficial digital flexor tendon injuries in 7 racing Thoroughbreds, an important finding was that gray-scale ultrasonography scores improved over the initial 3 months but then became static while elastography scores and strain ratios continued to improve with healing over the full 9 months that the horses were monitored.[3] Similar to as described above for Doppler, such information can be very useful for guiding informed decisions on increases in exercise intensity during rehabilitation as well as to monitor for any potential setbacks or re-injuries in which a previously stiff or "hard" tendon lesion suddenly becomes less stiff or "soft" again. Finally, both methods can be used to identify chronic tendon lesions that remain hypervascular and "soft" despite treatment and, therefore have a poor prognosis. Again, similar to as described above for Doppler, much less is known regarding the utility of elastography for ligaments as compared to tendons. In a study examining 33 suspensory branches, however, elastography correlated well with gray-scale ultrasound, MRI, and clinical examination findings, suggesting that it is a useful technique for monitoring lesions at this site.[12]

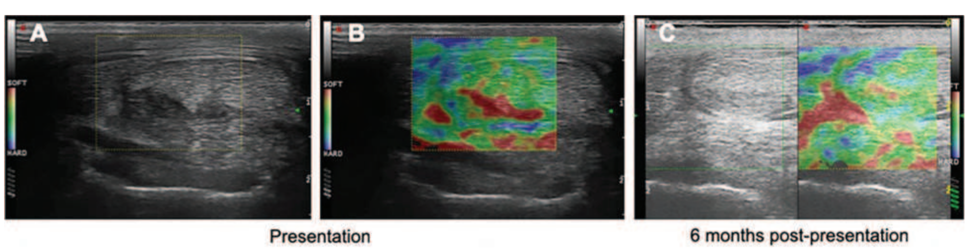

Fig. 2. Gray-scale (A) and elastography images (B and C) of the same lesion of the dorsal aspect of lateral lobe of the deep digital flexor tendon as shown in Fig. 1. The lesion was diffusely "soft" (red) at the time of presentation (B) but markedly improved by 6 months post-presentation as shown in the split screen gray-scale and elastography image of the lateral lobe (C).

MRI

MRI is widely recognized as a valuable modality for the diagnosis of tendon, ligament, cartilage, and bone injuries.[15–25] Low-field MRI (0.27T) is generally performed with the horse standing under sedation and has proven very useful for the diagnosis and re-evaluation of injuries in the distal limb, and particularly in the foot. High-field MRI (1.5T or 3T) provides improved image quality and resolution, but carries the associated risk and expense of general anesthesia. For this reason, it is rare to repeat a high-field MRI for monitoring or re-assessment unless the horse is unresponsive to therapy and/or has become increasingly lame despite therapy. In general, studies comparing the accuracy of low-field vs high-field MRI for the foot, pastern, and fetlock regions have found comparable results, with the exception of lesions of the articular cartilage and smaller anatomical structures, which were best visualized on high-field MRI.[17,18,24,25] Lastly, high-field MRI is more commonly utilized for the diagnosis of injuries localized to the carpus, tarsus, or proximal suspensory region due to the need for general anesthesia to avoid excessive motion artifacts in these regions.[26]

Computed Tomography

In equine practice, computed tomography (CT) has historically been used for the examination of osseous structures as MRI is considered the gold standard for soft-tissue imaging. However, when compared to MRI, CT has been shown to be useful for identifying soft-tissue lesions such as tears in the deep digital flexor tendon.[27–29] In addition, CT arthrography has been shown to be a reliable modality in detecting cruciate ligament injuries in the stifle when compared to radiography, ultrasonography, and arthroscopy.[30] Contrast-enhanced CT has also been shown to provide more information on angiogenesis compared to MRI, which may provide useful information regarding prognosis and treatment.[31] At this time, CT typically requires general anesthesia; however, there has recently been great advancement in the standing CT technology. As the standing CT technology becomes more advanced and more widely available, this modality could be very useful for monitoring sports medicine and rehabilitation injuries with the benefits of lack of general anesthesia, relatively quick procedure, and information regarding angiogenesis.

Nuclear Scintigraphy

Nuclear scintigraphy, or bone scans, are widely used in equine sports medicine for diagnosing not only osseous injuries but soft-tissue and vascular injuries as well. In the authors' practice, nuclear scintigraphy can be a useful tool for monitoring and reassessing bone bruises or osseous injuries identified on MRI without the need for repeat general anesthesia.[32,33]

3. Monitoring of Soft-Tissue Injuries

"Simple" Tendon and Ligament Lesions with Overt Fiber Pattern Disruption

In the authors' practice, soft-tissue lesions of the distal limb and outside of the hoof capsule that have overt fiber pattern disruption are generally monitored every 2–4 weeks initially during the acute phase and then every 4–8 weeks until healed. The imaging findings are assessed in combination with a physical and lameness evaluation. Results of these examinations guide decision making on rehabilitation protocols and eventual return to full work. Typically, an increase in exercise intensity is made only after a favorable lameness examination with improvement in healing from the previous ultrasound examination. In the authors' practice, the trainer and/or owner of all horses entering into a rehabilitation program are given the overall expectation for time to return to full work provided that the lesion heals well and are counseled on the importance of calm stall rest with controlled exercise. When needed, long-term sedatives such as reserpine[34] or trazadone[35] are prescribed for the horse to facilitate this. In addition, the trainer and/or owner are counseled on the importance of maintaining overall fitness as much as possible during the rehabilitation period by utilizing mobility, strength building, and core stability exercises.

Following strict stall rest as needed, controlled daily walking is generally instituted for 8 weeks with gradual increases in duration building up to 40 minutes by that 8-week mark. In the authors' sport horse practice, experience shows that this (sometimes) is best accomplished under saddle rather than in hand (depending on what is best for the safety of the rider and horse) to keep the horse focused and in the mindset of working. Provided that the 8-week recheck examination reveals improvement or no increase in lesion severity, trotting is gradually introduced to the rehabilitation program starting at very short, straight sets (i.e., long side of arena) with walking in between for the first week then gradually increasing weekly with the goal of 30–35 minutes of trot work with walk breaks by 16 weeks into the rehabilitation program. Ground poles, or cavalettis, are also gradually introduced during this trotting period to improve strength and proprioception and keep the horse engaged in work. It has been the authors' experience that trot work is often required to provide the biomechanical stimulus necessary for appropriate tendon healing and in particular the regression of vasculature. For this reason, unless a lesion is very severe and/or has worsened in terms of size and loss of fiber pattern, it is rare for the authors to extend the walking period rather than start the trotting period. After 8 weeks of trotting, however, the authors look for definitive improvement in both fiber pattern and regression of vasculature prior to the start of canter work and/or work of increased intensity like lateral work depending on the horse's discipline. Persistent hypervascularity at this stage, even with return to normal fiber pattern, is worrisome to the authors for the horse's prognosis and particularly the ability to increase work without further injury. At this stage, the authors re-evaluate the horse's rehabilitation program both in terms of management (i.e., horse and trainer/owner compliance) and rehabilitation modalities.

In general, the authors' preference is for a horse to be cantering under saddle for 4 weeks and doing well on recheck examination prior to any turnout in a sizeable paddock, but understand that this may not be feasible for all horses depending on temperament, etc. After this point, increase in work intensity is very disciplined and horse-specific but for all horses the authors like to see complete resolution of the lesion on gray-scale as well as complete regression of vasculature on Doppler prior to such an increase. Additionally, the lesion, should appear "hard" on elastography. Once a horse has returned to full work, it is common in the authors' practice to re-assess the old injury site every 3–6 months or sooner (depending on severity) to monitor for subtle signs of re-injury and then adjust work level and/or rehabilitation accordingly. In particular, the authors utilize Doppler imaging to evaluate for potential return of vascularity and elastography to assess for a "softening" of the tendon/ligament that may precede any changes in fiber pattern.

The above recommendations are basic exercise components of a rehabilitation protocol. There are many other options including, but not limited to, underwater treadmill, salt water spa, vibration plate, laser, shockwave, and therapeutic ultrasound that the authors' utilize depending on the case and the owners' desire and financial ability. Where applicable, these specific modalities and therapies are discussed below under specific conditions.

Digital Flexor Tendon Sheath Pathology

Pathology within the digital flexor tendon sheath (DFTS) can be challenging to accurately diagnose, treat, and rehabilitate. New methods have been described to better define DFTS pathology such as standard CT,[28] contrast tenography utilizing either radiography[36] or CT,[29] saline distension of the DFTS utilizing ultrasonography or MRI,[37] and dynamic ultrasonography.[38,39] In the authors' practice, it is common to utilize multiple imaging modalities in addition to tenoscopy in order to best characterize and treat DFTS pathology as well as provide owners with an accurate prognosis. Unlike "simple" tendon and ligament lesions described above, lesions/tears within the DFTS are at risk of adhesion formation and restriction from such adhesions and/or palmar/plantar annular ligament constriction which cause pain and can substantially limit performance.[39–41] For this reason, rehabilitation of these injuries in the authors' practice also includes specific passive and active range of motion (ROM) exercises. Passive ROM exercises involve a human moving the limb, and more specifically in this case, the fetlock joint region through the normal ROM, while active ROM exercises include walking in the underwater treadmill[42] and walking or trotting over ground poles. Water height in the underwater treadmill is adjusted on a case by case basis depending on the horse's comfort level. In addition, the authors often utilize therapeutic ultrasound, laser, and friction massage to try to limit and/or prevent adhesion formation, which is associated with poor prognosis.

Suspensory Branch Pathology

As with most soft tissues, ultrasound is the imaging modality of choice when evaluating the suspensory branches. Due to the ease of diagnosis via ultrasound, further advanced imaging such as MRI is usually not necessary. In the authors' opinion, a complete radiographic examination of the fetlock region is always recommended in suspensory branch cases to determine the full extent of the osseous changes of the proximal sesamoid bones, fetlock joint, and potentially splint bones as these changes can greatly affect prognosis, rehabilitation timeline, and treatment options. Confirming or diagnosing suspensory ligament branch disease can be difficult with many horses having ultrasonographic abnormalities that are not necessarily a cause of clinical lameness.[43–45] When trying to determine or confirm a suspensory branch lesion as the cause of lameness and/or an active lesion, besides using clinical judgment such as pain on palpation and positive flexion test, Doppler is frequently used in the authors' practice. As previously discussed, there is little research to support this,[12] but in the authors' experience increasing levels of hypervascularity on Doppler ultrasound are seen with increasing degrees of lameness and therefore suggestive of an active and clinical injury. An additional imaging modality that can be useful in suspensory branch injuries is nuclear scintigraphy. Nuclear scintigraphy is helpful to determine the amount of osseous response to a given lesion as well as again determine whether the lesion is active.

Typical ultrasonographic abnormalities of suspensory branches are changes in shape, enlargement, diffuse or discrete fiber abnormalities, and margin irregularities. Important additional abnormalities to note, which affect prognosis and rehabilitation protocols, are insertional fiber changes at the attachment on the sesamoid bones with associated degree of osseous changes (evaluated in conjunction with radiographs), and presence and degree of periligamentous fibrosis. As ligament and bone interfaces are known weak spots in healing, injuries involving this interface such as resorptive or osseous cyst-like lesions, slow the rehabilitation timeline down as well as decrease prognosis.[46] Periligamentous fibrosis is more commonly seen in the hindlimbs and is associated with a decreased prognosis.[43,45]

In the authors' practice, all of the previously described variations in suspensory branch lesions affect the rehabilitation protocols and modalities that are instituted. For example, lesions affecting the osseous structures are more likely to be treated with bisphosphonates and shockwave therapy. Horses with periligamentous fibrosis are encouraged to get therapeutic ultrasound and daily friction massages. All horses affected with suspensory branch disease are prescribed ROM exercises, whether it be passive ROM or active consisting of ground poles and underwater treadmill exercise; however, these exercises become even more important in cases with concurrent arthrosis of the fetlock joint. Return to work is determined in a similar fashion as described above for "simple" tendon and ligament injuries. Osseous components are followed with radiographic examination and potentially nuclear scintigraphy as well.

Proximal Suspensory Injuries

Forelimb proximal suspensory ligament injuries are most commonly diagnosed via ultrasound with the most common findings being enlargement and fiber pattern abnormalities. The suspensory ligament can be a more difficult structure to identify definitive abnormalities on ultrasound, as with the standard palmar metacarpal approach the medial and lateral margins are not always visualized and the normal architecture of the ligament contains fat and muscle fibers that can create a varied fiber pattern appearance.[47–49] Due to the previously described difficulties inherent on ultrasound of the suspensory ligament, other techniques such as nonweight-bearing examination to visualize the complete suspensory ligament margins and angle contrast ultrasonography to help distinguish between fiber abnormalities, scarring, normal tendon fibers, and normal fat and muscle fibers have been described.[47,48] An important part of the ultrasound examination is the origin of the suspensory ligament on the palmar metacarpal bone as enthesopathy affects prognosis and rehabilitation.

Radiographic examination of the proximal metacarpal region is an important adjunct to the ultrasound examination of the suspensory ligament. Varying degrees of osseous changes of the palmar third metacarpal bone at the origin of the suspensory ligament consisting of sclerosis, resorptive change, avulsion fragment, and stress fractures will change prognosis and treatment. Other important osseous structures that should be evaluated with the suspensory ligament are the splint bones. It is prudent to evaluate the suspensory ligament with most splint bone abnormalities. With exostosis of the metacarpal bones, it is not always possible to determine the amount of axial osseous proliferation radiographically. Ultrasound should be used to evaluate whether there is impingement into the suspensory or adhesion formation. In the author's practice, rarely is MRI needed to obtain an accurate diagnosis and prognosis with forelimb proximal suspensory cases. However, it can be useful in cases that are not responding to treatment or in cases of re-injury. In cases of axial splint bone proliferation, MRI can be useful to determine the full extent of the axial splint bone proliferation and adhesion formation, as these changes affect prognosis, treatment, and likelihood of re-injury.

To determine the full extent of the bone response, a nuclear scintigraphy examination can also be helpful, especially when evaluating potential stress fractures or avulsion fragments, which will greatly affect the rehabilitation protocol requiring prolonged rest and potential prognosis. In these cases, rehabilitation is not only geared towards the affected soft tissues but also the osseous structures as previously discussed with suspensory branches as these interfaces can be a major weakness during and after the healing phase.[46]

Hindlimb proximal suspensory injuries can be difficult to both diagnose and monitor.[50–53] Subtle lesions are often hard to detect on gray-scale ultrasound examination and neither Doppler nor elastography have proven particularly useful in these cases to date.[12] In addition, moderate-to-severe lesions that are visible on ultrasound can have additional pathology not always visible on ultrasound that would substantially change the horse's prognosis as well as candidacy for neurectomy of the deep branch of the lateral plantar nerve. High-field MRI is generally thought of as the gold standard for making a diagnosis and for assessing prognosis, because of the ability of high-field MRI to accurately detect pathology of the entire suspensory ligament, including the tarsal extension commonly called the proximal bundle or accessory ligament of the suspensory ligament, which cannot be visualized well on ultrasound examination (Fig 3).[50,53] Injuries in the tarsal extension can lead to persistent lameness despite treatment and even neurectomy as this extension is proximal to the insertion of the deep branch of the lateral plantar nerve. Other imaging findings indicative of a poor prognosis include adhesions of the suspensory ligament to the surrounding soft tissues or bone, which can also be a reason for failure to respond to neurectomy,[51] and advanced bone changes at the origin of the suspensory ligament on the plantar aspect of the third metatarsal bone that can be visualized on both ultrasound and MRI as well as radiographs if the bone changes are significant. It is also important to rule out tarsal disease in horses that block to the proximal suspensory ligament region as it is not uncommon for worse changes to be seen in the tarsus that may affect future prognosis and treatment options.[26,50] Such imaging findings warrant open discussions with the owner about realistic expectations for the horse, particularly when combined with poor conformation such as a straight hock or dropped fetlock. Proximal suspensory ligament lesions that are readily

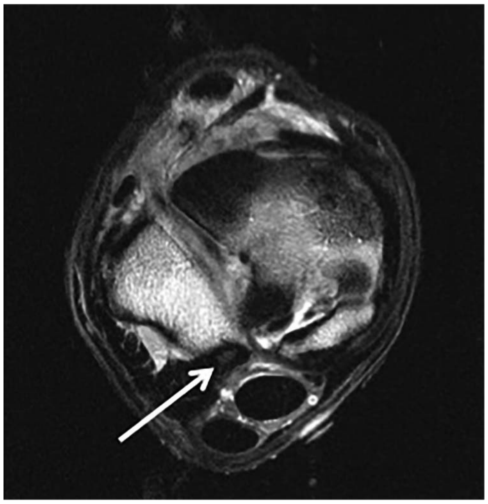

Fig. 3. Transverse PD MRI (1.5T) image of a hyperintense signal (white arrow) within the tarsal extension (accessory ligament) of the suspensory ligament.

visualized on gray-scale ultrasound examination and lack other additional findings on MRI are routinely monitored as described above for "simple" tendon and ligament injuries.

Soft-Tissue Injuries Within the Hoof Capsule

Soft-tissue injuries within the hoof capsule are undoubtedly best detected on MRI.[15,16,18,19–22] Unlike high-field MRI, low-field standing MRI is also commonly used for re-evaluation/monitoring of injuries to structures such as the collateral ligaments of the distal interphalangeal joint, the deep digital flexor tendon (DDFT), and the navicular apparatus. As ultrasonography techniques have advanced, it is also more commonplace now to be able to detect injuries within the hoof capsule using ultrasound in conjunction with the knowledge of the MRI findings. For example, insertional lesions of the deep digital flexor tendon diagnosed on MRI can be imaged and monitored using ultrasound via a transcuneal approach after thorough paring out of the frog and soaking of the foot (Fig. 4).[54] In the authors' practice, proper foot balance and therapeutic shoeing are a critical part of rehabilitation of soft-tissue injuries within the hoof capsule and are determined on a case-by-case basis. In the authors' experience, a substantial lesion of a collateral ligament requires a prolonged rehabilitation period compared to many other soft tissue injuries and also have a high likelihood of re-injury. Shockwave and laser are often utilized but both treatment and follow-up imaging are largely determined by lesion accessibility either inside or outside of the hoof capsule. Similarly, treatment of insertional lesions of the deep digital flexor tendon are limited in terms of access to the structure and often carry a poor prognosis in the authors' opinion for sustained athletic activity.

4. Monitoring of Bone and Cartilage Injuries

Bone Injuries

Increased use of MRI, particularly in sport horses, has led to increased findings of bone abnormalities, including bone marrow edema, sclerosis, and enthesiopathy.[26,55] While the clinical relevance of some of these lesions can be difficult to determine, a combination of MRI findings, diagnostic analgesia, and nuclear scintigraphy can be helpful to both determine clinical relevance and monitor response to treatment and rest. A recent study of 166 sport and pleasure horses undergoing low-field MRI of the fetlock region found a 76.5% prevalence of bone marrow lesions in the distal condyles of the third metacarpal bone with the dorsal aspects of the medial condyle and of the sagittal ridge being most common.[55] Lesion severity was not associated with lameness localization findings in this study, however, and the vast majority of the lesions found were grade 1 lesions extending less than 1/3 of the dorsal half of the condyle. The bone marrow lesions were considered the primary cause of lameness in only

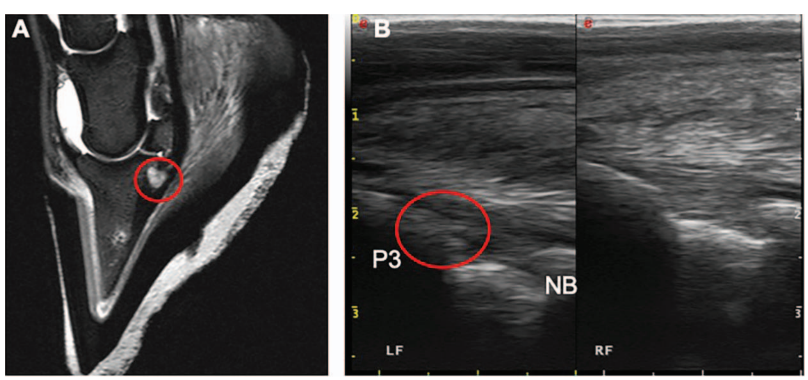

Fig. 4. MRI (1.5T) short tau inversion recovery (STIR) sagittal image of the left forelimb foot (A) and transcuneal ultrasound images (B) comparing the left forelimb and right forelimb impar and deep digital flexor tendon (DDFT) insertion on the distal phalanx. On both images of the left forelimb, the findings include impar ligament and DDFT insertional desmopathy with a resorptive or osseous cyst-like lesion (circled in red) at the insertion on the distal phalanx (P3). The navicular bone is labeled NB.

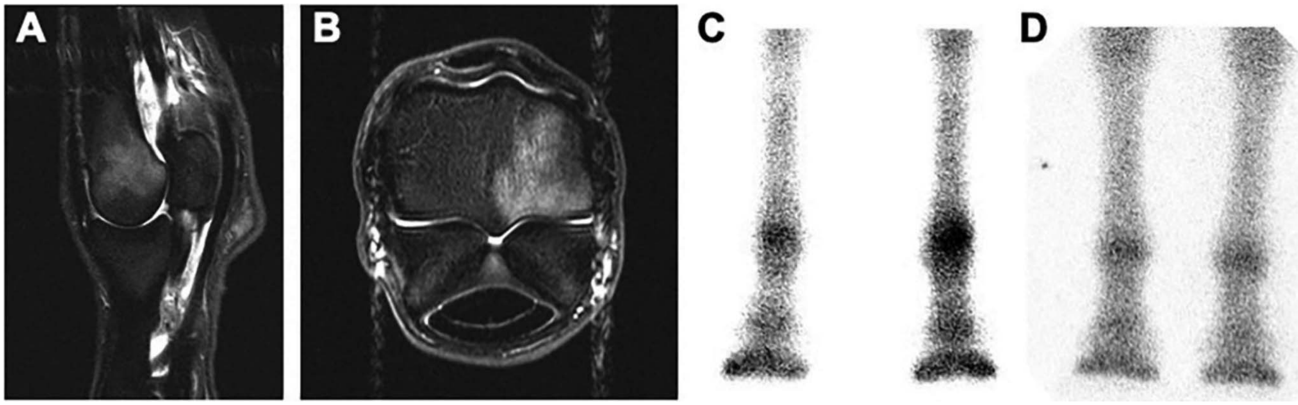

Fig. 5. Sagittal (A) and transverse (B) STIR MRI (1.5T) images revealing marked bone edema of the lateral condyle of the left forelimb third metacarpal bone considered to be the primary cause of lameness. The lesion remained present on recheck examination with nuclear scintigraphy performed approximately 2 months later (C) but was resolved on nuclear scintigraphy approximately 1 year later (D). For panels B–D, the lateral aspect of the left forelimb is on the right side of the image.

16% of the horses.[55] Another recent study of 103 non-racing horses, primarily western performance horses, undergoing high-field MRI of the tarsus found bone marrow lesions of the third tarsal bone to be significantly correlated to degree of lameness, while bone marrow lesions in other locations were not.[26] The findings of these studies suggest that bone marrow edema lesions must be carefully ruled in or out as the primary cause of lameness in a patient on a case-by-case basis. For lesions that are considered the primary cause of lameness, nuclear scintigraphy may be helpful for both confirming the diagnosis and for determining lesion resolution following treatment and rest in order to avoid repeated general anesthetic events for re-evaluation with high-field MRI, although this is also an option (Fig. 5). Nuclear scintigraphy may also be very useful for the monitoring of bone pathology of the foot previously diagnosed on MRI, including osseous trauma to the distal phalanx and ungular cartilages as well as enthesiophytes at the insertion of the deep digital flexor tendon on the distal phalanx (Fig. 6).[32] Generally, the authors' recommend a period of 90–120 days of rest and rehabilitation for bone marrow lesions prior to re-evaluation. Rehabilitation often involves the use of underwater treadmill and/or controlled exercise in soft footing to limit concussive forces. In addition, the authors' often utilize vibration plate and pulsed electromagnetic field therapy on these cases.

Cartilage Injuries and Osteoarthritis

Cartilage injuries are best diagnosed and monitored via high-field MRI as described above and arthroscopy when indicated. As cartilage has extremely poor healing capacity, prognosis and rehabilitation goals are aimed at limiting progression and restoring a normal joint environment as much as possible. In these cases, it is important to determine the extent of associated subchondral bone injury both for prognosis and rehabilitation timeline, as damage to subchondral bone will both decrease prognosis and substantially lengthen rehabilitation time. For all cases, rehabilitation is focused on preserving joint

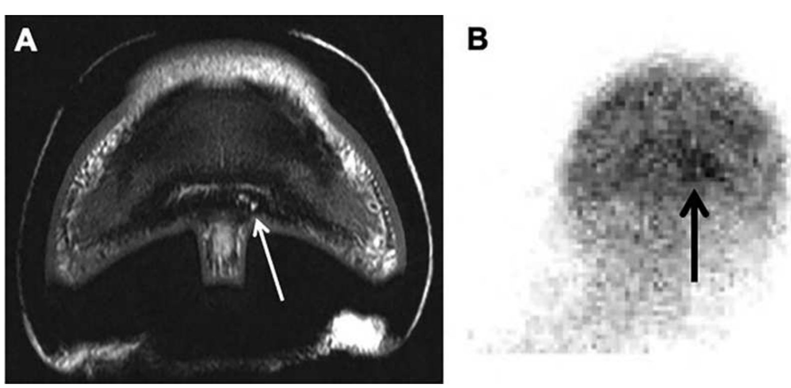

Fig. 6. Transverse STIR MRI (1.5T) image (A) of a lesion of the lateral lobe of the DDFT at the insertion on the distal phalanx (white arrow). Nuclear scintigraphy image (B) from a 1-year follow-up examination when a mild left forelimb lameness persisted showing increased radiopharmaceutical uptake at the insertion of the lateral lobe on the distal phalanx (black arrow).

ROM and encouraging mobility, which can be achieved using underwater treadmill in addition to other modalities. Treatment during an acute injury or inflammatory episode is often treated with a combination of stall rest, thermal therapy, and pulsed electromagnetic field therapy. Once inflammation and pain has subsided, consistent exercise is highly encouraged and in the authors' opinion many cases are best managed with open access to turn-out.

Acknowledgments

Declaration of Ethics

The Authors have adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Authors have no conflicts of interest.

References

1. Reef VB. Superficial digital flexor tendon healing: Ultrasonographic evaluation of therapies. *Vet Cli North Am Pract* 2001;17:159–178.
2. Whitcomb MB. Ultrasonographic evaluation of the distal extremity. *J Equine Vet Sci* 2009;1:47–59.
3. Tamura N, Nukada T, Kato T, et al. The use of sonoelastography to assess the recovery of stiffness after equine superficial digital flexor tendon injuries: A preliminary prospective longitudinal study of the healing process. *Equine Vet J* 2017;49:590–595.
4. Van Schie JT, Bakker EM, van Weeren PR. Ultrasonographic evaluation of equine tendons: A quantitative *in vitro* study of the effects of amplifier gain level, transducer-tilt, and transducer-displacement. *Vet Rad Ultrasound* 1998;39:151–160.
5. Boesen MI, Nanni S, Langberg H, et al. Colour Doppler ultrasonography and sclerosing therapy in diagnosis and treatment of tendinopathy in horses—A research model for human medicine. *Knee Surg Sport Trauma Arthrosc* 2007;15:935–939.
6. Estrada RJ, van Weeren PR, Van de Lest CHA, et al. Comparison of healing in forelimb and hindlimb surgically induced core lesions of the equine superficial digital flexor tendon. *Vet Comp Orthop Traumatol* 2014;27:358–365.
7. Hatazoe T, Endo Y, Iwamoto Y, et al. A study of the distribution of color Doppler flows in the superficial digital flexor tendon of young Thoroughbreds during their training periods. *J Equine Sci* 2016;26:99–104.
8. Kristoffersen M, Öhberg L, Johnston C, et al. Neovascularisation in chronic tendon injuries detected with colour Doppler ultrasound in horse and man: Implications for research and treatment. *Knee Surg Sport Traumatol Arthrosc* 2005;13:505–508.
9. Murata D, Misumi K, Fujiki M. A preliminary study of diagnostic color Doppler ultrasonography in equine superficial digital flexor tendonitis. *J Vet Med Sci* 2012;74:1639–1642.
10. Rabba S, Grulke S, Verwilghen D, et al. B-mode and power Doppler ultrasonography of the equine suspensory ligament branches: A descriptive study on 13 horses. *Vet Radiol Ultrasound* 208;59:453–460.
11. Lacitignola L, Rossella S, Pasquale DL, et al. Power Doppler to investigate superficial digital flexor tendinopathy in the horse. *Open Vet J* 2019;9:317–321.
12. Lustgarten M, Redding WR, Labens R, et al. Elastographic characteristics of the metacarpal tendons in horses without clinical evidence of tendon injury. *Vet Radiol Ultrasound* 2014;55:92–101.
13. Tamura N, Kuroda T, Kotoyori Y, et al. Application of sonoelastography for evaluating the stiffness of equine superficial digital flexor tendon during healing. *Vet Rec* 2017;180:120.
14. Ellison ME, Duenwald-kuehl S, Forrest LJ, et al. Reproducibility and feasibility of acoustoelastography in the superficial digital flexor tendons of clinically normal horses. *Am J Vet Res* 2014;75:581–587.
15. Dyson S, Murray R, Schramme M, et al. Magnetic resonance imaging of the equine foot: 15 horses. *Equine Vet J* 2003;35:18–26.
16. Dyson SJ. Medical management of superficial digital flexor tendonitis: A comparative study in 219 horses (1992–2000). *Equine Vet J* 2004;36:415–419.
17. Murray RC, Mair TS, Sherlock CE, et al. Comparison of high-field and low-field magnetic resonance images of cadaver limbs of horses. *Vet Rec* 2009;165:281–288.
18. Kottmeier LK, Seehusen F, Helweg M, et al. High-field (3 Tesla) MRI of the navicular apparatus of sound horses shows good agreement to histopathology. *Vet Radiol Ultrasound* 2020;61:48–57.
19. Murray RC, Schramme MC, Dyson SJ, et al. Magnetic resonance imaging characteristics of the foot in horses with palmar foot pain and control horses. *Vet Radiol Ultrasound* 2006;47:1–16.
20. Dyson S, Murray R. Verification of scintigraphic imaging for injury diagnosis in 264 horses with foot pain. *Equine Vet J* 2007;39:350–355.
21. Dyson SJ, Murray R, Schramme MC. Lameness associated with foot pain: Results of magnetic resonance imaging in 199 horses (January 2001–December 2003) and response to treatment. *Equine Vet J* 2005;37:113–121.
22. Dyson SJ, Murray R, Schramme M, et al. Collateral desmitis of the distal interphalangeal joint in 18 horses (2001–2002). *Equine Vet J* 2004;36:160–166.
23. de Zaniv D, Polidori C, di Giancamillo M, et al. Correlation of radiographic measurements of structures of the equine foot with lesions detected on magnetic resonance imaging. *Equine Vet J* 2016;48:165–171.
24. Barrett MF, Frisbie DD, King MR, et al. A review of how magnetic resonance imaging can aid in case management of common pathological conditions of the equine foot. *Equine Vet Educ* 2017;29:683–693.
25. Smith MA, Dyson SJ, Murray RC. The appearance of the equine metacarpophalangeal region on high-field vs. standing low-field magnetic resonance imaging. *Vet Radiol Ultrasound* 2011;52:61–70.
26. Barrett MF, Selberg KT, Johnson SA, et al. High field magnetic resonance imaging contributes to diagnosis of equine distal tarsus and proximal metatarsus lesions: 103 horses. *Vet Radiol Ultrasound* 2018;59:587–596.
27. Vallance SA, Bell RJW, Spriet M, et al. Comparisons of computed tomography, contrast enhanced computed tomography and standing low-field magnetic resonance imaging in horses with lameness localised to the foot. Part 1: Anatomic visualisation scores. *Equine Vet J* 2102;44:51–56.
28. Jones ARE, Ragle CA, Mattoon JS, et al. Use of non-contrast-enhanced computed tomography to identify deep digital flexor tendinopathy in horses with lameness: 28 cases (2014–2016). *J Am Vet Med Assoc* 2019;254:852–858.
29. Agass R, Dixon J, Fraser B. Computed tomographic contrast tenography of the digital flexor tendon sheath of the equine hindlimb. *Vet Radiol Ultrasound* 2018;59:279–288.
30. Nelson BB, Kawcak CE, Goodrich LR, et al. Comparison between computed tomographic arthrography, radiography, ultrasonography, and arthroscopy for the diagnosis of femorotibial joint disease in Western performance horses. *Vet Radiol Ultrasound* 2016;57:387–402.
31. Puchalski SM, Galuppo LD, Drew CP, et al. Use of contrast-enhanced computed tomography to assess angiogenesis in deep digital flexor tendonopathy in a horse. *Vet Radiol Ultrasound* 2009;50:292–297.
32. Quiney LE, Ireland JL, Dyson SJ. Evaluation of the diagnostic accuracy of skeletal scintigraphy for the causes of front

foot pain determined by magnetic resonance imaging. *Vet Radiol Ultrasound* 2018;59:490–498.
33. Ross MW, Stacy VS. Nuclear medicine. In: Ross MW, Dyson SJ, eds. *Diagnosis and management of lameness in the horse*. Philadelphia, PA: Elsevier Saunders; 2011.
34. Gilbertie JM, Davis JL, Davidson GS, et al. Oral reserpine administration in horses results in low plasma concentrations that alter platelet biology. *Equine Vet J* 2019;51:537–543.
35. Davis JL, Schirmer J, Medlin E. Pharmacokinetics, pharmacodynamics and clinical use of trazodone and its active metabolite m-chlorophenylpiperazine in the horse. *J Vet Pharmacol Ther* 2018;41:393–401.
36. Kent AV, Chesworth MJ, Wells G, *et al.* Improved diagnostic criteria for digital flexor tendon sheath pathology using contrast tenography. *Equine Vet J* 2020;52:205–212.
37. Daniel AJ, Leise BS, Selberg KT, et al. Enhanced ultrasonographic imaging of the equine distal limb using saline injection of the digital flexor tendon sheath: A cadaver study. *Vet J* 2019;247:26–31.
38. Garcia da Fonseca RM, Evrard L, Rabba S, et al. Dynamic flexion/extension and non-weight bearing ultrasonography is helpful for identifying manica flexoria tears in horses. *Vet Radiol Ultrasound* 2019;60:65–74.
39. DiGiovanni DL, Rademacher N, Riggs LM, et al. Dynamic sonography of the equine metacarpo(tarso)phalangeal digital flexor tendon sheath. *Vet Radiol Ultrasound* 2016;57:21–629.
40. Nixon AJ, Sams AE, Ducharme NG. Endoscopically assisted annular ligament release in horses. *Vet Surg* 1993; 22:501–507.
41. Wright IM, McMahon PJ. Tenosynovitis associated with longitudinal tears of the digital flexor tendons in horses: A report of 20 cases. *Equine Vet J* 1999;31:12–18.
42. Mendez-Angulo JL, Firshman AM, Groschen DM, et al. Effect of water depth on amount of flexion and extension of joints of the distal aspects of the limbs in healthy horses walking on an underwater treadmill. *Am J Vet Res* 2013; 74:557–566.
43. Marneris D, Dyson SJ. Clinical features, diagnostic imaging findings and concurrent injuries in 71 sports horses with suspensory branch injuries. *Equine Vet Educ* 2014;26:312–321.
44. Ramzan PHL, Palmer L, Dallas RS, et al. Subclinical ultrasonographic abnormalities of the suspensory ligament branch of the athletic horse: A survey of 60 Thoroughbred racehorses. *Equine Vet J* 2013;45:159–163.
45. Read RM, Boys-Smith S, Bathe AP. Subclinical ultrasonographic abnormalities of the suspensory ligament branches are common in elite showjumping warmblood horses. *Front Vet Sci* 2020;7:1–10.
46. Birch HL, Sinclair C, Goodship AE, et al. Nuclear Medicine. In: Hinchcliff KW, Kaneps AJ, Geor RJ, eds. *Equine sports medicine and surgery*. Philadelphia, PA: Elsevier Saunders; 2014.
47. Werpy NM, Denoix JM. Imaging of the Equine Proximal Suspensory Ligament. *Vet Clin North Am.-Equine Pract* 2012;28:507–525.
48. Werpy NM, Denoix JM, Mcilwraith CW, et al. Comparison between standard ultrasonography, angle contrast ultrasonography, and magnetic resonance imaging characteristics of the normal equine proximal suspensory ligament. *Vet Radiol Ultrasound* 2013;54:536–547.
49. Barrett MF, Manchon PT, Hersman J, et al. Magnetic resonance imaging findings of the proximal metacarpus in Quarter Horses used for cutting: Retrospective analysis of 32 horses 2009–2012. *Equine Vet J* 2018;50:172–178.
50. Labens R, Schramme MC, Robertson ID, et al. Clinical, magnetic resonance, and sonographic imaging findings in horses with proximal plantar metatarsal pain. *Vet Radiol Ultrasound* 2010;51:11–18.
51. Dyson S, Murray R, Pinilla MJ. Proximal suspensory desmopathy in hindlimbs: A correlative clinical, ultrasonographic, gross post mortem and histological study. *Equine Vet J* 2017;49:65–72.
52. Watts AE, Sampson S, Navas C. How to select and manage cases for hindlimb fasciotomy and neurectomy, in *Proceedings*. Am Assoc Equine Pract 2017;63:227–232.
53. Dyson S, Blunden A, Murray R. Magnetic resonance imaging, gross postmortem, and histological findings for soft tissues of the plantar aspect of the tarsus and proximal metatarsal region in non-lame horses. *Vet Radiol Ultrasound* 2017;58:216–227.
54. Jacquet S, Denoix JM. Ultrasonographic examination of the distal podotrochlear apparatus of the horse: A transcuneal approach. *Equine Vet Educ* 2012;24:90–96.
55. De Guio C, Ségard-Weisse E, Thomas-Cancian A, et al. Bone marrow lesions of the distal condyles of the third metacarpal bone are common and not always related to lameness in sports and pleasure horses. *Vet Radiol Ultrasound* 2019; 60:167–175.

How Imaging Findings in Western Sport Horses Relate to Performance and Lameness

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1. Introduction

Imaging of horses falls into two broad categories: imaging performed to diagnose the cause of a lameness or performance issue, and imaging performed to try to predict or rule out lesions that could cause problems in the future, such as the pre-purchase exam. Each of these scenarios presents unique challenges but both require a combination of clinical experience, scientific review, and educated guesses to come up with the appropriate answer. There are two specific steps to take when reviewing images: 1) analysis—find and describe the lesions and identify what is normal; and 2) synthesis—applying all the other pertinent details of the horse's history, signalment, and clinical exam, and integrating this information with the imaging findings to weigh risk and significance. Both of these steps are crucial and each must be performed in its own right. The analysis should be undertaken without bias based on clinical suspicion and be considered a fact-finding mission. The next step of synthesis is also essential—without pertinent clinical information, most imaging findings are of little value.

Many elements can influence the significance of imaging lesions. One of these elements is the horse's discipline. The reason for this is multifactorial and includes demands of the sport, breed predisposition, client expectations, and culture, among other factors. Western performance encompasses a range of disciplines with different expectations in terms of speed, agility, and longevity. The intention is to review common imaging findings that affect horses in these disciplines, what is known and what is suspected in terms of the significance of these findings in relation to performance and lameness.

2. Foot

By far the most commonly imaged area and most frequently localized source of lameness, the foot is complex and often requires more than one imaging modality for complete assessment.[1] However, as a first line, radiographs are not obsolete and still provide very valuable information.

The Quarter Horse dominates the Western disciplines and with that comes certain lesions to which these horses are prone. In particular, damage to the navicular apparatus is a primary concern. There are many radiographic changes that can be suggestive of navicular changes and have a range of significance.

Dilated Synovial Invaginations

The synovial invaginations of the navicular bone should be symmetric between limbs and ovoid or

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triangular in shape. Quarter Horses normally have smaller synovial invaginations than some other breeds such as Warmbloods and should be assessed as such. Even within the breed there is a range of normal and therefore comparison between limbs is helpful to identify some changes. The significance of dilated synovial invaginations remains a source of debate and depends on the degree of change. Recently it has been suggested that synovial invagination dilation may be associated with synovitis of the distal interphalangeal joint rather than primary navicular disease, although this concept needs further exploration.[2] In the author's opinion, mild-to-moderate synovial invagination dilation in the absence of other abnormalities in the bone can be incidental and may not change over time. Dilation of the synovial invaginations becomes a concern when the enlargement results in cyst-like dilation or extends to the palmar endosteum of the flexor cortex. Enlarged synovial invaginations that extend to the palmar aspect can cause pressure resorption of the flexor cortex, resulting in a flexor cortical defect, which is a clinically relevant finding.

Distal Border Fragments

Quarter Horses are a small component of the population in the reported studies regarding the significance of distal border fragments. The literature is mixed on the significance of these findings; the study with the greatest number of Quarter Horses did not show a significant relationship between distal border fragments identified on magnetic resonance imaging (MRI) and lameness.[3] On MRI, fragments can be seen on the distal border of otherwise completely normal navicular bones or can also be a component of other navicular apparatus changes. The significance is likely a continuum of severity with other changes, and in isolation, these fragments are not likely to be a primary source of lameness.

Proximal Vascular Channels

Dilation of the proximal vascular supply of the navicular bones can be difficult to identify radiographically until advanced changes are present, but observing the shape of the navicular bone on the lateral view is helpful to identify an increased concave margin to the proximal border of the navicular bone. This change is more readily identified with MRI. Dilation of the proximal vascular channels is rarely found incidentally, in sound limbs, or in isolation and is an indication of navicular disease that is clinically significant. Increased size and number of the proximal vascular channels has been shown to be associated with lesions of the flexor cortex and deep digital flexor tendon.[4]

Sclerosis

Trabecular and endosteal sclerosis of the navicular bone are significant indicators of navicular disease

Fig. 1. Navicular skyline view of an 8-year-old Quarter Horse used for roping. Radiographic changes include marked sclerosis of the spongiosa, decreased corticomedually distinction and lucencies consistent with flexor cortical lysis medial and lateral of the sagittal ridge.

and often accompany palmar fibrocartilage damage and/or flexor cortical bone loss (Fig. 1). This can be a challenge for image interpretation as positional artifacts can mimic sclerosis. As this is a clinically significant finding when real, it is important to distinguish artifact from true change. The finding should be repeatable on both the lateral and skyline radiograph; if seen on only one view, it is more likely artifact.

Flexor Cortical Lysis

Flexor cortical erosions are a clinically significant finding that are routinely associated with lameness. While small flexor cortex lesions can be found in the contralateral non or less lame leg on a bilateral MRI or computed tomography (CT) foot study, it is rare to find these lesions incidentally in horses that are in full work and completely sound. While some horses with these lesions can be serviceably sound and manageable for a period of time, generally these lesions progress and often have other comorbidities such as damage to the deep digital flexor tendon and navicular bursitis.

Deep Digital Flexor Tendinopathy

Damage to the deep digital flexor tendon can occur in conjunction with navicular disease or in isolation. While horses can manage for a while with some degree of tendon damage, lesions often progress or worsen with continued work. Dorsal border fraying is most frequently found at the level of the proximal recess of the navicular bursa and has been reported to have improved likelihood for return to work than other lesions types.[5] Deep digital flexor tendon damage is much more likely to be found in lame horses than sound horses, indicating that it is rarely an incidental finding.[6] An important practice note is that deep digital flexor tendon core lesions or splits at the level of the pastern often extend distally into the foot; therefore, if a deep digital flexor tendon tear is found on pastern ultrasound, an MRI is warranted to further investigate the extent of disease.

3. Pastern

Osteoarthritis of the pastern joint is of variable clinical significance and moderate changes can be found in the absence of lameness. Subchondral bone lysis, subchondral cystic lesions, and joint space narrowing are more likely to be significant.

4. Fetlock

The fetlock generally does not receive the same attention in Western horses as in racehorses and English sport horses. While a less common area of injury, there are still lesions of significance that pertain to Western performance horses. Evidence of osteoarthritis of the metatarsophalangeal joint may be of greater significance in team roping heeling horses, which are more prone to changes in this joint and to hind-limb lameness than heading horses.[7] Fetlock osteoarthritis is of variable clinical significance. Fetlock radiographs often do not adequately depict the degree of pathology in the joint, so horses that block to the fetlock and do not have sufficient radiographic changes to explain the lameness often benefit from MRI. Subchondral bone damage of the fetlock joint presents a management challenge and can result in long-term lameness. Western pleasure and competitive trail horses are more prone to repetitive stress injuries, including of the fetlock joint[a]; therefore, changes in this joint should be examined more critically in this population.

5. Forelimb Suspensory Apparatus

Reining and cutting horses have a propensity to develop forelimb suspensory ligament injuries. In cutting horses, the degree of lameness and severity of the suspensory ligament injury has not been shown to affect likelihood of return to work or earnings in limited age events, with 22 of 30 in the study returning to work.[8] However, it was not determined by the study whether these horses still had some degree of lameness despite the positive performance outcome.

The most common manifestation of suspensory ligament desmopathy is ligamentous enlargement (Fig. 2). This enlargement persists even after the resolution of the clinical signs; therefore, suspensory ligament changes found on ultrasound have to be correlated with lameness evaluation to assess significance. Bone marrow lesions (often called bone bruises) of the third metacarpal bone at the suspensory ligament origin are almost always of clinical significance. These require MRI for identification. Some horses that block to the proximal suspensory region can have almost no ligament change and almost all of the pathology is related to the bone.

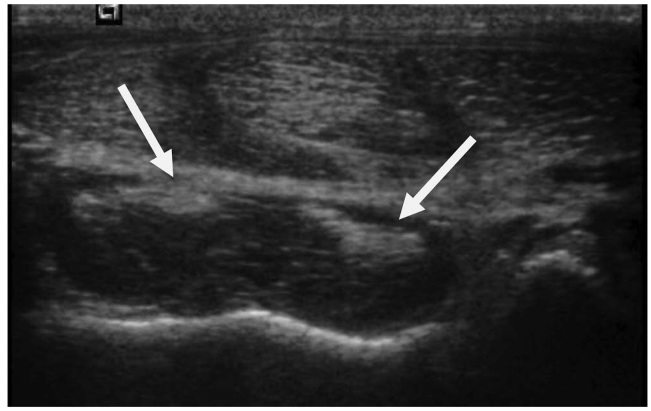

Fig. 2. Transverse, non-weight bearing off-angle ultrasound of a cutting horse with lateral to the left. The suspensory ligament is diffusely enlarged with palmar displacement of the fat and muscle bundles (arrows).

In such cases, these horses may have relatively normal ultrasound findings and MRI can be valuable for detecting the primary source of lameness.

6. Superficial Digital Flexor Tendon

Older Quarter Horses have been reported to suffer more from damage to the proximal aspect of the forelimb superficial digital flexor tendon with a low rate of return to work.[9] Western performance horses are less likely to develop a classic core lesion and more frequently have peripheral tendon tears. This pattern has been reported in cutting horses in the mid metacarpus with good rate of return to work (82%) and low recurrence rate (18%).[10] In the author's experience, the reinjury rate seems to be higher in reining horses, who tend to get lesions that "zipper" or extend up or down from the original injury site. It is crucial when performing the ultrasound scan to extend the range of the ultrasound into the carpal canal to avoid missing lesions that are clinically significant. Therefore, the significance of superficial digital flexor tendon injuries should be weighed more heavily when they are in the proximal metacarpus and/or carpal canal and when reining horses are affected.

7. Carpus

Similar to the fetlock, the carpus receives less attention in Western horses. Carpal arthritis has been reported as a low percentage as a cause of lameness in barrel horses.[11] While it is certainly a less common cause of forelimb lameness than foot-related pain, barrel horses are prone to more severe osteoarthritis of the carpus compared to other Western performance disciplines (Fig. 3). Often these horses are able to manage mild-to-moderate osteoarthritis of the carpus and may not present for carpal-related lameness until the changes are more advanced. This is important in relation to longevity and client expectations for career length; a barrel horse with

Fig. 3. Flexed lateral view of the carpus in a 7-year-old barrel horse. There are multiple osteochondral fragments of the radiocarpal joint, including in the palmar aspect of the joint (circle).

milder carpal osteoarthritis may be able to run for many years before it becomes performance limiting. Although not proven in the literature, it seems that off the track Quarter Horses that have raced longer and are then used as second career barrel horses may be more prone to carpal disease[b].

Reining horses can have repetitive osseous stress and sclerosis of the third carpal bone, similar to that of racehorses, and therefore including a skyline view of the carpus is warranted in these horses with lameness localized to the carpus.

8. Elbow and Shoulder

While not specific to the Western performance horse, subchondral bone injury, osteochondrosis, and osteoarthritis of the elbow and shoulder do not tend to be well tolerated and findings of disease in these joints is usually clinically significant.

9. Hind Suspensory Apparatus

Hind-limb suspensory ligament disease affects all disciplines but is particularly problematic in cutting[12] and reining horses. In rope horses, more suspensory injuries have been reported in heading horses than heeling horses.[13] Lameness due to suspensory ligament damage can be challenging to definitively diagnose because of the overlap in blocking patterns and propensity for Western performance horses to have concurrent distal tarsal disease. A retrospective review of tarsal/metatarsal MRIs predominantly of Western performance horses found that almost 47% of the horses that had lameness resolve with diagnostic analgesia of the proximal suspensory ligament (PSL) actually had more distal tarsal changes than changes to the PSL.[14]

Ultrasound of the PSL is the most common diagnostic imaging modality. It is the author's firm opinion that an ultrasound of the PSL must include assessment of the ligament with the limb nonweight bearing. Similar to the forelimb, the most common manifestation of PSL desmopathy is enlargement and this will persist even when clinical signs resolve; therefore, it must be correlated with the results of the lameness exam. Similar bone resorption and proliferation of the plantar cortex will also persist even when lameness resolves. The severity of ligament and metatarsal (MT3) changes have not been found to significantly correlate with the degree of lameness.[14] In a retrospective review of tarsal and metatarsal MRIs in cutting horses, 9 of 17 horses diagnosed with PSL disease on MRI did not return to work. There was no association between severity of lesions and the likelihood to return to work or the degree of lameness[c]. The surprise being that one cannot predict outcome based on the severity of the injury.

10. Tarsus

Distal tarsal osteoarthritis is a major contributor to hind-limb lameness in Western horses across all disciplines. However, there is a fairly large range of clinical significance of tarsal changes, which can make them a challenge to interpret. In the juvenile horse, dorsal wedging or malformation of the tarsal bones indicates an increased likelihood of developing osteoarthritis and should be noted as a risk. The distal intertarsal joint is more prone to ankylosis than the tarsometatarsal joint. The earlier phases of ankylosis, particularly when accompanied with subchondral bone lysis, are more likely to result in lameness, in the author's opinion. Once physiologically fused, the distal intertarsal joint will have marked radiographic changes but may not be clinically significant. The author is also of the opinion that lysis that extends to the plantar aspect of the joint and involves the second and/or fourth tarsal bone tends to cause more severe or difficult-to-manage lameness than changes confined to the dorsal aspect of the joint.

Sclerosis of the central and third tarsal bones is a normal physiologic adaptive response—to a point. Once the bones become moderately to severely sclerotic, the risk of fracture increases. In particular, barrel horses and rope horses seem more prone to central tarsal bone fractures than some of the other disciplines, perhaps related to speed work and turning. These horses have a common presentation of coming up acutely, moderately to severely lame while working and often have no soft tissue swelling or other localizing signs. The most common orientation of the central tarsal bone slab fracture precludes its identification on a standard four-view tarsal series, risking missing the significant diagnosis.[15] A dorsal 20–30° medial-plantarolateral oblique view is the optimal view for identifying this particular type of fracture and should always be included when the history suggests this type of injury.

Bone marrow lesions ("bone bruises") of the distal tarsal bones will have uptake on a bone scan but require MRI to accurately localize and characterize the lesion. Horses with tarsal bone marrow lesions have variable lameness and may improve to diagnostic analgesia of the PSL, distal tarsus, or may require a peroneal tibial nerve block. These lesions can be seen along with other tarsal changes but also can be found in horses with otherwise completely normal tarsi, likely as a result of trauma.

11. Stifle

Stifle injuries are found among all disciplines but cutting horses in particular suffer from stifle disease, primarily affecting the medial femoral tibial joint. Subchondral bone defects and cysts of the medial femoral condyle found on screening radiographs of cutting horses have not been found to be associated with decreased performance outcome.[16] However, this study had a limited number of horses with more severe condylar lesions and also lameness data were not known, therefore the long-term outcome of these changes still remains somewhat unknown and controversial.

Optimally if a subchondral bone defect is identified, the horse should undergo an ultrasound to assess for other changes in the joint. If the joint is otherwise relatively normal without synovitis and no more than mild-moderate effusion, the defect is of questionable significance, particularly if the horse is already in work. Many working cutting horses carry some effusion in the joint and if the joint capsule is not thick and there is not synovial proliferation, the fluid can be incidental.

Horses can have mild osteophytes of the medial tibial condyle incidentally found on radiographs. However, further osteoarthritic changes of the medial femoral tibial joint including osteophytes of the axial or abaxial margins of the medial femoral condyle and sharp elongation of the medial tibial intercondylar eminence are usually clinically significant findings and are uncommonly found on screening exams of sound, unmedicated horses (Fig. 4).

In the author's opinion, tears of the medial meniscus and medial cranial meniscotibial ligament are also rarely incidental and are typically found in conjunction with other joint disease such as synovitis and osteoarthritis. When found with articular cartilage damage and other joint disease, the prognosis

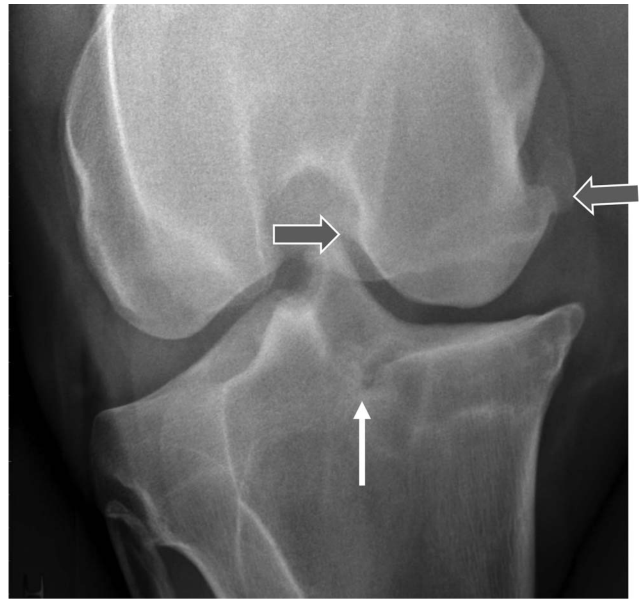

Fig. 4. Caudo-cranial view of the stifle with severe axial and abaxial osteophytes of the medial femoral condyle, osteophyte of the medial tibial condyle, elongation of the medial tibial intercondylar eminence and resorption of the fossa of the medial cranial meniscotibial ligament.

for return to work lessens.[17] In studies that included all or the majority Western horses, reported rates of return to full work for horses with meniscal damage ranged from 38%[18] to 29%.[17] Mineralization of the medial meniscus is a poor prognostic indicator and when found radiographically should be further explored with ultrasound and/or arthroscopy.

Injuries to the lateral femoral tibial joint are relatively rare in comparison to the medial, but can occur either in isolation or in conjunction with medial femoral tibial joint pathology. Effusion of the lateral femoral tibial joint is typically not seen incidentally and is generally suggestive of stifle pathology, either diffusely due to communication of joint pouches or originating from the lateral femoral tibial joint.

12. Axial Skeleton

Overall, the axial skeleton receives less attention in Western than English sport horses. Interest in cervical lesions is increasing but there is a dearth of information about how this is manifested specifically in Western horses.

Barrel horses are more likely than other Western disciplines to be assessed and treated for back problems, particularly impinging spinous processes of the thoracolumbar spine.[19] Impinging spinous processes are of variable clinical significance and even marked radiographic abnormalities can be clinically incidental. The combination of radiographic abnormalities, evidence of back pain and, when possible to acquire, increased uptake on a bone scan, improves the likelihood that the changes are significant.

13. Conclusion

It is important to understand the individual Western performance disciplines and the demands they place on the horses, which can affect the impact of radiographic abnormalities in terms of performance and outcome. Additionally, each discipline comes with its own culture and expectations, which can also affect how radiographic finding are weighed. Finally, utilize the two-part process of image interpretation—objective assessment followed by individual synthesis for the most accurate evaluation of the significance of the radiographic findings.

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Declaration of Ethics

The Author has adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Author has no conflicts of interest.

References and Footnotes

1. Johnson SA, Donnell JR, Donnell AD, et al. Retrospective analysis of lameness localization in Western performance horses, in *Proceedings*. Am Assoc Equine Pract 2017;63:213.
2. Olive J, Marine V. Distal border synovial invaginations of the equine distal sesamoid bone communicate with the distal interphalangeal joint. *Vet Comp Orthop Traumatol* 2017; 30:107–110.
3. Yorke EH, Judy CE, Saveraid TC, et al. Distal border fragments of the equine navicular bone: Association between magnetic resonance imaging characteristics and clinical lameness. *Vet Radiol Ultrasound* 2013;55:35–44.
4. Rijkenhuizen ABM, Németh F, Dik KJ, et al. The arterial supply of the navicular bone in adult horses with navicular disease. *Equine Vet J* 1989;21:418–424.
5. Cillán-Garcia E, Milner PI, Talbot R, et al. Deep digital flexor tendon injury within the hoof capsule; does lesion type or location predict prognosis. *Veterinary Record* 2013;173:70.
6. Blunden A, Murray R, Dyson S. Lesions of the deep digital flexor tendon in the digit: A correlative MRI and post mortem study in control and lame horses. *Equine Vet J* 2009;41:25–33.
7. Dabareiner RM, Cohen ND, Carter K, et al. Lameness and poor performance in horses used for team roping: 118 cases (2000–2003). *J Am Vet Med Assoc* 2005;10:1694–1699.
8. Barrett MF, Manchon PT, Hersman J, et al. Magnetic resonance imaging findings of the proximal metacarpus in Quarter Horses used for cutting: Retrospective analysis of 32 horses 2009–2012. *Equine Vet J* 2018;50:172–178.
9. Chesen AB, Dabareiner RM, Chaffin KM, et al. Tendinitis of the proximal aspect of the superficial digital flexor tendon in horses: 12 cases (2000–2006). *J Am Vet Med Assoc* 2009; 234:1432–1436.
10. Tipton TE, Ray CS, Hand R. Superficial digital flexor tendonitis in cutting horses: 19 cases (2007–2011). *J Am Vet Med Assoc* 2013;243:1162–1165.
11. Dabareiner RM, Cohen ND, Carter K, et al. Musculoskeletal problems associated with lameness and poor performance among horses used for barrel racing: 118 cases (2000–2003). *J Am Vet Med Assoc* 2005;227:1646–1650.
12. Swor TM, Dabareiner RM, Honnas CM, et al. Musculoskeletal problems associated with lameness and poor performance in cutting horses: 200 cases (2007–2015). *J Am Vet Med Assoc* 2019;254:619–625.
13. Dabareiner RM, Cohen ND, Carter K, et al. Lameness and poor performance in horses used for team roping: 118 cases (2000–2003). *J Am Vet Med Assoc* 2005;226:1694–1699.
14. Barrett MF, Selberg KT, Johnson SA, et al. High field magnetic resonance imaging contributes to diagnosis of equine distal tarsus and proximal metatarsus lesions: 103 horses. *Vet Radiol Ultrasound* 2018;59:587–596.
15. Knuchell JA, Spriet M, Galuppo LD, et al. Fracture of the central tarsal bone in nonracehorses: Four cases. *Vet Radiol Ultrasound* 2016;57:403–409.
16. Barrett MF, McIlwraith WC, Contino EK, et al. Relationship between repository radiographic findings and subsequent performance of Quarter Horses competing in cutting events. *J Am Vet Med Assoc* 2018;252:108–115.
17. McCoy AM, Smith RL, Herrera S, et al. Long-term outcome after stifle arthroscopy in 82 Western performance horses (2003–2010). *Vet Surg* 2019;48:956–965.
18. Ferris DJ, Frisbie DD, Kisiday JD, et al. Clinical outcome after intra-articular administration of bone marrow-derived mesenchymal stem cells in 33 horses with stifle injury. *Vet Surg* 2014;43:255–265.
19. Honnas C. Pre-purchase examination for Western Speed Event Horses (roping and barrel horses), in *Proceedings*. Am Assoc Equine Pract 2019;65:469–472.

[a]Frisbie D and Johnson S. Fort Collins, CO. (personal communication) 2020.
[b]Hague TB. Edmond, OK. (personal communication) 2020.
[c]Barrett MF. Personal observation.

How to Select Forages for Equine Athletes

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1. Introduction

Equine athletes, or performances horses, are a unique group of horses who require a more nutrient-dense diet than their idle or maintenance counterparts. Although the term is not well defined, most consider a horse an athlete or performance horse when they are in moderate, heavy, or very heavy work, which is defined as riding with an elevated heart rate (≥90 beats per minutes) for ≥3 hours each week with a combinations of intensities ranging from speed work to slow work to other skilled work (e.g., jumping).[1] A 500-kg mature horse in moderate to very heavy exercise requires 23 to 34.5 Mcal of digestible energy (DE) each day compared to an idle horse of the same weight who needs only 15 Mcal daily.[1] The requirement for other nutrients, including amino acids, vitamins, and minerals, also increase with exercise.[1] To achieve this level of nutrition, performance horses are commonly fed grains and concentrates; however, forage should still make up at least half of the ration, or more when possible.[1,2] Therefore, equine practitioners often need to advise performance horse owners and managers on the selection of forages, whether as pasture, hay, or other alternatives.

2. Selecting Pasture Forages

Many owners like to maximize pasture access due to the benefits of grazing, including socialization, exercise, and a reduction in the incidence of colic,[3] gastric ulcers,[4] stereotypical behaviors,[5] and osteochondritis dissecans in growing horses.[6] Most well-managed pastures can meet the nutritional needs of adult horses up to moderate exercise, with voluntary dry matter intake (DMI) ranging from 1.5 to 3.1% of bodyweight (BW).[1] However, the nutrient value of pasture forage is highly variable and depends on grazing height,[7] management (e.g., fertility),[8] forage species,[9–13] time of day,[14] season,[14–16] and environmental conditions.[17,18] For example, in Minnesota,[10,11] different forage types were evaluated for nutrient values by grazing horses, including cool-season grasses, alfalfa (*Medicago sativa* L.), and teff (*Eragrostis tef* [Zucc.] Trotter) (Table 1). Teff, an annual warm-season grass, consistently had a lower equine DE and crude protein (CP) and greater amounts of neutral detergent fiber (NDF) on a dry matter (DM) basis than alfalfa and cool-season grasses.[10,11] Although teff had lower CP, only plasma threonine concentration was lower after 4 hours of grazing, with no effect on protein synthesis of cultured equine satellite cells, indicating that amino acids were absorbed or available in sufficient

NOTES

Table 1. Forage Nutritive Value (on a Dry Matter Basis) for Alfalfa, Cool-Season Grass, and Teff Grazing by Horse During the Summer (July) in Minnesota

	CP[1]	ADF	NDF	Equine DE
	% DM			Mcal/kg
Alfalfa	22[a]	35[a]	46[c]	2.3[a]
Cool-Season Grasses	24[a]	30[b]	53[b]	2.2[b]
Teff	14[b]	37[a]	67[a]	2.0[c]

[a-c]Within a column, means without a common letter superscript differ based on a Tukey test ($\alpha = 0.05$).
[1]CP, crude protein; ADF, acid detergent fiber; NDF, neutral detergent fiber; DE, digestible energy; DM, dry matter.

amounts regardless of differences in the forage species.[10]

If an increase in pasture nutrient density is desired, improvements should be made to pasture management, including avoidance of over-grazing, fertilizing according to soil tests, controlling weeds, and implementing a rotational grazing system. Additionally, legumes (e.g., alfalfa) can be seeded into pastures to increase DE, and longer periods of grazing can be offered to increase voluntary intake.[20] Interestingly, Glunk et al[20] found that restricting pasture access accelerated pasture intake, especially for horse grazing <9 hours each day.

Unfortunately, it is not usually practical for performance horses to graze continuously due to training and show schedules. Table 2 outlines the estimated DE intake of adult horses grazing the forages described in DeBoer et al.[10,11] at various DMI. If a performance horse in heavy work is able to meet their DE needs through grazing 2.5% of their BW, then most other nutritional needs, including trace minerals, are usually met.[1] However, because all forages are deficient in sodium, a white salt block or lose salt should always be provided. Productive pastures should be ≥75% desired forage cover with pasture heights of 15 to 20 cm.[7–13] Although it is not common to graze pure legumes, grazing alfalfa pastures with DMI ≥2.0% BW could meet the energy demands of horses in moderate to very heavy exercise.[1] Horses in moderate to heavy work with DMI of ≥2.5% BW grazing cool-season grass or teff pastures could meet their DE through grazing. However, horses in very heavy work would not meet their DE requirements by grazing teff or cool-season grass pastures and would require supplementation. This example demonstrates the importance of both DMI and forage species in maximizing DE when grazing performance horses. Although DMI can be challenging to estimate, most horses grazing for 15 hours a day can consume between 1.4 and 2.5% BW depending on the time of year and pasture forage availability.[19] Interestingly, restricting pasture access has been shown to accelerate pasture DMI rate, especially for horses grazing for ≤9 hours per day.[20]

Table 2. Estimated Amount of Equine Digestible Energy Intake Per Day for a 500 kg Mature Horse with Increasing Amounts of Dry Matter Intake of Different Pasture Forages[1]

	Dry Matter Intake (% BW[2])			
	1.5	2.0	2.5	3.0
	Equine DE (Mcal)			
Alfalfa	17	23	29	35
Cool-Season Grasses	17	22	28	33
Teff	15	20	25	30

[1]Equine DE summarized from DeBoer et al.[10]
[2]BW, body weight; DE, digestible energy.

3. Selecting Hay

Hay is commonly fed to all classes of horses. Similar to that in pasture, nutrient density is determined by forage species, management conditions (e.g., fertility), and maturity at which the hay is harvested. Selecting hay for performance horses comes down to both physical evaluation and chemical analysis.

Physical Analysis

All horses' hay should be physically evaluated for a number of characteristics, including the following:

1. Species. Knowing the forage species present in the hay is important because different forages contain different amounts of nutrients.[21] As an example, Table 3 outlines historical averages and ranges of some forage nutritive values based on the major forage types, including cool-season grasses, legumes (e.g., alfalfa), Bermudagrass (*Cynodon dactylon* L., warm-season perennial grass), and oat (*Avena sativa* L., cool-season annual grass) hay tested by Equi-Analytical (Ithaca, New York). Although forage identification takes time and practice, being able to identify beneficial forages also helps to rule out hay infested with weeds and toxic plants.
2. Maturity. Some experts will argue that forage maturity when the hay is harvested is the greatest driver of nutrient value. However, it is likely a combination of both species and maturity. More mature hay tends to be higher in structural fiber components of NDF and acid detergent fiber (ADF) and lower in DE.[21,22] Signs of maturity are larger stems, taller plants, and more seed heads (in grasses) and flowers (in legumes).
3. Touch. Hay should be soft to the touch. Horses have sensitive mouths, lips, and tongues, and forages that are excessively rough can deter and limit ingestion. Roughness can be a result of excessive maturity, abrasives seeds heads (e.g., foxtail, *Setaria* species),[23] and plants with spines (e.g., this-

Table 3. Historical Means (with Range) of Nutrient Values of Common Dried (e.g., Hay) Forage Types Tested at Equi-Analytical (Ithaca, NY)[2]

	CP[1]	ADF	NDF	Equine DE	RFV
	% DM			Mcal/kg	
Legume	21 (19–24)	31 (27–34)	39 (34–44)	2.6 (2.2–2.7)	159 (132–186)
Cool-Season Grasses	11 (7–15)	39 (34–43)	62 (55–69)	2.0 (1.8–2.2)	89 (73–105)
Bermudagrass	11 (8–14)	35 (31–39)	66 (62–71)	2.1 (2.0–2.2)	87 (77–95)
Oat	8 (5–11)	37 (32–42)	59 (52–65)	1.9 (1.8–2.2)	97 (80–112)

[1]CP, crude protein; ADF, acid detergent fiber; NDF, neutral detergent fiber; DE, digestible energy; RFV, relative feed value; DM, dry matter.
[2]Values retrieved from https://equi-analytical.com/interactive-common-feed-profile/ on 01/29/2020.

tles and *Cirsium* species). Staniar et al[22] found a negative correlation between horse intake and maturity of teff hay.

4. Color. A rich, green color can indicate highly palatable hay with readily digestible nutrients. However, professionals should not get too hung up on color. Hays with a bleached or faded color usually correlate with longer drying times, rainfall while in the windrow, or storage in sun-rich locations. Interestingly, rained-on hay may be a suitable forage if the rain occurred soon after cutting, the rain was a single or short event, the rain intensity was higher versus a longer or lower intensity event, and the forage was not re-wetted many times.[24] Regardless of color and rainfall, most hays will be lacking in vitamins and some minerals, which require supplementation for all classes of horses.[1] Therefore, it is best to have faded, and especially rained-on, forage analyzed.
5. Smell. All horse hay should smell clean and free of mold and dust. Horses are highly sensitive to dust and mold particles found in hay,[25] which when inhaled can result in respiratory problems.[26] It has been suggested that hay containing less than 1,000,000 cfu/g is considered relatively safe for livestock.[27] However, it is generally accepted that horses are more susceptible to health issues as a result of mold exposure; therefore, it has been suggested that horse hay have no more than 500,000 cfu/g of mold.[28] If concerns about mold arise, a laboratory analysis can determine mold levels. To reduce the impact of spore inhalation during feeding, current management strategies include soaking for ≤15 minutes[29] or steaming[30] hay. Regardless, hay exceeding 500,000 cfu/g of mold should not be fed to horses.
6. Toxic Plants. All hay should be completely free of toxic plants. Most experts agree that non-toxic weeds should make up less than 10% of hay due to the lower nutrient profile of non-toxic weeds. Unfortunately, there is no chemical test or forage analysis that can identify toxic plants or non-toxic weeds; this must be done through physical evaluation.

Chemical Analysis

Many laboratories across the United States can evaluate hay for nutrient values; however, professionals should ensure the laboratory offers an equine DE estimation and an evaluation of components used to estimate nonstructural carbohydrates (NSCs). Additionally, it is equally important that a representative sample is submitted to the laboratory. Commonly suggested guidelines for most forage nutritive values exist, but research correlating their use in horse diets is lacking. Some of the forage nutritive values commonly used when evaluating horse hay include the following:

1. Moisture. Moisture at the time of baling is directly correlated to the formation of mold.[28] To basically eliminate the risk of mold formation in the bale, hay should have ≤15% moisture at the time of baling. In the absence of wrapping and propionic acid use, hays over 17% moisture have a high probability of molding, whereas hays over 25% moisture pose the threat of severe heat damage and serve as a potential fire hazard.[28]
2. Crude Protein. CP is a measure of the protein concentration in the hay and an estimation of amino acid content. CP varies based on a number of factors, including species (Table 3), maturity,[22] and soil fertility.[8] A horse in moderate to very heavy work requires ≥768 g of CP each day. Using average CP values in Table 3 and NRC requirements,[1] it is highlighted that horses would need to consume 4 to 5 kg of legume hay to meet the CP needs of horses in moderate to very heavy work. In comparison, these same horses would need to consume 10 to 13 kg of oat hay to meet their needs.
3. Acid Detergent Fiber. ADF is a measurement of the insoluble fiber, including cellulose and lignin.[31] As the plant matures, ADF values increase:[21] therefore, ADF can also be used as an indicator of maturity. Although

Table 4. Estimated Amount of Equine Digestible Energy Intake Per Day for a 500 kg Mature Horse with Increasing Amounts of Dry Matter Intake of Different Hay Types[1]

	Dry Matter Intake (% BW[2])			
	1.5	2.0	2.5	3.0
	Equine DE (Mcal)			
Legume	20	26	33	39
Cool-Season Grasses	15	20	25	30
Bermudagrass	16	21	26	32
Oat	14	19	24	29

[1]Equine DE taken from Table 3.
[2]BW, body weight; DE, digestible energy.

no dietary requirements for ADF in the horse's diet have been established, many agree that ADF indicates nutrient digestibility,[32] with ADF ≤45% indicating acceptable nutrient digestibility. However, others claim that ADF is not valid for predicting digestibility.[31]

4. Neutral Detergent Fiber. NDF is a measurement of the insoluble fiber, including hemicellulose, cellulose, ligno-cellulose, and lignin.[31] As the plant matures, NDF values increase because the insoluble fibers provide the plant with strength and rigidity as it grows[9]; therefore, NDF can also be used as an indicator of maturity. Although no dietary requirements for NDF in the horse's diet have been established, many suggest NDF values of ≤65% will maximize horse intake. NDF has been negatively correlated with horse intake in both hay[22] and pasture.[9] Warm-season grasses tend to be higher in NDF than cool-season grasses[9] due to known differences in cell wall content; however, warm-season grasses are commonly fed to all classes of horses.[22,33] Increasing the digestibility of warm-season grasses is best accomplished by harvesting hay in an earlier stage of growth and keeping pastures in a vegetative or more immature growth stage.[33]
5. Equine DE. Measurement of DE in the hay is used to balance the energy portion of the equine diet. A 500-kg mature horse in moderate to very heavy exercise requires 23 to 34.5 Mcal of DE each day.[1] Table 4 outlines the estimated DE intake of adult horses consuming hay at various DMI using DE values summarized in Table 3. Due to their increased energy requirements, performance horses are commonly fed legume hays or legume mixed hays. Consuming ≥2.0% BW legume hay would meet, or exceed, the energy demands of horses in moderate to very heavy exercise.[1] Horses in moderate to heavy work with DMI of ≥2.5% BW consuming cool-season grass, Bermudagrass, and oat hays would meet their daily DE requirement. However, horses in very heavy work would not meet their DE requirements by consuming these hays. Similar to pasture, this example demonstrates the importance of both DMI and forage species in maximizing DE when feeding performance horses hay.
6. Relative Feed Value. Relative feed value (RFV)[34] is commonly used when selecting hay intended to feed cattle but is not commonly used when assessing horse hay. Generally, RFV can be used as a guideline in identifying hay quality because greater RFVs tend to reflect higher quality hays with greater intake and digestibility potential.

Other nutrient values can be tested for in forage, including NSC components, vitamins, and minerals. Vitamin and mineral requirements do increase with workload.[1] Although NSC requirements have not been established for performance horses, dietary guidelines have been suggested for horses with polysaccharide storage myopathy[35] and insulin resistance.[36] In these cases, complete diets with ≤10 and 12% NSC have been suggested for horses diagnosed with polysaccharide storage myopathy and insulin resistance, respectively.

4. Conclusions

Performances horses require a more nutrient-dense diet; therefore, professionals should focus on selecting legumes or less mature forages for these horses. In pastured performance horses, this means maximizing grazing time and access to well-maintained pastures that include more nutrient-dense forages, including legumes. When selecting hay, physical evaluation should include identification of the species and maturity and sensory evaluation for touch, smell, and color. Although loosely defined, commonly accepted chemical analysis of better quality hay include mold counts of ≤500,000 cfu/g, moisture of ≤15%, ADF of ≤45%, and NDF of ≤45%. CP and DE requirements for performance horses are well defined and tend to be more easily met when feeding alfalfa hay, mixes, or less mature grass hays. Although the focus of this paper is forage selection, care should be taken prior to feeding forages (and grains and supplements) to ensure a balanced ration.

Acknowledgments

Declaration of Ethics

The Authors have adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Authors have no conflicts of interest.

References

1. NRC. *Nutrient requirements of horses*. 6th ed. Washington, D.C.: The National Academies Press, 2007.
2. Becvarova I, Pleasant RS, Thatcher CD. Clinic assessment of nutritional status and feeding program in horses. *Vet Clin N Amer* 2009;25:1–21.
3. Hudson J, Cohen N, Gibbs P, et al. Feeding practices associated with colic in horses. *J Amer Vet Med Assoc* 2001;219: 1419–1425.
4. Murray M. Gastric-ulcers in adult horses. *Comp Cont Ed Prac Vet* 1994;16:792–794.
5. Pell SM, McGreevy PD. A study of cortisol and beta-endorphin levels in stereotypic and normal Thoroughbreds. *Appl Anim Behaviour Sci* 1999;64:81–90.
6. Bell RA, Nielson BD, Waite K, et al. Daily access to pasture turnout prevents loss of mineral in the third metacarpus of Arabian weanlings. *J Am Sci* 2001;79:1142–1150.
7. Fleurance G, Fritz H, Duncan P, et al. Instantaneous intake rate in horses of different body sizes: Influence of sward biomass and fibrousness. *Appl Anim Behav Sci* 2009;117: 84–92.
8. Gillen RL, Berg WA. Nitrogen fertilization of a native grass planting in western Oklahoma. *J Range Mange* 1998;51: 436–441.
9. DeBoer ML, Sheaffer CC, Grev AM, et al. Yield, nutritive value and preference of annul warm-season grasses grazed by horses. *Agronomy J* 2017;109:2136–2148.
10. DeBoer M, Martinson K, Kuhle K, et al. Plasma amino acid concentrations of horses grazing alfalfa, cool-season perennial grasses and teff. *J Equine Vet Sci* 2018;72:72–78.
11. DeBoer ML, Hathaway MR, Kuhle KJ, et al. Glucose and insulin response of horses grazing alfalfa, perennial cool-season grass, and teff across seasons. *J Equine Vet Sci* 2018;68:33–38.
12. Grev AM, Sheaffer CC, DeBoer ML, et al. Preference, yield, and forage nutritive value of annual grasses under horse grazing. *Agronomy J* 2017;109:1561–1572.
13. Catalano DN, Sheaffer CC, Grev AM, et al. Yield, forage nutritive value, and preference of legumes under horse grazing. *Agronomy J* 2019;111:1312–1322.
14. McIntosh B. Circadian and seasonal variation in pasture nonstructural carbohydrates and the response of grazing horses [PhD Diss]. Blacksburg, VA: Virginia Polytechnic Institute and State University, 2007.
15. Hoffman RM, Wilson JA, Kronfeld DS, et al. Hydrolyzable carbohydrates in pasture, hay and horse feeds: Direct assay and seasonal variation. *J Anim Sci* 2001;79:500–506.
16. Frank N, Elliott SB, Chameroy KA, et al. Association of season and pasture grazing with blood hormone and metabolite concentrations in horses with presumed pituitary pars intermedia dysfunction. *J Vet Intern Med* 2010;24:1167–1175.
17. Volaire F, Lelièvre F. Production, persistence, and water-soluble carbohydrate accumulation in 21 contrasting populations of *Dactylis glomerata L.* subjected to severe drought in the south of France. *Aust J Agr Res* 1997;48:933–944.
18. Williams CA, Kenny LB, Burk AO. Effects of grazing system, season, and forage carbohydrates on glucose and insulin dynamics of the grazing horse. *J Anim Sci* 2019;97:2541–2554.
19. Dowler LE, Siciliano PD, Pratt-Phillips SE, et al. Determination of pasture dry matter intake rate in different seasons and their application in grazing management. *J Equine Vet Sci* 2012;32:85–92.
20. Glunk EC, Pratt-Phillips SE, Siciliano PD. Effect of restricted pasture access on pasture dry matter intake rate, dietary energy intake, and fecal pH in horse. *J Equine Vet Sci* 2013;33:421–426.
21. Martinson K, Jung H, Hathaway M, et al. The effect of soaking on carbohydrate removal and dry matter loss in orchardgrass and alfalfa hays. *J Equine Vet Sci* 2012;32: 332–338.
22. Staniar WB, Bussard JR, Repard NM, et al. Voluntary intake and digestibility of teff hay fed to horses. *J Anim Sci* 2010;88:3296–3303.
23. Johnson PJ, LaCarrubba AM, Messer NT, et al. Ulcerative glossitis and gingivitis associated with foxtail grass awn irritation in two horses. *Equine Vet Educ* 2012:24:182–186.
24. Fonnesbeck PV, Garcia MM, Hernandez De, et al. Estimating yield and nutrient losses due to rainfall on field-drying alfalfa hay. *Anim Feed Sci and Tech* 1986;16:7–15.
25. Clarke AF, Madelin T. Techniques for assessing respiratory health hazards from hay and other source materials. *Equine Vet J* 1987;19:442–447.
26. Beeler-Marfisi, J, Clark ME, Wen X, et al. Experimental induction of recurrent airway obstruction with inhaled fungal spores, lipopolysaccharide, and silica micropspheres in horses. *Am J Vet Res* 2010;71:682–689.
27. Adams RS, Kephart KB, Ishler VA, et al. Mold and mycotoxin problems in livestock feeding. Extension publication (DAS 93–21). University Park, PA: Penn State University, College of Ag Sci and Cooperative Extension, 1993.
28. Martinson K, Coblentz W, Sheaffer C. The effect of harvest moisture and bale wrapping on forage quality, temperature, and mold in orchardgrass hay. *J Equine Vet Sci* 2011;31: 711–716.
29. Moore-Colyer MJS. Effects of soaking hay fodder for horses on dust and mineral content. *Anim Sci* 1996;63:337–342.
30. Earing JE, Hathaway MR, Sheaffer CC, et al. The effect of hay steaming on forage nutritive values and dry matter intake by horses. *J Anim Sci* 2013;91:5813–5820.
31. Van Soest PJ, Robinson JB, Lewis BA. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. *J Dairy Sci* 1991;74:3583–3597.
32. Harbers LH, Smith WH. Digestibility of 3 grass hays by the horse and scanning electron microscopy of undigested leaf remnants. *J Anim Sci* 1981;3:1671.
33. Hansen TL, Chizek EL, Zugay OK, et al. Digestibility and retention time of coastal Bermudagrass (*Cynodon dactylon*) hay by horses. *Animals* 2019;9:1–19.
34. Rohweder DA, Barnes RF, Jorgeson N. Proposed hay grading standards based on laboratory analyses for evaluating quality. *J Anim Sci* 1978;47:747–759.
35. Borgia L, Valberg SJ, Watts K, et al. Glycemic/insulemic response to feeding hay with different water soluble carbohydrate content in healthy and polysaccharide storage myopathy-affected horses. *J Equine Vet Sci* 2009;29:355–357.
36. Frank N. Insulin resistance and equine metabolic syndrome. In: Robinson NE, Sprayberry KA, eds. *Current therapy in equine medicine*. St. Louis, Missouri: Elsevier Publications; 2009;727–740.

How to Select a Concentrate for Performance Horses

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1. Introduction

A performance horse is one that is regularly given forced exercise. The intensity and duration of exercise varies greatly with different types of performance activities or disciplines. Nutrient requirements for horses performing different intensities of exercise have been established and classified under the intensities of light, moderate, heavy, and very heavy.[1] The nutrient requirements for energy, protein, macro minerals, trace minerals, and vitamins are different for horses performing these different intensities of exercise. This creates a need to select different concentrates depending on type and duration of exercise. Feed companies manufacturing concentrates for performance horses will vary the amounts of essential nutrients, and even the sources of these nutrients, to satisfy the nutrient requirements of the performance horse and to appeal to consumers. Feed manufacturers will also write feeding instructions to account for horses performing at different intensities. The challenge for the consumer, and ultimately for the veterinarian assisting the consumer, is to determine which concentrate is best suited for that individual horse or group of horses.

2. Forage

The topic of selecting a forage for performance horses has been previously discussed in these *Proceedings*.[2] However, it is important to re-emphasize that high-quality forage (baled hay, pasture, hay cubes/pellets, chaff) can be a rich source of energy, protein, minerals, and vitamins for performance horses. If performance horses are getting a large proportion of essential nutrients from consumption of high-quality forage, the horse will require less supplemental concentrate to satisfy the requirements for those nutrients. Previous studies have highlighted that feeding increased volumes of grain increase the risk of digestive upset;[3] thus, feeding the minimum amount of concentrate necessary to satisfy nutrient requirements and maintain proper body condition can have a positive impact on health. Selection of different forage type and the timing of specific forage-type meals have also been reported to have a positive influence on minimizing the risk of developing equine gastric ulcer syndrome in performance horses.[4–6] Therefore, it is recommended that all performance horses be fed free-choice, high-quality forage. Once the impact and nutrient contribution of the forage portion of the diet is known, the diet can be

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complemented with the proper concentrate for the performance horse.

3. Nutrient Requirements of Performance Horses

All performance horses require energy, protein, minerals, and vitamins. The requirements for these essential nutrients have been established by peer-reviewed science, with a complete review of the requirements available from the National Research Council.[1] The nutrient requirements of horses are expressed on a body weight (BW) basis as the amount of nutrient required per day. As the intensity and duration of exercise increase, the requirements for these essential nutrients generally increase. For example, a 500-kg horse in light exercise would have a digestible energy requirement of 20 Mcal/day. Increasing the intensity to moderate exercise results in a 16.5% increase in digestible energy requirement to 23.3 Mcal/day.[1] Nutrient requirement for protein, minerals, and vitamins also increase with exercise intensity. To satisfy the nutrient requirements of a performance horse as it moves from light exercise to exercise of higher intensity and duration will require the selection of a concentrate capable of delivering more nutrients. To evaluate the nutrient profile of the concentrate, a reliable source of information exists in the text of a concentrate feed tag.

4. Nutrient Profile of Concentrates—The Feed Tag

Concentrates formulated for horses will have different amounts of energy, protein, fat, fiber, minerals, and vitamins. Horse feed manufacturers in the United States are required by law to have a feed tag indicating select nutrition data. The exact data and method of listing data is controlled by individual states under the umbrella of the Association of American Feed Control Officials (AAFCO).[7] Required information on an equine feed tag includes product name, purpose statement, guaranteed analysis, ingredient listing, feeding directions, manufacturer's or distributor's name and address, and weight statement. An equine feed tag gives a regulated, reliable means of making product comparisons and serves as the initial basis for making product selections. While the feed tag contains a significant amount of information, there are several items to review that will make selecting a concentrate for a performance horse easier.

Purpose Statement

The purpose statement indicates the class of horse for which the concentrate was formulated. Concentrates for horses will have one of the following intended purposes: growing, broodmare, maintenance, or performance. If regular forced exercise is being conducted, the horse should be fed a concentrate intended for a "performance" horse. Feeds designed for growth, pregnancy/lactation, maintenance, or seniors are not targeted toward the nutrient requirements of a performance horse and therefore they are not the best choice. For example, feeding an adult performance horse with good dentition a low-calorie, complete "senior" feed at a rate below manufacturer's feeding guidelines is not appropriate. A complete senior feed is designed for a horse with poor dentition and contains a high fiber content, low calorie content, and low nutrient fortification, which is not suitable for a performance horse. Complete feeds are intended to fully or partially replace the forage portion of the diet. Since complete feeds are formulated and fortified to replace forage in the diet, the feeding rates of these products are typically very high in the range of 1%–1.5% of BW/horse/day. This high recommended daily intake makes feeding below recommended levels probable when horses still have access to hay. Even if the performance horse does not require an abundance of calories (energy) these complete senior feeds do not contain the proper vitamin/mineral fortification when fed below manufacturers' feeding recommendations.

Guaranteed Analysis

The guaranteed analysis will give nutrient content of a concentrate in standard units of measure. The guaranteed analysis from one feed can then be easily compared to another feed. It must be understood that guaranteed analysis statements do not include all of the nutrients in a feed. For example, one item that is not listed as part of the guaranteed analysis statement is energy (calorie) content of the feed. AAFCO's omission of an energy value for feed makes it difficult to determine suitability of feeds for horses exercising at different intensities. The energy (calorie) content of feed can be acquired directly from the feed manufacturer, if requested. However, other information on a feed tag will give clues to the energy content of the product. For example, feeds with higher levels of crude fat will generally have a higher calorie content compared to feeds with lower fat content. When sugar levels of feed are listed, feeds with higher sugar will have a higher energy content compared to lower sugar feeds, provided the levels of fat are the same. Items to pay attention to on the guaranteed analysis include crude protein, crude fat, crude fiber, calcium, phosphorus, and vitamin E. For performance horses, the target crude protein should be a minimum of 11%–13% since protein and amino acids are vital for both development and repair of muscle and bone. A minimum crude fat level of 6% is desired, since fat is a safe, effective energy source for performance horses. The crude fiber guarantee is more difficult to interpret since fiber can originate from "hay" sources or from "super fiber" sources such as beet pulp and soybean hulls. The energy value is much higher with super fiber sources of fiber compared to hay sources of fiber. Generally, the ingredient statement can be referred to for the identification of fiber sources. If the feed does not include super fibers, the fiber content of a performance feed should be less than 15%. If super fibers are included in the ingredient statement, an acceptable fiber content as high as 20% is acceptable. With respect to calcium and phosphorus, there should be more calcium in the feed compared to phosphorus. The ideal ratio of these two nutrients is 1.5–2 parts calcium to 1 part phosphorus. The final item to evaluate in the guaranteed analysis is vitamin E content. The vitamin E content should be greater than 100 IU/lb. This is one nutrient for which the phrase, "more is better," actually holds true. A high vitamin E content is desired due to poor vitamin E stability in stored forage.

Ingredient Statement

The ingredient statement contains valuable information since it allows comparison of ingredients utilized in the manufacturing of the feed. Under federal law, AAFCO requires all ingredients to be listed in descending order of predominance by weight in the product.[6] Two limitations with ingredient statements are first, it does not allow the manufacturer to designate the quality or grade of ingredient utilized in the product. So, comparing oats on one tag versus oats on another tag does not speak to quality of the oat. The second limitation is with the terms used to list ingredients: individual terms versus collective terms. The individual terms list the actual ingredients such as oats, corn, and barley whereas the collective term allows the manufacturer to utilize the term "grain products" instead of the names of individual grains. Comparison of feed tags, one with individual terms and the other with collective terms, is nearly impossible to gain meaningful information. When looking at a feed tag with individual ingredients listed, selection of feeds with processed grains such as oats, corn, and barley will yield more energy compared to feeds containing grain byproducts such as wheat middlings. The inclusion of alternative energy sources such as vegetable oils, beet pulp, and soybean hulls is also beneficial. These energy sources are very safe to feed performance horses and their inclusion decreases the reliance on cereal grain as the sole energy source.

Directions for Use

The feeding directions are important because they represent the amount of commercial concentrate (lbs/day or % of horse BW/day) that is necessary to satisfy the nutrient requirement of the horse. The feeding directions are based on the weight, activity, and nutrient requirements of the horse. Recommended feeding rates have a very specific purpose and are intended to serve as a guide for proper usage. They are not there simply to drive higher consumption rates and to sell more feed. It is critical the client feed the recommended amount of concentrate per day otherwise the product will not provide the correct nutrition. If the horse requires more or less concentrate to maintain proper body condition than is recommended on the feeding tag, a different product should be selected. For example, a horse in a high body condition may not require the manufacturer's recommended minimum amount of concentrate necessary to satisfy nutrient requirements without gaining weight. For this horse, a low-intake, more nutrient-dense feed would be appropriate.

5. Selecting a Concentrate

To select a concentrate for a performance horse, the equine practitioner has two methods that can be utilized. The first is the mathematical method involving the chemical analysis of ingredients, determination of nutrient requirements, and mathematical calculation to select the type and amount of concentrate to satisfy the horse's nutrient requirements. The second method is to approximate the value of forage and utilize body condition of the horse to estimate the type and amount of concentrate necessary for the performance horse.

Mathematical Method

The mathematical method is a full-ration analysis. The practitioner would begin by uniformly sampling the hay being fed to the horse.[8] Since hay would vary from batch to batch, the analysis would need to be conducted with each new load of hay received by the client. The representative hay sample would then be sent to the laboratory for chemical analysis to determine nutrient profile. The nutrient profile of the forage would then be multiplied by the amount (weight) of forage fed to the horse on a daily basis. If performance horses are fed free-choice high-quality forage, it will provide a significant source of nutrients reducing the amount of concentrate that must be fed to satisfy nutrient requirements. A mature horse would typically consume from 1.5%–2.5% of BW in dry forage per day. Conversely, if poor-quality hay is fed, the horse will consume less forage and require higher amounts of concentrate. The second step is to determine the work intensity of the horse, which will ultimately determine the nutrient requirement for the horse. Light exercise is described as exercise with a mean heart rate, over the entire exercise bout, of 80 beats/min for a duration of 1–3 hours/week. Moderate exercise is described as exercise with a mean heart rate of 90 beats/min for a duration of 3–5 hours/week. Heavy exercise is described as exercise with a mean heart rate of 110 beats/min for a duration of 4–5 hours/week. Finally, very heavy exercise is described as exercise with a mean heart rate of 110–150 beats/min for a duration of 1 hour per/week if done at full-speed to 6–12 hours/week if done at a slower speed. Examples of performance activities are listed in Table 1.

The next step is to subtract the nutrients provided by forage from the nutrient requirement of the exercising horse. This will provide the amount of nutrients that must be supplied by the concentrate portion of the diet. The final step is to evaluate feed tags from concentrates intended for performance horses to determine which one provides the desired

Table 1. Example of Performance Activities of Horses in Light, Moderate, Heavy, and Very Heavy Exercise Categories

Exercise Category	Types of Events
Light	Recreational riding, initial stages of training programs, show horses (occasional)
Moderate	School horses, recreational riding, breaking/training, ranch work, show horses (more frequent)
Heavy	Ranch work, polo, show horses (strenuous), low-medium level eventing, race training (middle stages)
Very heavy	Racing (Quarter Horse, Thoroughbred, Standardbred, endurance), elite 3-day eventing

amount of nutrients at a feeding rate that maintains proper body condition of the horse. There are several software programs that can do these calculations.[9–11] If the practitioner does not feel comfortable with this method, they can consult with an equine nutritionist to obtain a ration evaluation.

Approximate Method

The method of selecting the proper concentrate for a performance horse is quicker, albeit not as accurate, as the mathematical method. In this method, begin by ensuring the client is providing the horse with free-choice access to high-quality forage. Next, weigh the amount (lbs/day) of concentrate currently being fed to the horse. The third step is to determine whether the amount of concentrate that is currently being fed is properly maintaining optimum body condition of the performance horse. If the horse is too thin or too fat, the amount of concentrate will need to be modified. The final step is to select a concentrate intended for a performance horse that can be fed within the range necessary to optimize body condition of the horse. This method of selecting a concentrate does not rely on conducting an objective analysis of the diet. The practitioner does not collect and submit a forage sample for analysis. Instead, it is a subjective method to manage body condition of the horse by selecting a concentrate that fits into the feeding range necessary to maintain proper body condition. This method relies on trust or positive experience with the concentrate manufacturer and the expertise of their nutritional staff to formulate all of the nutrients necessary for a performance horse in that daily feeding rate.

6. Practical Examples of Appropriate Concentrates for Performance Horses

The equine practitioner will care for performance horses under a variety of exercise intensities. The following are several common types of exercise and concentrates that would be appropriate for these situations.

Infrequent Light Exercise

An example of this type of exercise would be occasional riding done mostly at a walk or slow trot, such as trail riding or flat work done in an arena. If these horses are given free-choice access to high-quality forage (hay/pasture) they often do not require a significant amount of additional energy (calories) to maintain body condition. Many clients will select a concentrate designed for a performance horse or even a “senior” but then underfeed the product according to manufacturer’s guidelines. Underfeeding any concentrate will result in the horse’s nutrient requirements not being met. Instead of a concentrate, these horses are better suited for a pelleted, low-intake, concentrated source of protein, vitamins, and minerals. These products are called ration balancers or supplement pellets. The daily intake, depending on manufacturer and fortification level, is between 1 and 2 lbs/horse/day for a 1,000-lb animal. Therefore, the first example of a “performance” horse would not be fed a grain-based concentrate, but instead be fed a ration balancer pellet.

Frequent Light Exercise

An example of exercise would be 4–5 days per week, with exercise done at walk (40%), trot (50%), and canter (10%). The exercise duration would be approximately 30–40 minutes per day. These horses would be involved in recreational riding and showing and require a modest energy intake beyond the calories provided by high-quality forage. The typical concentrate intake would be 3–5 lb per 1000-lb horse/day. These horses are best suited with a lower fat (4%–6%), low to moderate protein (11%–13%), concentrate formulated for performance horses.

Moderate Exercise

An example of moderate exercise would be 4–5 days per week, with exercise done at walk (30%), trot (55%), canter (10%), and specialized training (5%). Examples of specialized training include jumping, cutting, or other skill work. The exercise duration would be approximately 45–60 minutes per day. These horses may be involved in frequent showing, a lesson/school program, western speed events such as roping, medium-level dressage, or ranch work. These horses would require a moderate amount of energy beyond that which could be supplied by free-choice forage. The typical intake would be in the 5–8 lb per 1000-lb horse/day. These horses are best suited with a moderate fat (8%–10%), low to moderate protein (11%–13%) concentrate formulated for performance horses.

Heavy Exercise

An example of heavy exercise would be 4–6 days per week, with exercise done at walk (20%), trot (50%), canter (15%), and specialized training (15%). Examples of specialized training include galloping, jumping, polo, eventing, or other skill work. The exercise duration would be approximately 60 minutes per day. They may be involved in frequent showing with travel, polo, low-to-medium-level 3-day eventing, higher levels of dressage, Grand Prix–level jumping, and endurance riding. These horses would require significant amounts of energy beyond that which could be supplied by free-choice forage. The typical intake would be in the 8–10 lb per 1000-lb horse/day. These horses are best suited with a higher-fat (10%–14%), moderate-protein (13%–15%) concentrate formulated for performance horses. The extra fat is required to meet energy requirements while the extra protein helps build and repair muscle and bone tissue.

Very Heavy Exercise

An example of very heavy exercise would be 4–6 days per week, with exercise done at high speed such as galloping or sprinting for a duration of $<$10 minutes/day. This type of exercise may also include exercise done for longer duration (1–2 hours/day) with a heavy emphasis on skill and endurance activities. These horses are typically involved in flat track racing (Thoroughbred and Quarter Horse), Standardbred racing, elite 3-day event horses, and high-goal polo horses. They require the majority of their energy from the concentrate portion of the diet. The typical concentrate intake would be in the 12–15 lbs per 1000-lb horse/day. These horses are best suited with a medium-fat (8%–10%), moderate-protein (13%–15%) concentrate formulated for performance horses. Very high-fat diets are typically avoided for these horses since the sprinting activities utilize a higher muscle-glycogen reserve, and high-fat feeds are not as palatable when fed in the amounts necessary to maintain body condition. The extra protein is essential to help build and repair muscle and bone tissue.

7. Summary

In summary, begin feeding performance horses by providing free access to fresh, clean water. The next step is to provide adequate energy; this is the only dietary factor in which adequacy can be visually determined with the use of body condition evaluation. If too much energy (too many calories) is fed, the horse gains weight or becomes fat; on the other hand, if not enough energy (too few calories) is fed, the horse becomes thin or loses weight. The status of other critical nutrients cannot be assessed by visual assessment alone. Determination of dietary adequacy for other critical nutrients can only be done with ration analysis. To provide energy to the performance horse, begin with feeding good-quality forage (pasture/hay) and add additional energy with the use of a combination of starch, fat, and super-fibers. Utilizing an appropriate concentrate to complement available forages will ensure all nutrients are being met in the performance horse's diet.

Acknowledgments

Declaration of Ethics

The Authors have adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Authors have no conflicts of interest.

References

1. National Research Council. *Nutrient requirements of horses: sixth revised edition*. Washington, DC: The National Academies Press; 2007.
2. Martinson K, Williams C. How to select forages for equine athletes, in *Proceedings*. Am Assoc Equine Pract 2020;66: 45–49.
3. Durham AE. The role of nutrition in colic. *Vet Clin N Am Equine Prac* 2009;25:67–78.
4. Nadeau JA, Andrews FM, Mathew AG, et al. Evaluation of diet as a cause of gastric ulcers in horses. *Am J Vet Res* 2000;61:784–790.
5. Lybbert T, Gibbs P, Cohen N, et al. Feeding alfalfa hay to exercising horses reduces the severity of gastric squamous mucosal ulceration in, *Proceedings*. Am Assoc Equine Pract 2007;53:525–526.
6. Reese R, Andrews F. Nutrition and dietary management of equine gastric ulcer syndrome. *Vet Clin N Am Equine Pract* 2009;25:79–92.
7. Animal Feed Labeling Guide. Champlain, IL: Association of American Feed Control Officials; 2019.
8. Equi-Analytical Laboratory Services. Taking a hay sample. 2019. Available from: https://equi-analytical.com/wp-content/uploads/2014/03/Taking-a-Hay-Sample-2019_final.pdf.
9. Equi-Balance [Computer Software]. Performance horse nutrition. 2008. Available from: https://performancehorsenutrition.com/store/equi-balance.
10. MicroSteed [Computer Software]. Kentucky Equine Research. Available from: https://ker.com/tools/microsteed/.
11. FeedXL [Computer Software]. Available from https://feedxl.com/.

How to Feed the Overweight Performance Horse

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1. Introduction

What is a performance horse? When is a horse considered an athlete? Generally, athletic horses have higher energy and nutrient requirements than adult horses at maintenance. The 2007 National Research Council's (NRC) Nutrient Requirements of Horses publication defines athletic categories (Table 1) and weekly workloads (Table 2) that provide context to published energy and nutrient requirements for the equine athlete.[1] NRC athletic categories do not capture all athletic disciplines, and average energy requirements for work may overestimate the needs of the overweight performance horse. A horse's energy requirement is influenced by activity but also by individual factors (metabolism and demeanor). Horses used for pleasure riding have higher odds of obesity than horses used in competition.[2]

Generally, for athletes, a lean body condition conveys an athletic advantage due to a higher power-to-weight ratio. Furthermore, equine obesity reduces evaporative cooling,[3] reduces reproductive efficiency,[4] increases the risk of insulin dysregulation,[5–7] and increases the risk of laminitis,[8,9] none of which are beneficial to general health or athletic performance. Therefore, body condition score (BCS)[10,11] (Table 3) should be considered when determining performance horses' energy requirements and subsequently building the diet/ration.

Case

There are numerous disciplines for the equine athlete. Although the details regarding a single equine athlete will not be representative of other equine athletes (discipline, energy and nutrient requirements, feeds available, and management), the general process of conducting a nutrition assessment and building a ration is the same. A 14-year-old [some breed] gelding with a body weight of 636 kg (1,400 lbs) and a BCS of 7/9 (Table 1)[10,11] will be used as an example case for illustration. In this example, the gelding is worked, on average, 5 hours per week, consisting of a total of 90 minutes (1.5 hours) walk, 165 minutes (2.75 hours) trot, 30 minutes (0.5 hour) canter, and 15 minutes (0.25 hour) jumping. According to the NRC, this work classifies as a "moderate" workload.

BCS and Estimating Ideal Body Weight

First, the target BCS should be determined. Although body condition scoring is subjective, it correlates well with body fat percent.[12] For the athlete, the author's preferred BCS is 4/9–5/9. However, the type of athletic discipline often influences the owner/caregiver/rider/trainer-desired BCS. In some

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Table 1. NRC 2007[1] Athletic Categories

Category	Distance (mi)	Intensity
Endurance	>2	Low
Middle distance[a]	0.5–2	75–95% max HR
Sprint[b]	<0.25	100% max HR

[a]Several minutes (e.g., Thoroughbred or Standardbred racing).
[b]Less than 1 minute (e.g., Quarter Horse racing).
HR, heart rate.

disciplines, a BCS of 4/9–5/9 is not considered desirable. There are consequences to being overweight and the owner/caregiver/rider/trainer should be educated as to these consequences. However, the author recognizes that the target BCS will likely be some consensus in balancing ideal and what is deemed acceptable in certain disciplines. For the gelding in this example, the target BCS is set at a 5/9.

Second, the gelding's estimated ideal or target body weight should be determined. True ideal body weight will be that when the gelding has achieved a BCS of 5/9. In general, each BCS represents 22.7 kg (50 lbs). Therefore, to drop 2 BCS points (from a 7/9 to a 5/9), the gelding would need to lose an estimated 45.4 kg (100 lbs); thus, the estimated target body weight would be 591 kg (1,300 lbs) (1,400 lbs minus 100 lbs). Once the target body weight is established, then the recommended diet/ration may be designed. When designing a diet, water, energy, and essential nutrients, along with DM, should be carefully considered. The goal is to promote weight loss while meeting essential nutrient needs and reducing the risk of metabolic and gastrointestinal abnormalities (e.g., colic).

Water

Water is the most important ingredient in any horse's ration. An old myth was to not lead a hot horse to water. Water should not be restricted; however, do not let a horse drink so much at once where they colic due to rapid gastric distention. Water intake and requirements are influenced by many factors, including total dry matter consumed,[1] dry matter content of feed (higher with hay vs. pasture),[13] protein intake,[14] sweat production, water salinity,[15] water temperature,[1,16] and ambient temperature.

Energy and Dry Matter

A horse's diet may be designed based on a dry matter target (DM) or a digestible energy target. This section will review the use of both methods. Feeding based on a DM target is more practical, although less precise. When feeding to a DM target (i.e., generally when trying to achieve weight loss) the author targets a daily DM goal of 1.5% body weight. Therefore, the 591-kg (1,300-lb) horse would be fed 8.9 kg (19.5 lbs) DM. If the forage has 92% DM, then the horse would consume 9.6 kg (21.1 lbs) as fed (AF; 8.9 kg DM/0.92 = 9.7 kg or 21.3 lb AF). Feeding by dry matter is quick and easy because all that is needed is the target body weight. However, depending on the forage quality, the total daily calories fed could be quite different. For example, if a horse is fed a relatively high-quality grass hay with 2.2 Mcal/kg DM (1.0 Mcal/lb DM) vs. a relatively poor-quality grass hay with 1.8 Mcal/kg DM (0.8 Mcal/lb DM), then daily calories would be 21.3 Mcal and 17.5 Mcal, respectively, a difference of 3.9 Mcal per day or 121 Mcal per month.

Feeding based on a digestible energy target is more precise; however, a forage nutrient analysis is needed. When feeding to a digestible energy target, the NRC web-based program (https://nrc88.nas.edu/nrh/) may be used to identify the horse's energy requirement. According to the NRC,[1] a 591-kg (1,300-lb) working/training horse at moderate workload (i.e., the example gelding) requires 27.6 Mcal digestible energy (1 Mcal = 1 kcal = 1 calorie). However, this does not account for needed negative energy balanced to promote weight loss. For weight loss, the author generally targets NRC low adult maintenance requirements (30.3 kcal/kg[1] ideal body weight), which would translate to 17.9 kcal for the example gelding. Although the low adult maintenance requirement does not account for the level of work, it is important to consider that energy requirements vary by individual and some individuals require substantial energy restriction.

Table 2. NRC 2007[1] Weekly Workloads and Examples

Exercise Category	Hours/Week	Walk (%)	Trot (%)	Canter (%)	Galloping/Jumping (%)
Light[a]	1–3	40	50	10	0
Moderate[b]	3–5	30	55	10	5
Heavy[c]	4–5	20	50	15	15
Very heavy[d]	1+ hour at speed or 6–12 hours slow				

[a]Examples: recreational riding, beginning training, and infrequent showing.
[b]Examples: school horses, recreational, beginning training, frequent showing, polo, and ranch.
[c]Examples: polo, strenuous showing, low/medium eventing, and moderate race training.
[d]Examples: racing and elite 3-day.

Table 3. Body Condition Score (BCS) Descriptors by Region

		Sites					
BCS	Description	A Crest of Neck	B Withers	C Behind the Shoulder	D Over the Ribs	E Along the Back	F Tailhead Region
1	Poor (extremely emaciated, no fatty tissue felt)	Bone structure prominent	Bone structure prominent	Bone structure prominent	Bones project prominently	Bones project prominently	Bone prominent
2	Very thin (emaciated)	Structures discernible	Structures discernible	Structures discernible	Bones prominent	Slight fat covering over vertebrae; bones prominent	Bone prominent
3	Thin	Structures faintly discernible	Structures faintly discernible	Structures faintly discernible	Slight fat layer felt, but easily seen	Fat built up about halfway on vertebrae	Bone prominent
4	Moderately thin	Not obviously thin	Not obviously thin	Not obviously thin	Faint outline	Slight ridge	Fat felt
5	Moderate	Blends smoothly into body	Rounded	Rounded	Easily felt, not seen	Level	Fat beginning to feel spongy
6	Moderately fleshy	Fat beginning to be deposited	Fat beginning to be deposited	Fat beginning to be deposited	Fat feels spongy	May have slight crease	Fat feels soft
7	Fleshy	Noticeable fat deposited	Noticeable fat deposited	Noticeable fat deposited	Felt, but noticeable fat deposition	May have crease	Fat is soft
8	Fat	Prominent crest of neck	Filled with fat	Filled with fat	Difficult to feel	Crease	Fat prominent
9	Extremely fat	Bulging fat	Budging fat	Budging fat	Patches of fat	Obvious crease	Budging

[a]Adapted from https://www.vetmed.vt.edu/vth/services/nutrition/docs/BCS_Equine.pdf and Henneke et al.[10]

Evaluating current and past diets is relatively time-consuming but provides details about the horse that help to refine key nutritional goals. For example, if the 591-kg (1,300-lb) gelding in moderate work was currently consuming 24.6 Mcal digestible energy per day, then recommending a diet that provides 27.6 Mcal (per NRC) would promote weight gain. If the gelding was consuming 24.6 Mcal per day, then a more appropriate energy goal would be 80% of current intake or 19.7 Mcal. Another consideration is if the horse's activity level has changed, as digestible energy provision should match energy expenditure (e.g., reducing concentrate during recovery and off-season). Some horses are rather efficient and require a significant degree of restriction, below 30.3 kcal/lb ideal body weight.[17] For the active horse, severe energy restriction is hopefully not needed and certainly should not be a starting point. Regardless of where the energy goal is initiated (e.g., 27.6 Mcal [NRC moderate work] or 17.9 Mcal [30.3 kcal/kg body weight] for the 591-kg [1,300-lb] gelding), the appropriateness of the plan will be determined through strategic monitoring (see Monitoring section).

Generally, a performance horse's energy needs can be met by forage, concentrate, or a combination of the two. However, concentrates (e.g., commercial performance feeds, grains, and brans) are more energy dense than forages (e.g., 2.6–3.3 Mcal/kg AF) and, thus, are generally not indicated for the overweight performance horse. Horses generally obtain more than 50% of energy requirements from microbial fermentation, specifically volatile fatty acids.[18,19] Although the horse in heavy activity is not likely to be able to meet energy needs with forage alone, horses at a lower level of activity and lower energy need are more likely to meet their energy need with forage alone. Furthermore, the insoluble fiber in forage (e.g., cellulose) is slowly fermented by gut microbes, supports a neutral hindgut pH and symbiotic gut microbiota, and thus promotes overall gut health.

For this example, if the available grass hay contains 2.0 Mcal/kg DM (0.909 Mcal/lb DM) and 92% DM (average per Equi-Analytical grass hay data[20]), then the energy density may be converted to an AF basis by multiplying the percent DM (92%)[20] by the energy density, 2.0 Mcal/kg DM $\times$ 0.92 = 1.8 Mcal/kg AF (0.836 Mcal/lb AF). Notably, forage quality is highly dependent on the stage of maturity at which it is consumed or cut to make hay. Ideally, a forage analysis would be conducted and should include an estimate of digestible energy (calculated from analyses of crude protein, fat, structural carbohydrates, non-structural carbohydrates [NSCs], and mineral content), neutral detergent fiber (NDF), and crude protein. The NDF represents forage cell wall (cellulose, hemicellulose, and lignin) and is a negative indicator of quality and a positive indicator of forage bulk. Therefore, the higher the NDF, the bulkier the forage and thus more filling, which is helpful for the horse with a high voluntary DM intake.[21,22] Anecdotally, grass hay with >70% NDF on a DM basis is high in that horses may not be able to eat enough to maintain a healthy weight.

Table 4. NRC 2007[1] Anticipated Dry Matter Intake by Workload

Workload	Anticipated DM Intake (% BW)
Light exercise	2
Moderate exercise	2.25
Heavy exercise and very heavy exercise	2.5

DM, dry matter; BW, body weight

If the daily energy requirement for the gelding is 17.9 Mcal, then the gelding would need 9.9 kg (17.9 Mcal/1.8 Mcal/kg AF) of this grass hay AF per day, which translates to 9.1 kg (9.9 $\times$ 0.92) or 1.5% of ideal body weight (9.1/591 kg body weight). Conversely, if the daily energy requirement for the gelding is 27.6 Mcal, then feed 15.3 kg (27.6 Mcal/1.8 Mcal/kg AF) of average quality grass hay AF per day, which translates to 14.1 kg DM (15.3 kg $\times$ 0.92) or 2.4% of ideal body weight. Anticipated daily DM intake for moderate work load is 2.25% body weight (Table 4).[1] Therefore, neither scenario is expecting the gelding to consume too much, thus concentrates do not appear to be needed to meet energy needs. Furthermore, both scenarios provide at least 1.5% of BW in DM per day.

Non-Structural Carbohydrates

Diets high in NSCs (includes sugars, starch, and fructan) increase the risk of insulin dysregulation and laminitis, which are associated with obesity.[23,24] Activity positively influences insulin regulation; thus, active overweight horses may have a lower risk of insulin dysregulation. Regardless, limiting NSCs will likely limit the risk of insulin dysregulation. Although some authors suggest limiting NSCs to <10% of diet DM, the author targets an NSC level lower than the current diet. Forage is lower in NSCs than concentrates, particularly grain-based concentrates. Grasses and alfalfa are similar in NSC content, although the high end for grasses is higher than for alfalfa.[20,25] Hay may be soaked to reduce water-soluble carbohydrates (sugars and fructan) in forage.[26] However, some water-soluble nutrients in the DM are lost. Forage NSCs should be considered along with forage quality and energy density. If feeding based on DM, the forage with the lower NSC concentration would be an ideal choice. In addition to being more energy dense, concentrates are generally higher in NSC than forage, which can reduce insulin sensitivity[23] and increase the risk of colic, especially without transition/gradual introduction.[27]

Nutrient Requirements

The requirements for several essential nutrients are considered to be higher in the athletic horse. According to the NRC,[1] a 591-kg (1,300-lb) working/training horse at moderate work load (i.e., the example gelding) requires 908 g crude protein, 39 g lysine, 41 g calcium, 25 g phosphorus, 21 g sodium, 63 g chloride, 38 g potassium, 14 g magnesium, 18 g sulfur, 0.6 mg cobalt, 118 mg copper, 4.1 mg iodine, 473 mg iron, 473 mg manganese, 473 mg zinc, 1.2 mg selenium, 26,595 IU vitamin A, 3,901 IU vitamin D, 1,064 IU vitamin E, 67 mg thiamine, and 27 mg riboflavin.

Regardless of the energy need of the individual, the author sets essential nutrient goals to match the NRC requirements for the given physiologic status/life stage. Otherwise said, regardless of whether the gelding's actual energy requirement was 27.6 or 17.9 Mcal per day, the essential nutrient goal should still be set as that required for a working/training horse at moderate workload.

Generally, if forage meets the energy needs, it will also meet the protein and amino acid needs. However, when instituting a prescribed weight loss plan, this is not always the case. According to Equi-Analytical, grass hay contains 109 (±18) grams of protein per kg on a DM basis or 100 grams of protein per kg on an AF basis.[20] If feeding 9.9 or 15.3 kg of average quality grass hay, then the protein provided would be 990 or 1,530 grams per day, respectively, which exceed the 908 grams required daily for the 591-kg (1,300-lb) working/training horse at moderate work load. Excessive dietary protein is not beneficial, as protein positively influences water requirements due to increased endogenous heat production and increased need for renal nitrogen excretion. Protein metabolism generates more heat production, as compared to carbohydrate and fat metabolism, which increases sweat production, subsequently increasing water and electrolyte losses. Furthermore, increased nitrogen (ammonia) in the urine can reduce barn air quality.

Forage needs to be complemented with a ration balancer to provide the micronutrients that the forage does not. Furthermore, if the forage does not meet protein requirements, then supplemental protein is needed. Although the concentration and availability of nutrients in forage varies by region, forage format (fresh pasture vs. hay) and soil type, several micronutrients (e.g., sodium, chloride, copper, zinc, selenium, and vitamin E) may be deficient if forage is the only source of nutrients. It is important to consider regional differences in forage availability and nutrient content, as the micronutrients needed will vary. Sodium chloride may be met by providing free choice access to a white or trace mineral (≥95% sodium chloride) block, preferably near a fresh water source. Additional nutrients may be provided with balancer pellets, which are highly fortified commercial feeds and are meant to be fed in small quantities. Balancer pellets are a good option to balance the forage because (1) it gives the caregiver something to feed, which is often an important factor in the human-animal-bond, and (2) they are generally readily consumed and, thus, easier to monitor intake. Equine-specific granular or block-type vitamin-mineral products may be fed free choice, preferably near a water source, but intake is generally more difficult to monitor, particularly when offered in a group setting.

Antioxidant requirements, like for vitamin E, are higher for athletes, as free radicals are a byproduct of energy metabolism. Vitamin E is generally adequate in fresh/pasture forage, but is deficient in processed forage (e.g., hay).[28]

Monitoring

Body weight and BCS should be evaluated monthly. The target weight loss rate is 0.5–1.0 BCS point per month or 11.3–22.7 kg (25–50 lbs) per month. If weight loss is too slow or has not occurred, check compliance. If the caregiver has been compliant but weight loss has been slow, then further reduce energy by 10–20%. For any adjustment, be cognizant of daily DM provision. Although the author prefers not to drop daily DM below 1.5% of target body weight, 1.0% of target body weight should be used as a minimum target.[17,29] The author recommends working with a veterinary nutritionist when daily DM falls below 1.5% body weight. If daily DM drops below 1.5% of target body weight, consider implementing a means to slow forage consumption (e.g., slow hay feeders) and monitoring more closely for colic. If the caregiver has not been compliant, investigate the cause and help the caregiver establish a management plan that is sustainable.

Acknowledgments

Declaration of Ethics

The Author has adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

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References

1. NRC. *Nutrient requirements of horses*. 6th ed. Washington DC: The National Academies Press; 2007.
2. Robin CA, Ireland JL, Wylie CE, et al. Prevalence of and risk factors for equine obesity in Great Britain based on owner-reported body condition scores. *Equine Vet J* 2015;47:196–201.
3. Sillence M, Noble G, McGowan C. Fast food and fat fillies: The ills of western civilisation. *Vet J* 2006;172:396–397.
4. Vick M, Sessions D, Murphy B, et al. Obesity is associated with altered metabolic and reproductive activity in the mare: Effects of metformin on insulin sensitivity and reproductive cyclicity. *Reprod Fertil Dev* 2006;18:609–617.
5. Hoffman RM, Boston RC, Stefanovski D, et al. Obesity and diet affect glucose dynamics and insulin sensitivity in Thoroughbred geldings. *J Anim Sci* 2003;81:2333–2342.
6. Frank N, Elliott S, Brandt L, et al. Physical characteristics, blood hormone concentrations, and plasma lipid concentra-

tions in obese horses with insulin resistance. *J Am Vet Med Assoc* 2006;228:1383–1390.
7. Vick M, Adams A, Murphy B, et al. Relationships among inflammatory cytokines, obesity, and insulin sensitivity in the horse. *J Anim Sci* 2007;85:1144–1155.
8. Coleman MC, Belknap JK, Eades SC, et al. Case-control study of risk factors for pasture-and endocrinopathy-associated laminitis in North American horses. *J Am Vet Med Assoc* 2018;253:470–478.
9. Treiber K, Kronfeld D, Geor R. Insulin resistance in equids: Possible role in laminitis. *J Nutr* 2006;136:2094S–2098S.
10. Henneke DR, Potter GD, Kreider JL, et al. Relationship between condition score, physical measurements and body-fat percentage in mares. *Equine Vet J* 1983;15:371–372.
11. University of Kentucky College of Agriculture, Food and Environment Agriculture. 2019. Body condition scoring horses: step-by-step. Available at: https://thehorse.com/164978/body-condition-scoring-horses-step-by-step/. Accessed on January 2, 2020.
12. Fowler AL, Pyles MB, Bill VT, et al. Relationships between measurements of body fat in Thoroughbred horses. *J Equine Vet Sci* 2020;85:102873.
13. Williams S, Horner J, Orton E, et al. Water intake, faecal output and intestinal motility in horses moved from pasture to a stabled management regime with controlled exercise. *Equine Vet J* 2015;47:96–100.
14. Oliveira CA, Azevedo JF, Martins JA, et al. The impact of dietary protein levels on nutrient digestibility and water and nitrogen balances in eventing horses. *J Anim Sci* 2015;93:229–237.
15. Butudom P, Schott HC, Davis MW, et al. Drinking salt water enhances rehydration in horses dehydrated by frusemide administration and endurance exercise. *Equine Vet J Suppl* 2002;513–518.
16. Butudom P, Barnes DJ, Davis MW, et al. Rehydration fluid temperature affects voluntary drinking in horses dehydrated by furosemide administration and endurance exercise. *Vet J* 2004;167:72–80.
17. Argo CM, Curtis GC, Grove-White D, et al. Weight loss resistance: A further consideration for the nutritional management of obese Equidae. *Vet J* 2012;194:179–188.
18. Vermorel M, Vernet J, Martin-Rosset W. Digestive and energy utilisation of two diets by ponies and horses. *Livest Prod Sci* 1997;51:13–19.
19. McNeil N. The contribution of the large intestine to energy supplies in man. *Am J Clin Nutr* 1984;39:338–342.
20. Equianalytical. Interactive common feed profile. Available at: https://equi-analytical.com/interactive-common-feed-profile/. Accessed on December 11, 2019.
21. Crozier JA, Allen VG, Jack NE, et al. Digestibility, apparent mineral absorption, and voluntary intake by horses fed alfalfa, tall fescue, and Caucasian bluestem. *J Anim Sci* 1997;75:1651–1658.
22. Staniar WB, Bussard JR, Repard NM, et al. Voluntary intake and digestibility of teff hay fed to horses. *J Anim Sci* 2010;88:3296–3303.
23. Treiber K, Hess T, Kronfeld D, et al. Dietary energy sources affect insulin sensitivity and Beta-cell responsiveness of trained Arabian geldings during endurance exercise. *J Anim Physiol Anim Nutr* 2005;89:427–433.
24. Treiber K, Boston R, Kronfeld D, et al. Insulin resistance and compensation in Thoroughbred weanlings adapted to high-glycemic meals. *J Anim Sci* 2005;83:2357–2364.
25. Longland A, Byrd B. Pasture nonstructural carbohydrates and equine laminitis. *J Nutr* 2006;136:2099S–2102S.
26. Müller CE, Nostell K, Bröjer J. Methods for reduction of water soluble carbohydrate content in grass forages for horses. *Livest Sci* 2016;186:46–52.
27. Curtis L, Burford JH, England GCW, et al. Risk factors for acute abdominal pain (colic) in the adult horse: A scoping review of risk factors, and a systematic review of the effect of management-related changes. *PLoS One* 2019;14:e0219307.
28. Finno CJ, Valberg SJ. A comparative review of vitamin E and associated equine disorders. *J Vet Intern Med* 2012;26:1251–1266.
29. Durham AE, Frank N, McGowan CM, et al. ECEIM consensus statement on equine metabolic syndrome. *J Vet Intern Med* 2019;33:335–349.

How to Feed Performance Horses for Optimal Digestive Health

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1. Introduction

Horses are non-ruminant herbivores, highly adapted to the slow intake of a plant-based, high-fiber diet. However, modern-day management practices of performance horses have shifted toward overall reduced access to forage and increased reliance on the practice of meal-feeding. This shift is not only counter to best feeding and management practices to promote optimal digestive health, but it has placed equine athletes at a higher risk of gastrointestinal disturbances such as gastric ulcers, recurrent colic, and conditions involving inflammation of the bowel. Clinical signs of these disturbances may include irritability, weight loss, poor appetite, chronic diarrhea, among others. While proper diagnosis and appropriate medical treatment in these patients is critical, it is also important to evaluate the horse's diet and feeding management practices.

Performance horses are typically managed under conditions that are not conducive to optimal digestive health. Increased confinement in stalls and meal feeding affect the physiology of the digestive tract by altering both intestinal motility and the microbiome environment, increasing colic risk.[1] Feeding large, high-starch grain meals that exceed >1 g/kg body weight (BW)/meal, a practice common in horses with high dietary energy requirements, has been linked to greater risk of nonglandular gastric ulcers.[2] The high-stress lifestyle and over-use of nonsteroidal anti-inflammatory drugs that is more commonly observed in the performance horse population has been associated with alterations in intestinal permeability ("leaky gut") and an increased risk of right dorsal colitis.[3,4] Fortunately, basic equine nutrition principles for promoting good digestive health can be applied in such a way to either 1) maintain and/or improve athletic performance or 2) support medical treatment of performance horses suffering from gastrointestinal disease. This paper will outline specific nutrition and feeding management guidelines that promote optimal digestive health, with a focus on the performance horse.

2. Feeding and Management Practices

Forages

It is a long standing recommendation for horses to receive a minimum of 1% BW in forage per day in order to maintain proper digestive function, but this minimum recommendation is commonly overlooked in performance horse management situations. And while 1% BW is the minimum recommendation, 1.5–2% BW is a better target in most cases, and it is recommended that forage make up at least 50% of the

NOTES

total daily ration when possible.[5] Forage requirements can be met by both preserved forages (long-stemmed hay, hay pellets, chopped hay, and commercially available forage-replacement alternatives) and fresh pasture. Forage intake while on pasture can vary greatly, and total dry matter intake while grazing is dependent upon several factors, including total hours of access and overall pasture quality. Studies have shown that horses allowed 4 hours or less of daily pasture access will consume 0.22 ± 0.02 kg DM/100 kg BW/hour, and horses allowed more than 4 hours of daily pasture access will consume 0.11 ± 0.02 kg DM/100 kg BW/hour.[6] For example, if a 500-kg horse were allowed to graze on pasture for 6 hours per day, dry-matter intake would be expected at 3.3 kg, which is equivalent to approximately 3.7 kg hay (as-fed basis).

Chewing long-stemmed forage increases saliva output, and saliva contains bicarbonate, which helps to buffer acid secretions in the stomach.[7] Maximizing access to forage will increase time spent chewing, as well as potentially decreasing boredom and stress while confined. Horses in a natural setting are estimated to graze for approximately 14 hours each day.[8] When stalled, the horse's opportunity to forage is limited, and the utilization of small-hole hay nets (3.2-cm and 4.4-cm openings) as opposed to feeding from the stall floor is an effective way to increase the overall time to consumption of hay and better mimics grazing conditions.[9]

Perhaps the most significant feature of forage in terms of digestive health is that it supplies the fermentable fiber required by the hindgut microbes to function properly. When feeding a hindgut fermenter such as the horse, maintaining a healthy population of hindgut microorganisms plays a critical role in not only digestion, but overall horse health. Together with their genetic material and interactions with each other in their environment, these hindgut microbes are a part of a diverse and complex ecosystem referred to as the "equine microbiome." The importance of a healthy microbiome environment cannot be overstated, and recent advances in laboratory techniques and gene sequencing technology have made it easier to isolate, identify, and quantify the specific organisms present in the horse's hindgut. The newest frontier in equine nutrition research involves delving into the equine microbiome, and scientists are currently working to characterize what both a healthy and unhealthy equine microbiome looks like, in addition to how that microbial ecosystem can be manipulated to improve horse health and performance.[10,11]

Concentrates

The demands of exercise and performance increase digestible energy and nutrient requirements of the horse. When forage alone cannot meet these increased demands, a concentrate feed will be required to meet the nutritional needs of the performance horse. Concentrates include cereal grains like corn, oats, and barley, as well as commercially available pelleted and textured grain mixes. When appraising the impact of concentrates on digestive health, meal size, and composition are important factors to consider, especially in relation to preventing starch overload in the hindgut. The horse's small intestine is well suited to digest starch, a useful energy source for many performance horses, up to a certain point. Many studies have attempted to elucidate the upper limit of small intestinal starch digestion to prevent starch from reaching the hindgut. Small intestinal starch digestion varies somewhat with cereal grain source (i.e., oat starch is more digestible than barley starch) and processing (i.e., mechanical and hydrothermal), but a general guideline is to limit starch intake, regardless of the source, to <2 g/kg BW/meal in order to prevent starch overload and rapid fermentation in the hindgut.[12,13] Practically, this translates into feeding no more than a 2.5 kg meal of a cereal grain-based concentrate (40% starch) for a 500-kg horse (or, limiting meal size to 0.5% of the horse's BW). Limiting the starch content of a meal even further may be warranted in certain circumstances (i.e,. in horses with insulin dysregulation or gastric ulcers), but this is a good benchmark goal for most healthy performance horses. For horses that are prone to bolting or rushing their concentrate meals, feeding hay before the concentrate meal can also help to slow the rate of intake.[14]

Concentrate composition will also dictate the total amount of starch contained in a meal. Concentrate meals consisting of straight cereal grains will contain the highest concentration of starch, while multi-ingredient rations and commercially available products will vary considerably depending on the proportion of ingredients in the ration or feed formulation. Book values for cereal grains are readily available, and if the starch level of a commercially available horse feed product is not listed on the feed tag, the manufacturer should be able to provide that information upon request. Many commercially available products for performance horses contain added fat and fiber, which are used as additional sources of digestible energy. This is generally positive in terms of digestive health, as it reduces reliance on starch to serve as the primary energy source, as well as supplies additional digestible fiber. For horses with elevated energy requirements, feeding fat- and fiber-added rations increases the energy density of the diet and in most cases is a recommended practice. However, there is an upper threshold for small intestinal fat digestion that, if exceeded, can reduce the digestibility of certain nutrients. The inclusion of fat at up to at least 10% of total dry matter intake (forage + concentrate) appears to have minimal negative impact on digestive health.[15] Because forages are naturally low in fat (1% to 3% DM basis), exceeding this level of fat in the total ration is not common, even with the use of high-fat concentrate feeds (>10% to 14% fat).

Feed Additives and Supplements

There is an overwhelming array of "digestive aid" supplements and feed additives for horses available on the market, and their use is especially popular in performance horse rations. While some may play a role in promoting digestive health, there is no substitute for proper feed selection and implementation of appropriate feeding practices. Without those in place, no supplement or additive can have any significant impact on overall digestive health. While a full review of additives and supplements is not within the scope of this discussion, there are a few points to consider related to their selection and use. Some of the more common additives that have been studied in relation to their impact on digestive health include probiotics (live strains of microorganisms), prebiotics (substrates for microbial fermentation), and yeast cultures and yeast derivatives. When evaluating the efficacy of these additives, it cannot be assumed that results obtained in studies conducted in human or other lab animal species will apply to the horse. Look for published data that confirm safety and efficacy in the species of interest (the horse) that show a clear justification for recommended dosage. Rather than relying on an additive or supplement to promote digestive health, consider them as adjunct support for an overall feeding program that follows the principles outlined above related to forage and concentrate feeding and management practices.

Feed Transitions

Changes in the amount or type of feed offered to a horse should be implemented gradually, to allow the digestive system to adapt and to prevent digestive disturbances. Large increases or decreases in total volume of feed offered should occur gradually as well. This applies to fresh pasture, preserved forages (i.e., hay), and concentrate feeds. It is recommended that horses not acclimated to grazing be introduced to lush pasture over a period of several days.[5] When transitioning from one type of hay to a different type of hay, and even from one batch of hay to a new batch of the same hay variety, it is good practice to combine the old and new hay for a minimum of several days and for up to 2 weeks as the transition is made. When making the switch from one concentrate feed to another, a good general rule of thumb is to make the change at a rate of no more than approximately 0.5 kg per day. This conservative approach to feed transitions will further promote digestive health, especially in performance horses with a history of digestive upset.

3. Feeding Recommendations for Certain Gastrointestinal Conditions

Gastric Ulcers

It is well documented that performance horses are at a high risk for the development of gastric ulcers, specifically equine squamous gastric disease (ESGD). Little evidence exists for the role of diet in equine glandular gastric disease.[16] In addition to following the principles of feeding management outlined above, there are some special considerations for horses being treated for or with a history of ESGD. Without alterations in the feeding and management of these horses, it is likely that squamous ulcers will return once treatment is complete. When managing horses with ESGD, additional feeding recommendations are to provide as much turnout on pasture as possible, allow free choice access or offer hay frequently (4–6 meals/day), limit starch content of concentrate meals to <1 g/kg BW, and avoid orally administered hypertonic electrolyte solutions.[16] Feeding smaller, more frequent meals and incorporating alfalfa hay into the forage component of the ration are also recommended to lessen the severity and prevent the recurrence of gastric ulcers.[17] The inclusion of alfalfa hay in the diet, preferably provided at regular 5- to 6-hour intervals, is recommended as it has been shown to buffer gastric contents and decrease gastric ulcer severity.[18] Gastric protectant and buffering supplements that have published data behind them may also have a role in maintaining proper gastric pH and promoting a healthy gastric environment, and these include a pectin-lecithin complex and a natural-source mineral complex rich in seaweed-derived calcium.[19,20]

Chronic Colic

A wide variety of conditions may result in frequent bouts of colic, and the horse should be screened for such conditions and treated appropriately. Long-term feeding management recommendations for these horses are based on following the feeding and management practices outlined above, as well as minimizing common colic risk factors (Table 1). Stabled horses with reduced access to grazing are 3 times more likely to suffer from colic, and pasture access should be maximized when possible.[21] Only highly digestible feeds should be utilized, and small, frequent meals should be offered throughout the day. In addition to grass pasture, good forage options include high-quality grass hay, alfalfa hay or grass-alfalfa mix hay, soaked alfalfa cubes, and beet pulp. Having hay tested at a forage testing lab[a] will ensure that the forage is of acceptable quality, as consumption of overly mature hay can easily lead to colic in sensitive horses. A general guideline is the higher the relative feed value, the less mature and the better the hay quality. In horses with a history of chronic colic, aim for feeding hay with a relative feed value of >86. Alfalfa hay should be avoided in horses with a history of or increased risk of enteroliths, as the higher protein and mineral content increases colonic pH which has been implicated to be a predisposing factor for enterolith formation.[22,23] Finally, supplementing 1–2 Tbsp per day of plain white salt or a commercial electrolyte supplement may encourage water intake, especially

Table 1. Common Risk Factors for Colic[21,24,25,26]

Dietary	Management
Recent change in batch of hay	Recent change in housing
Recent change in type of grain or concentrate fed	Increased hours spent in a stable
Decreased exposure to pasture	Administration of an anthelmintic during the prior 7-day period
Feeding >6 pounds of oats/day	Failure to receive regular deworming
Feeding large concentrate meals	Failure to receive regular dental care
Feeding hay from round bales	Regular exercise vs. always pastured
Feeding <1% BW forage per day	Recent change in exercise program
Feeding poor quality forage	
Feeding primarily alfalfa hay high in crude protein and minerals (enteroliths)	

in the colder months when some horses drink significantly less water.

Inflammation of the Intestinal Tract and Hindgut Dysfunction

Many medical conditions, including inflammatory bowel disease, chronic diarrhea, right dorsal colitis, and colonic ulcers, feature some level of inflammation of the intestinal tract and hindgut dysfunction, and the recommended dietary strategies to address symptoms in horses with diagnosed or suspected inflammatory bowel conditions or other related disturbances of the hindgut are similar. The basic feeding objectives when addressing bowel inflammation and hindgut dysfunction are 1) reduce the mechanical and physiologic demand on the colon, and 2) promote mucosal healing. A reduction in mechanical load can best be accomplished by reducing or eliminating long-stemmed forage from the ration for a period of 3 to 8 months, with the length of time being dictated by the response of the horse. Eliminating long-stemmed forage and feeding a low bulk ration will substantially reduce total dry matter intake and reduce ingesta particle size, helping to alleviate mucosal trauma. Select a high-quality pelleted complete feed with built-in forage fortified with vitamins, minerals, and additional amino acids (commercially available senior horse feeds work well) in order to provide an easily digestible ration that meets all the horse's nutrient requirements. Dividing the daily ration into small, frequent meals (4 to 6 per day) will promote consistent intake and encourage normal gastrointestinal motility. In some cases, a small amount of high-quality forage may be included in the ration, but only if the horse can tolerate it. Alfalfa hay should be used with caution in horses with chronic diarrhea, as alfalfa is known to have a laxative effect in some horses. Forage selection recommendations for chronic colic also apply to horses with bowel inflammation. The horse can also be allowed to graze small amounts of fresh grass (10- to 15-minute intervals, 4 to 6 times daily). Intermittent psyllium mucilloid supplementation is recognized as a management tool to reduce sand accumulation in the horse's digestive tract, but daily supplementation has been suggested to further promote ingesta passage and reduce mucosal trauma. Studies in other species have shown that the endogenous production of the short-chain fatty acid, butyrate (a product of the microbial fermentation of psyllium), may aid in mucosal healing, therefore psyllium supplementation warrants consideration in the treatment of equine gastrointestinal disease.[3] Although controlled studies are lacking, some reports have identified recommended daily feeding rates for psyllium to be 1) 100 grams per day, and 2) 5 tablespoons every 12 to 24 hours, to promote mucosal healing and repair in colitis cases.[27,28] The implementation of a low-bulk ration can sometimes be met with owner resistance, but discussing the rationale behind this approach and explaining the temporary nature of the feeding plan can help to increase owner compliance and overall success. Long-stemmed forage can be gradually reintroduced to the ration once symptoms have improved, to identify how much and what type of forage the horse can best tolerate on a long-term basis. It is important to continually monitor these horses closely, as they seem to be more sensitive to dietary and management changes.

4. Conclusion

Following basic nutrition principles that promote optimal digestive health when feeding performance horses will serve to support athletic performance and prevent digestive disturbances. When an equine athlete is not meeting performance expectations and/or experiences symptoms related to poor digestive health, the evaluation of feeding and management practices, and making appropriate adjustments, will support any necessary medical treatment and improve overall outcome.

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Declaration of Ethics

The Author has adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Author is employed as an equine nutritionist for Purina Animal Nutrition, a commercial horse feed manufacturer.

References and Footnote

1. Blikslager A. Colic prevention to avoid colic surgery: A surgeon's perspective. *J Equine Vet Sci* 2019;76:1–5.
2. Luthersson N, Nielsen KH, Harris P, et al. Risk factors associated with equine gastric ulceration syndrome (EGUS) in 201 horses in Denmark. *Equine Vet J* 2009;41:625–30.
3. Stewart AS, Pratt-Phillips S, Gonzalez LM. Alterations in intestinal permeability: The role of the "leaky gut" in health and disease. *J Equine Vet Sci* 2017;52:10–22.
4. Davis JL. Nonsteroidal anti-inflammatory drug associated right dorsal colitis in the horse. *Equine Vet Educ* 2017;29: 104–113.
5. National Research Council. Nutrient requirements of horses. 6th revised ed. Washington, DC: The National Academies Press; 2007.
6. Dowler, LE, Siciliano PD. Prediction of hourly pasture dry matter intake in horses. *J Equine Vet Sci* 2009;29:354–355 (abstr).
7. Merritt AM, Julliand V. Gastrointestinal physiology. In: Geor RJ, Harris PA, M Coenen M, eds. *Equine applied and clinical nutrition.* Elsevier, 2013;3–32.
8. Fleurance G, Duncan P, Mallevaud B. Daily intake and the selection of feeding sites by horses in heterogeneous wet grasslands. *Anim Res* 2001;50:149–156.
9. Glunk EC, Hathaway MR, Weber EJ, et al. The effect of hay net design on rate of forage consumption when feeding adult horses. *J Equine Vet Sci* 2014;34:986–991.
10. Julliand V, Grimm P. The microbiome of the horse hindgut: History and current knowledge. *J Anim Sci* 2016;94:2262–2274.
11. Costa MC, Weese JS. Understanding the intestinal microbiome in health and disease. *Vet Clin North Am Equine Pract* 2018;34:1–12.
12. Julliand V, Fombelle AD, Varloud M. Starch digestion in horses: The impact of feed processing. *Livestock Sci* 2006; 100:44–52.
13. Hoffman RM. Carbohydrates. In: Geor RJ, Harris PA, M Coenen M, eds. *Equine applied and clinical nutrition*. Elsevier, 2013;156–167.
14. Gordon, ME, Davison K, Jerina ML. The effects of feeding order, time of day, and treatment adaptation on rates of hay and concentrate intake. *J Equine Vet Sci* 2015;35:429 (abstr).
15. Warren LK, Vineyard KR. Fat and fatty acids. In: Geor RJ, Harris PA, M Coenen M, eds. *Equine applied and clinical nutrition*. Elsevier, 2013;136–155.
16. Sykes BW, Hewetson M, Hepburn RJ, et al. European College of Equine Internal Medicine Consensus Statement—Equine gastric ulcer syndrome in adult horses. *J Vet Intern Med* 2015;29:1288–1299.
17. Andrews FM, Larson C, Harris P. Nutritional management of gastric ulceration. *Equine Vet Educ* 2017;29:45–55.
18. Nadeau JA, Andrews FM, Matthew AG. Evaluation of diet as a cause of gastric ulcers in horses. *Am J Vet Res* 2000; 61:784–790.
19. Venner M, Lauffs S, Deegen E. Treatment of gastric lesions in horses with pectin-lecithin complex. *Equine Vet J* 1999; 31:91–96.
20. Gordon ME, Vineyard KR, Andrews FM. The effect of a natural-source mineral supplement on gastric juice pH in horses. *J Equine Vet Sci* 2017;52:58 (abstr).
21. Durham AE. The role of nutrition in colic. *Vet Clin Equine* 2009;25:67–78.
22. Hassel DM, Spier SJ, Aldridge BM, et al. Influence of diet and water supply on mineral content and pH within the large intestine of horses with enterolithiasis. *Vet J* 2009;182: 44–9.
23. Hassel DM, Rakestraw PC, Gardner IA, et al. Dietary risk factors and colonic pH and mineral concentrations in horses with enterolithiasis. *J Vet Intern Med* 2004;18:346–349.
24. Cohen ND, Gibbs PG, Woods AM. Dietary and other management factors associated with colic in horses. *J Am Vet Med Assoc* 1999;215:53–60.
25. Hillyer MH, Taylor FGR, Proudman CJ, et al. Case control study to identify risk factors for simple colonic obstruction and distension colic in horses. *Equine Vet J* 2002;34:455–463.
26. Hudson JM, Cohen ND, Gibbs PG, et al. Feeding practices associated with colic in horses. *J Am Vet Med Assoc* 2001; 219:1419–1425.
27. Galvin N, Dillon H, McGovern F. Right dorsal colitis in the horse: Minireview and reports on three cases in Ireland. *Irish Vet J* 2004;57:467–273.
28. Jones SL. Inflammatory diseases of the gastrointestinal tract causing diarrhea. In: Reed SM, Bayly WM, Sellon DC, eds. *Equine internal medicine*. 3rd ed. St. Louis, MO: Saunders Elsevier; 2013;857–876.

[a]Equi-Analytical, Ithaca, NY; www.equi-analytical.com.

Feeding Performance Horses with Myopathies

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1. Introduction

In combination with exercise, nutrition is an essential component of managing horses with myopathies. The optimal feeding program for an individual is tailored to the diagnosis of a specific underlying myopathy.

2. Classification of Exertional Myopathies

Exertional myopathies are defined by muscle pain and impaired performance during or after exercise. Exertional rhabdomyolysis (ER) represents a subset of exertional myopathies characterized by elevations in serum creatine kinase (CK) and aspartate transaminase (AST) activities. Forms of ER include type 1 polysaccharide storage myopathy (PSSM1), type 2 polysaccharide storage myopathy (PSSM2) in Quarter Horses, malignant hyperthermia, recurrent exertional rhabdomyolysis (RER), and myofibrillar myopathy (MFM) in Arabians.[1-5]

There are other exertional myopathies, such as PSSM2 and MFM in Warmbloods, that are not typically characterized by elevations in serum CK and AST activities.[6] Horses with these exertional myopathies have exercise intolerance and show reluctance to go forward, collect, and engage the hindquarters. Because these clinical signs are not specific to muscle disease, causes of decreased performance such as behavior, rider, tack, and orthopedic lameness need to be ruled out prior to investigating a primary exertional myopathy.

Exertional Rhabdomyolysis

Overt ER can arise as a sporadic event due to extrinsic factors such as exercise in excess of training, nutritional imbalances, or exercise during viral illness. ER can also occur as a chronic disease due to intrinsic abnormalities in muscle function. Acute clinical signs of ER are similar across the spectrum of etiologies and include muscle stiffness, shortened hindlimb stride, reluctance to move, and firm, painful hindquarter muscles. Anxiety, pain, sweating, and increased respiratory rate are common signs.

Sporadic ER

Sporadic forms of ER develop from exercise in excess of training, dietary imbalances (including high nonstructural carbohydrate (NSC) content and low forage content), and deficiencies in electrolytes.[7,8] ER may be exacerbated by inadequate dietary selenium and vitamin E.

NOTES

Chronic ER

Chronic forms of ER appear to develop in horses due to intrinsic abnormalities in muscle function. In some cases, muscle dysfunction is attributed to a single gene defect.[9,10] In other cases, there may be multiple genes impacting muscle dysfunction or post-translational modifications of gene products that arise under certain environmental stimuli.

Recurrent Exertional Rhabdomyolysis

Recurrent exertional rhabdomyolysis describes a subset of ER that is believed to be due to an abnormality in the regulation of muscle contraction and relaxation.[11–13] Research into RER has primarily been performed in Thoroughbreds and to a lesser extent in Standardbreds.[11,14–16] There are reports of ER in racing Quarter Horses, Arabians, and Warmbloods that may have the same underlying cause based on the overlapping histories, clinical signs, muscle biopsy findings, and response to management.[17] Mares more commonly have RER than males, although no general correlation has been observed between episodes of ER and stages of the estrous cycle.[18] Nervous horses, particularly nervous fillies, have a higher incidence of ER than calm horses.[14,19,20] Diet also has an impact with Thoroughbreds fed more than 2.5 kg of grain being more likely to show signs.[21] Research suggests that horses with RER may have an inherent abnormality in intramuscular calcium regulation that is intermittently manifested during exercise in stressful environments.[13,22]

Polysaccharide Storage Myopathy

Several acronyms have been used for polysaccharide storage myopathy (PSSM), including EPSM and EPSSM.[23–25] Muscle biopsies from PSSM-afflicted horses are characterized by the presence of abnormal polysaccharide inclusions, which are typically amylase resistant in PSSM1 and amylase sensitive in PSSM2.

PSSM1

PSSM1 is caused by an autosomal-dominant gain-of-function mutation in *GYS1* that results in elevated glycogen synthase activity and >1.5-fold higher muscle glycogen concentrations in skeletal muscle.[10] The enzyme mutation enhances synthesis of glycogen and appears to disrupt metabolism of this energy substrate. The severity of clinical signs of PSSM1 can vary widely from asymptomatic to severe incapacitation. The most common trigger for ER is less than 20 minutes of light exercise, particularly if the horse has been rested for several days prior to exercise or is unfit. Diets high in NSC also increase the risk of muscle pain and stiffness in PSSM1 horses.[26] The gold standard for diagnosis of PSSM1 is genetic testing for the *GYS1* mutation performed on whole blood or hair root samples.

PSSM2

PSSM2 is a histopathologic designation that indicates the presence of abnormal-appearing amylase-sensitive or amylase-resistant polysaccharide in muscle biopsies of horses lacking the *GYS1* mutation. Importantly, the term PSSM2 does not indicate a specific etiology since no common genetic mutations or biochemical aberrations have been defined in these horses to date. Commercial genetic tests for PSSM2 have not been scientifically validated through peer-reviewed publication. Approximately 28% of cases of PSSM diagnosed by muscle biopsy in Quarter Horse-related breeds would be classified as PSSM2.[27] Quarter Horses with PSSM2 present with ER and have biochemical elevations in muscle glycogen concentrations. PSSM2 seems to be common in both high-performance Quarter Horse types such as barrel racing, reining, and cutting horses as well as pleasure and halter horses. About 80% of Warmblood horses diagnosed with PSSM by muscle biopsy are classified as PSSM2.[27] The clinical presentation of PSSM2 in Warmbloods is often that of exercise intolerance rather than overt ER, and biochemical elevations in muscle glycogen are uncommon.

Myofibrillar Myopathy

Myofibrillar myopathy (MFM) is a recently identified disorder presenting with exercise intolerance or intermittent ER that is defined by specific histopathology.[5,6] The hallmark histopathologic feature of MFM is cytoplasmic aggregates of the cytoskeletal protein desmin in scattered muscle fibers. Desmin functions to align sarcomeres at the Z-disc and tether them to the cell membrane. MFM may represent a more extreme subset of PSSM2 in Warmbloods and Arabians, but further research is required. Mean muscle glycogen concentrations in Warmblood and Arabian horses with MFM are similar to controls.[28,29]

MFM in Warmbloods

Warmblood horses diagnosed with MFM by muscle biopsy have an insidious onset of exercise intolerance notable by 6–8 years of age characterized by a lack of stamina, unwillingness to go forward, inability to collect, abnormal canter transitions, and inability to sustain a normal canter.[6] Unresolved hindlimb lameness, stiffness, muscle pain and, rarely, an episode of ER are reported.[29] Serum CK and AST activities are usually within normal limits unless samples are taken in conjunction with ER. A recent study found no association between commercial genetic tests for MFM and a clinical and histopathologic diagnosis of MFM in Warmblood horses.[30] The basis for MFM in Warmblood horses appears to be related to the individual effects of diet, exercise, and training on gene and protein responses to exercise with downstream effects on muscle mass, the alignment of contractile proteins, mitochondrial function, and oxidative stress (unpublished observations).

MFM in Arabians

Arabian endurance horses diagnosed with MFM usually have a history of intermittent elevations in serum CK activity after endurance rides (>10,000 U/L) or during exercise that follows a week or more of rest.[5] Horses do not always show the same degree of pain, sweating, and reluctance to move, as is frequently seen in other forms of acute ER. Myoglobinuria can be observed in horses with only mild muscle stiffness. Between episodes, the heart rate, lactate, CK, and AST responses to exercise are normal. The basis for MFM in Arabian horses appears to be related to a need for enhanced cysteine synthesis, decreased cysteine-based antioxidants, and oxidative stress.[31]

3. Management of Chronic Exertional Muscle Disorders

Altering diet and exercise regimes to compensate for underlying defects is often the best available strategy to assist horses with exertional myopathies. Identifying and eliminating any known factors that trigger ER are also important in preventing further episodes. Controlled treatment trials have been performed to validate management strategies for RER and PSSM1.[26,32,33] Less evidenced-based information is available with regard to management of PSSM2 and MFM, and recommendations are based largely on retrospective studies or clinical impressions.[17,34]

4. Feeding Programs for Horses with Myopathies

A nutritionally balanced diet with appropriate caloric intake and adequate protein, vitamins, and minerals is a core element in treating all forms of exertional myopathies. As with all classes of horses, the development of a ration for these horses includes a series of steps.

1. **Determine daily nutrient requirements.** A horse's nutrient requirements depend on age, breed, body size, growth rate, level of exercise, and other considerations. The National Research Council last published its recommendations for horses in 2007.[35] National Research Council requirements are often considered minimums for many nutrients. Recommendations that are more commonly used in practice are also available in commercially available software[a,b].
2. **Select type and intake of forage.** Forage should be the foundation of every equine feeding program, so it is important to establish both the type and expected intake of forage before choosing concentrates or supplements.
3. **Select energy sources in concentrate.** One of the keys to managing exertional myopathies is controlling the source of energy in a ration. Energy requirements in the US are expressed in terms of megacalories (Mcal) of digestible energy (DE). DE can be supplied from nonstructural carbohydrates (NSCs), fat, structural carbohydrates (fiber), and protein. NSC is the sum of water-soluble carbohydrates (WSCs) (sugars) and starch. Most concentrates fed to ER horses are low in NSC and high in fat. Unfortunately, determining the NSC content of commercial concentrates is not easy since these nutrients rarely appear as guarantees on feed tags or bags. Although the American Association of Feed Control Officials currently suggests that commercial feed products that bear labeling claims related to carbohydrate content should include max sugar (ESC) and max starch in the guaranteed analysis, there is not an agreed-upon method for measuring ESC and starch. Therefore, many state regulatory agencies do not allow these nutrients to appear with other nutrient analyses such as protein, fat, or crude fiber. Feed manufacturers often supply this information in supporting literature or on the internet, but these figures are not regulated by any governmental agency. Most feed manufacturers use Equi-Analytical in Ithaca, NY[c] to determine WSC and starch values in feeds, and horse owners and veterinarians can also send feeds and forages to this lab for analysis.
4. **Calculate intake of concentrate to meet energy requirement.** The quantity of concentrate required by a horse equals the DE requirement of the horse minus the DE supplied by forage. The DE requirement is dependent upon the activity level and the current energy status of the horse. DE requirements will vary depending on whether the horse needs to lose, gain, or maintain its body weight.
5. **Calculate intake of other nutrients (protein, minerals, vitamins) provided from forage and concentrate.** Most commercial concentrates are formulated to meet nearly all of the protein, mineral, and vitamin requirements of the horse if fed at a typical level of intake as recommended on the feed bag. Often, a horse will be fed below this expected range of intake and additional fortification will be required. This is particularly true when horses are fed high-quality forage or if they need to lose weight.
6. **Supplement-required nutrients not provided by forage and concentrate.** Supplements are often necessary to provide nutrients not found in the forage and concentrate, either because of low concentrate intakes or to supply levels of nutrients that are greater than typically added to commercial feeds. Electrolytes, amino acids, vitamin E, and other antioxidants fall into this category for horses suffering from myopathies.

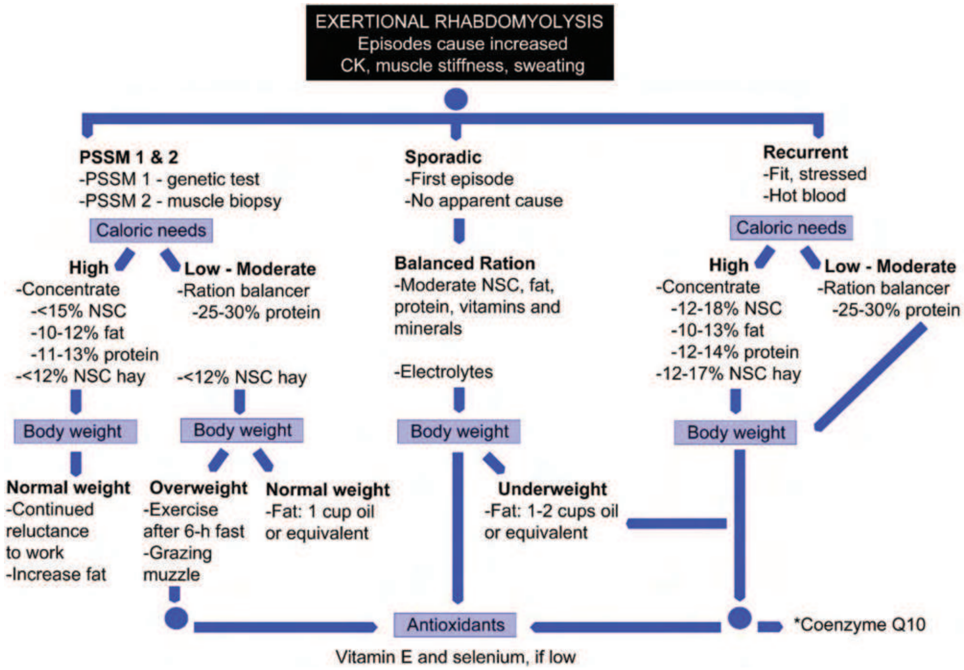

Fig. 1. An approach to managing horses with clinical signs of ER characterized by muscle stiffness, sweating, reluctance to move, and increased serum CK activity. Decisions should be based on the underlying myopathy, the horse's caloric needs, and current body weight.
*These are suggested recommendations based on current research in normal horses and anecdotal reports from the field and have not yet been tested on horses with this myopathy.

5. Exertional Rhabdomyolysis

A general approach to designing a ration for horses with primary clinical signs of ER is outlined in Fig. 1.

6. Sporadic ER

Nutrient Requirements

Total nutrient requirements will vary depending on the horse's size, breed, discipline, and level of activity. DE requirements will vary from near maintenance to twice maintenance.

Forage

Since low forage intake may contribute to sporadic bouts of ER, provide adequate quantities of high-quality forage. Performance horses will typically consume 1.5%–2% of body weight per day of hay. Good-quality grass or grass-legume mixed hays (55%–65% neutral detergent fiber [NDG], 10%–12% crude protein [CP], 10%–17% NSC) are preferable.

Energy Sources

A concentrate with moderate levels of soluble carbohydrate (20%–30% NSC), fat (4%–8%), and fiber (20%–30% NDF) is appropriate. Horses with sporadic ER do not necessarily benefit from increased dietary fat, so addition of fat should depend upon caloric needs.

Concentrate Intake

Concentrate intake will depend on the horse's DE requirement, and the quality and quantity of forage. If low concentrate (<3 kg/d) is required, supplemental protein, minerals, and vitamins may be required. This is best accomplished with appropriately fortified ration balancer pellets. Underweight horses may benefit from additional vegetable oil (120–240 mL) or stabilized rice bran (0.5–1 kg).

Supplements

Electrolyte imbalances and deficiencies are a common cause of sporadic ER. Horses should have free-choice access to a salt block and be supplemented with salt or a commercial electrolyte at levels to meet requirements. This can vary from 30 to 60 g/day with light sweating and up to 120–150 g/day with heavy sweating. Furosemide administration (5 cc) results in around 20 g of sodium and 35 g chloride loss in urine in the first 4 hours after administration.[36]

Selenium and vitamin E status should be evaluated. Low serum levels of either nutrient warrant supplementation. For horses with a neuromuscular disease, serum vitamin E levels should be checked periodically to ensure levels are > 3 μg/mL and supplemental vitamin E dosages adjusted accordingly. Large individual variation has been found in serum alpha tocopherol concentrations when horses are supplemented with 2000–5000 IU/day of vitamin E.[37] Natural-source vitamin E is more bioavailable than synthetic sources, and either micellized[d] or nanodispersed[e] sources rapidly restore serum status.[37,38]

7. RER

Nutrient Requirements

As with sporadic ER, RER nutrient requirements will vary depending on the horse's size, breed, discipline, and level of activity. DE requirements will vary from near maintenance to twice maintenance. RER occurs most frequently in Thoroughbred and Standardbred racehorses that have DE requirements of 30–35 Mcal DE/day.

Forage

Thoroughbred horses do not appear to show the same significant increase in serum insulin concentrations in response to consuming hay with an NSC of 17% as seen in Quarter Horses.[39] This fact combined with the high caloric requirements of racehorses suggests that it is not as important to select hay with very low NSC content in RER Thoroughbreds as it is in PSSM horses. Anecdotally, some trainers find horses with RER have more frequent episodes of ER on alfalfa hay, in which case it should be avoided on an individual basis. The nervous disposition of some RER horses may predispose them to gastric ulcers, and thus frequent provision of hay with a moderate NSC and mixed alfalfa content may be indicated.

Energy Sources

Substitution of fat for NSC in an energy-dense ration significantly reduces muscle damage in exercising RER horses. A controlled trial using a specialized feed[f] developed for RER showed that NSC should provide no greater than 20% and fat should provide between 20% and 25% of daily DE intake for optimal management of RER horses requiring high DE intakes (>30 Mcal DE/day).[32] The benefit of a high-fat diet for RER does not appear to be a change in muscle metabolism. Pre- and post-exercise muscle glycogen and lactate concentrations are the same in RER horses fed a low-starch, high-fat diet compared with a high-starch diet.[32,40] Rather, low-NSC, high-fat diets in RER horses may decrease muscle damage by assuaging anxiety and excitability, which are tightly linked to developing rhabdomyolysis in susceptible horses. High-fat, low-NSC diets fed to fit RER horses produce lower glucose, insulin, and cortisol responses and led to a calmer demeanor and lower pre-exercise heart rates.[41] Neurohormonal changes may develop in response to high serum glucose, insulin, and cortisol concentrations, resulting in an anxious demeanor.

Concentrates

Racehorses in full training typically consume 6–7 kg/day of concentrate. Racehorse concentrates for RER horses should contain 12%–18% NSC and 10%–13% fat. To maintain high energy densities (3.2–3.4 Mcal DE/kg), they should also contain sources of highly digestible fiber such as beet pulp or soy hulls. The beneficial effects of low-NSC, high-fat rations appear to be more directly related to the glycemic and insulinemic nature of the feeds rather than their absolute NSC and fat content. Therefore, the ingredients used in a concentrate also affect its suitably as an RER feed. WSCs produce higher glycemic responses than starch. Molasses is extremely glycemic in horses,[42] but added fat greatly reduces glycemic response, even in high-NSC feeds.[43,44] Glycemic response is also affected by rate of intake and rate of gastric emptying.[44,45]

While a calm demeanor is desired during training, some racehorse trainers feeding low-NSC, high-fat feeds prefer to supplement with a titrated amount of grain three days prior to a race to potentially boost liver glycogen and increase a horse's energy during the race.

As with sporadic ER, concentrate intakes <3 kg/day may not provide adequate amounts of protein, minerals, or vitamins and a balancer pellet may be required.

Studies in RER horses show that significant reductions or normalization of post-exercise serum CK activity occurs within a week of commencing a low-starch, high-fat diet.[32] Days of no training and standing in a stall are discouraged because post-exercise CK activity is higher after 2 days of rest compared with values taken when performing consecutive days of the same amount of submaximal exercise.[32]

8. PSSM1

Nutrient Requirements

Meeting the horse's caloric requirements for an ideal body weight is the most important consideration in designing a ration for PSSM, as many horses with PSSM are easy keepers and may be overweight at the time of diagnosis. Adding excessive calories in the form of fat to the diet of an obese horse may produce metabolic syndrome and is contraindicated. If necessary, caloric intake should be reduced by using a grazing muzzle during turnout, feeding hay with a much lower NSC content at 1%–1.5% of body weight, providing a low-calorie ration balancer, and gradually introducing daily exercise. Rather than provide dietary fat to an overweight horse, fasting for 6 hours before exercise can be used to elevate plasma free fatty acids prior to exercise and alleviate any restrictions in energy metabolism in muscle.

Forage

Quarter Horses develop a significant increase in serum insulin concentrations in response to consuming hay with an NSC of 17%, whereas insulin concentrations are fairly stable when fed hay with 12% or 4% NSC content.[33] Because insulin stimu-

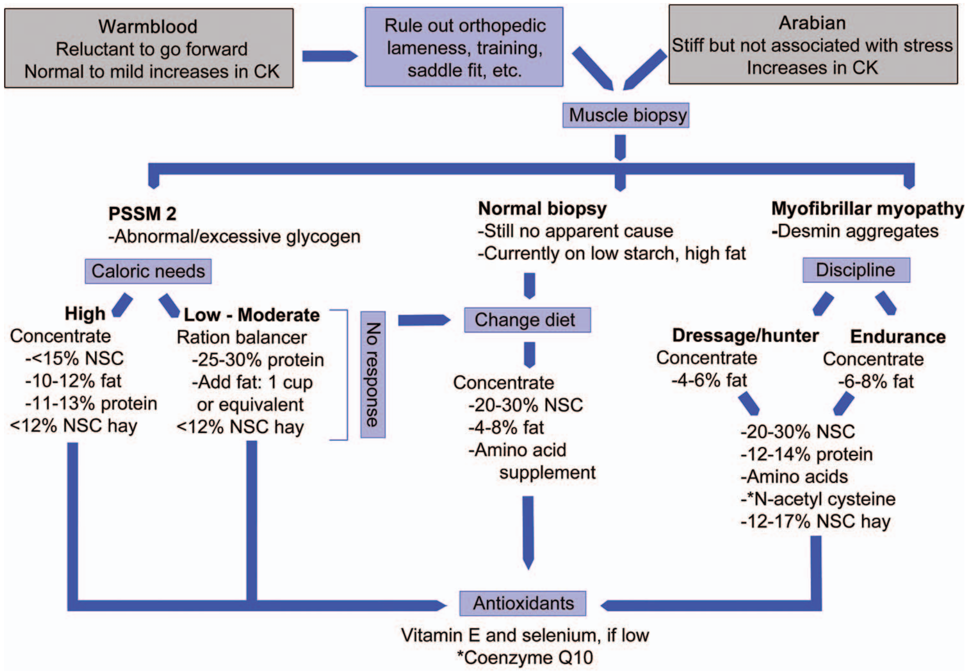

Fig. 2. An approach to managing horses with clinical signs of exertional myopathy characterized by exercise intolerance and normal to mildly increased serum CK activity. To conclude that a myopathy is responsible for exercise intolerance, other common causes should first be ruled out.
*These are suggested recommendations based on current research in normal horses and anecdotal reports from the field and have not yet been fully tested on horses with this myopathy.

lates the already overactive enzyme glycogen synthase in the muscle of PSSM1 horses, selecting hay with 12% or less NSC is advisable. The degree to which the NSC content of hay should be restricted below 12% NSC depends on the caloric requirements of the horse. Feeding a low-NSC (<5%), high-fiber (>65% NDF) hay provides room to add an adequate amount of fat to the diet of easy keepers without exceeding the daily caloric requirement and inducing excessive weight gain. For example, a 500-kg lightly exercised horse generally requires 18 Mcal DE/day. A mixed-grass hay (12% NSC, 55% NDF, 2.0 Mcal DE/kg) fed at 9 kg/day meets the horse's daily caloric requirement. In contrast, 8 kg of a 4% NSC hay (1.7 Mcal DE/kg) would provide 13.6 Mcal DE/day, which would allow a reasonable addition of 4.4 Mcal DE from fat per day (530 mL of vegetable oil).

Energy Sources

A high-NSC diet increases the propensity to develop muscle pain with aerobic exercise in PSSM1 horses.[26] A high-NSC diet results in enhanced glycogen synthase activity, which may impair oxidative metabolism of substrates such as pyruvate and fatty acids. PSSM horses on high-NSC diets have low plasma non-esterified free fatty acid concentrations, possibly due to suppression of lipolysis by high insulin.[26] Low dietary starch and fat supplementation facilitate muscle fat metabolism in PSSM1 horses.

Concentrates

Concentrates for PSSM1 horses should be low in NSC (<15%) and low glycemic. High fat (10%–12%) can be included in the concentrate but, if daily intake is low (<2 kg/d), then additional fat supplementation may be required from added vegetable oil (120–240 mL) or stabilized rice bran. Hydrated, rinsed beet pulp produces a very low glycemic response and can be used as a carrier for added vegetable oil.[42] One kilogram of beet pulp (prehydrated weight) and 1 cup (240 mL) of vegetable oil and 500 g of a balancer pellet (to meet protein, mineral, and vitamin requirements) would provide around 6.0 Mcal DE, which is equivalent to the DE supplied by 2 kg of a typical commercial concentrate.

Exertional Myopathies

A current approach to managing horses with exertional myopathies that are characterized by exercise intolerance and normal serum CK activity is outlined in Fig. 2. This approach is based on muscle biopsy diagnosis of PSSM2 or MFM and not based on a diagnosis using commercial genetic tests for PSSM2 or MFM that have not been scientifically validated through peer-reviewed publication.[30]

9. PSSM2 and Myofibrillar Myopathy

As mentioned above, PSSM2 appears to represent a histologic description of glycogen staining in muscle biopsy rather than one specific disease.[29] With a lack of information on the cause of PSSM2, the low-NSC, high-fat PSSM1 diet has been universally recommended for all horses diagnosed with PSSM regardless of whether PSSM1 or PSSM2.[46] Recommendations for feeding PSSM2, however, have now evolved according to breed based on recent research into muscle glycogen concentrations, histologic markers, and molecular approaches that better subclassify PSSM2.

Biochemical analysis of muscle biopsies indicates that Quarter Horses with PSSM2 have muscle glycogen concentrations that are as high as PSSM1 and that lack abnormal desmin staining characteristic of MFM (unpublished observation). Thus, the PSSM1 diet remains the appropriate recommended diet for Quarter Horses with PSSM2. An unpublished survey of horse owners indicates that episodes of ER significantly decrease with this dietary approach (personal observation).

Biochemical analysis of muscle biopsies in Arabians and Warmblood horses with PSSM2 has found that glycogen concentrations are similar to those of healthy, breed-matched controls.[28,29] Thus, the rationale for a low-NSC diet in these breeds appears lacking. Additionally, a subset of PSSM2 horses has been found to have a histologic marker (desmin aggregation) indicative of MFM, a muscle disorder characterized by weakness, atrophy, and myofibrillar disarray.[6] Based on this new finding and transcriptomic and proteomic analyses of muscle from horses with MFM, a new dietary approach has been developed for MFM horses.[31]

This new diet is informed by indictors that aberrations in cysteine-based antioxidants, oxidative stress, and the mitochondrial respiratory chain are key drivers of MFM.[31] An unanswered question is whether desmin aggregation is a late stage of PSSM2 in Arabians and Warmbloods and, if so, would Arabians and Warmbloods with PSSM2 that lack desmin aggregation benefit from the MFM diet outlined below. It seems sensible to assume that if PSSM2 horses have not responded satisfactorily to a low-NSC, high-fat diet, a trial period of 6–8 weeks on the MFM diet would be warranted (Fig. 2). Note that these recommendations are developed based on a muscle biopsy diagnosis of MFM, which does not appear to correspond with MFM diagnosis by commercial genetic tests.[30]

Because the caloric/nutrition needs and symptomology differ between MFM endurance Arabians capable of performing hours of aerobic exercise and MFM Warmbloods incapable of satisfactorily performing for 45 minutes, dietary approaches differ.

Nutrient Requirements

MFM involves muscle sarcomere breakdown and atrophy, so rations should focus on providing quality protein and specific amino acids to aid in sarcomere regenesis. Additionally, since oxidative stress is likely involved in the degenerative process, antioxidants or precursors of antioxidants are important to support the mitochondrial respiratory chain, the major source of reactive oxygen species in exercising muscle.

Forage

MFM horses will typically consume 1.5%–2% of body weight per day of hay. Good-quality grass or grass-legume mixed hays (55%–65% NDF, 10%–12% CP, 10%–17% NSC) are preferable.

Energy Sources

In the US the trend for feeding Warmbloods has been toward low-NSC, high-fat diets. This is not the case in Europe. Elite European sport horses consume feeds that are higher in NSC (25%–35%) and more moderate in fat (4%–6%).[47] There is no evidence that extremely low-NSC, high-fat diets are needed by Warmbloods with MFM. In addition, there does not appear to be a scientific reason why additional fat, a potential source of oxidative stress, would be of benefit to Warmbloods with MFM. Arabian endurance horses are typically fed higher fat diets, as Arabians depend more on fat oxidation than Thoroughbreds during exercise.[48] However, since MFM in Arabian endurance horses is related to oxidative stress resulting from fat oxidation, it is questionable whether these horses need extremely high levels of fat intake (>15% total DE intake).

Concentrates

Both Warmbloods and Arabian endurance horses in the US are typically fed fairly low levels of concentrate. In a survey of US endurance riders, concentrate intake averaged 2.27 kg/day.[49] The riders preferred lower protein concentrates (10% CP) and overall protein content of the diet averaged 10.2%, ranging from 6.2% to 15.7%. Endurance riders feed low-protein rations because they are concerned that high-protein diets may increase body heat, urine production, and water needs. While this level of protein intake may meet crude protein requirements in normal horses, it may be deficient in specific amino acids such as lysine, methionine, and threonine needed for muscle repair and generation of cysteine-based antioxidants. Leucine stimulates protein synthesis in the muscle post-exercise,[50] which would be beneficial to MFM horses. Therefore, concentrates for MFM horses should include higher levels of protein (12%–14% CP) containing high-quality amino acids and moderate levels of NSC (20%–30%) and fat (4%–8%).

Supplements

Amino acids

For horses with symmetrical topline muscle atrophy and horses with MFM, amino acid supplements are currently recommended.[6,51] Whey-based proteins are recommended because they are rich in cysteine. Cysteine is a key component of many antioxidants, and Arabian horses with MFM appear to have an increased cysteine requirement following exercise.[31]

Antioxidants

Horses with MFM have decreased expression of mitochondrial proteins and antioxidants in their muscle.[31] Coenzyme Q10 (CoQ10) is a key component of the first step in the mitochondrial electron transport chain. Arabian and Warmblood horses with MFM have decreased expression of proteins involved in this first step. When fed with amino acids, CoQ10[g] increases mitochondrial proteins when fed to healthy horses (Valberg unpublished). CoQ10 is used in human muscle disorders and is now being trialed as a supplement for MFM horses.

Acknowledgments

Declaration of Ethics

The Authors have adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

Dr. Pagan is the founder and owner of Kentucky Equine Research, which owns MicroSteed® Ration Evaluation Software, Nano-E®, Re-Leve® and Nano-Q10™. Dr. Valberg is one of the patent holders for the genetic test for type 1 polysaccharide storage myopathy and receives royalties from genetic testing and receives royalties from the sale of the equine feed Re-Leve®.

References and Footnotes

1. Valberg SJ, Cardinet GH, Carlson GP, et al. Polysaccharide storage myopathy associated with recurrent exertional rhabdomyolysis in horses. *Neuromuscul Disord* 1992;2:351–359.
2. McCue ME, Armien AG, Lucio M, et al. Comparative skeletal muscle histopathologic and ultrastructural features in two forms of polysaccharide storage myopathy in horses. *Vet Pathol* 2009;46:1281–1291.
3. Aleman M, Nieto JE, Magdesian KG. Malignant hyperthermia associated with ryanodine receptor 1 (C7360G) mutation in Quarter Horses. *J Vet Intern Med* 2009;23:329–334.
4. Valberg SJ, Mickelson JR, Gallant EM, et al. Exertional rhabdomyolysis in Quarter Horses and Thoroughbreds: One syndrome, multiple aetiologies. *Equine Vet J Suppl* 1999; 30:533–538.
5. Valberg SJ, McKenzie EC, Eyrich LV, et al. Suspected myofibrillar myopathy in Arabian horses with a history of exertional rhabdomyolysis. *Equine Vet J* 2016;48:548–556.
6. Valberg SJ, Nicholson AM, Lewis SS, et al. Clinical and histopathological features of myofibrillar myopathy in Warmblood horses. *Equine Vet J* 2017;49:739–745.
7. Harris P, Colles C. The use of creatinine clearance ratios in the prevention of equine rhabdomyolysis: A report of four cases. *Equine Vet J* 1988;20:459–463.
8. Harris PA. An outbreak of the equine rhabdomyolysis syndrome in a racing yard. *Vet Rec* 1990;127:468–470.
9. Aleman M, Riehl J, Aldridge BM, et al. Association of a mutation in the ryanodine receptor 1 gene with equine malignant hyperthermia. *Muscle Nerve* 2004;30:356–365.
10. McCue ME, Valberg SJ, Miller MB, et al. Glycogen synthase (GYS1) mutation causes a novel skeletal muscle glycogenosis. *Genomics* 2008;91:458–466.
11. Beech J, Lindborg S, Fletcher JE, et al. Caffeine contractures, twitch characteristics and the threshold for Ca(2+)-induced Ca2+ release in skeletal muscle from horses with chronic intermittent rhabdomyolysis. *Res Vet Sci* 1993;54: 110–117.
12. Beech J. Chronic exertional rhabdomyolysis. *Vet Clin North Am Equine Pract* 1997;13:145–168.
13. Lentz LR, Valberg SJ, Balog EM, et al. Abnormal regulation of muscle contraction in horses with recurrent exertional rhabdomyolysis. *Am J Vet Res* 1999;60:992–999.
14. MacLeay JM, Sorum SA, Valberg SJ, et al. Epidemiologic analysis of factors influencing exertional rhabdomyolysis in Thoroughbreds. *Am J Vet Res* 1999;60:1562–1566.
15. Valberg S, Jonsson L, Lindholm A, et al. Muscle histopathology and plasma aspartate aminotransferase, creatine kinase and myoglobin changes with exercise in horses with recurrent exertional rhabdomyolysis. *Equine Vet J* 1993;25: 11–16.
16. Lindholm A, Johansson HE, Kjaersgaard P. Acute rhabdomyolysis ("tying-up") in Standardbred horses. A morphological and biochemical study. *Acta Vet Scand* 1974;15:325–339.
17. Hunt LM, Valberg SJ, Steffenhagen K, et al. An epidemiological study of myopathies in Warmblood horses. *Equine Vet J* 2008;40:171–177.
18. Fraunfelder HC, Rossdale PD, Rickets SW. Changes in serum muscle enzyme levels in associated with training schedules and stages of oestrus cycle in Thoroughbred racehorses. *Equine Vet J* 1986;18:371–374.
19. Isgren CM, Upjohn MM, Fernandez-Fuente M, et al. Epidemiology of exertional rhabdomyolysis susceptibility in standardbred horses reveals associated risk factors and underlying enhanced performance. *PLoS One* 2010;5:e11594.
20. Upjohn MM, Archer RM, Christley RM, et al. Incidence and risk factors associated with exertional rhabdomyolysis syndrome in National Hunt racehorses in Great Britain. *Vet Rec* 2005;156:763–766.
21. MacLeay JM, Valberg SJ, Pagan JD, et al. Effect of ration and exercise on plasma creatine kinase activity and lactate concentration in Thoroughbred horses with recurrent exertional rhabdomyolysis. *Am J Vet Res* 2000;61:1390–1395.
22. Lentz LR, Valberg SJ, Herold LV, et al. Myoplasmic calcium regulation in myotubes from horses with recurrent exertional rhabdomyolysis. *Am J Vet Res* 2002;63:1724–1731.
23. Valberg SJ, MacLeay JM, Billstrom JA, et al. Skeletal muscle metabolic response to exercise in horses with 'tying-up' due to polysaccharide storage myopathy. *Equine Vet J* 1999; 31:43–47.
24. Valentine BA, Van Saun RJ, Thompson KN, et al. Role of dietary carbohydrate and fat in horses with equine polysaccharide storage myopathy. *J Am Vet Med Assoc* 2001;219: 1537–1544.
25. Valentine BA, McDonough SP, Chang YF, et al. Polysaccharide storage myopathy in Morgan, Arabian, and Standardbred related horses and Welsh-cross ponies. *Vet Pathol* 2000;37:193–196.
26. Ribeiro WP, Valberg SJ, Pagan JD, et al. The effect of varying dietary starch and fat content on serum creatine kinase activity and substrate availability in equine polysaccharide storage myopathy. *J Vet Intern Med* 2004;18:887–894.
27. McCue ME, Ribeiro WP, Valberg SJ. Prevalence of polysaccharide storage myopathy in horses with neuromuscular disorders. *Equine Vet J Suppl* 2006:340–344.
28. McKenzie EC, Eyrich LV, Payton ME, et al. Clinical, histopathological and metabolic responses following exercise in Arabian horses with a history of exertional rhabdomyolysis. *Vet J* 2016;216:196–201.
29. Lewis SS, Nicholson AM, Williams ZJ, et al. Clinical characteristics and muscle glycogen concentrations in warmblood

horses with polysaccharide storage myopathy. *Am J Vet Res* 2017;78:1305–1312.
30. Williams ZJV, Petersen, JL, Ochala J, et al. Candidate gene coding sequence variants, expression, and muscle fiber contractile force in Warmblood horses with myofibrillar myopathy. *Equine Vet J* (submitted).
31. Valberg SJ, Perumbakkam S, McKenzie EC, et al. Proteome and transcriptome profiling of equine myofibrillar myopathy identifies diminished peroxiredoxin 6 and altered cysteine metabolic pathways. *Physiol Genomics* 2018;50:1036–1050.
32. McKenzie EC, Valberg SJ, Godden SM, et al. Effect of dietary starch, fat, and bicarbonate content on exercise responses and serum creatine kinase activity in equine recurrent exertional rhabdomyolysis. *J Vet Intern Med* 2003;17:693–701.
33. Borgia L, Valberg S, McCue M, et al. Glycaemic and insulinaemic responses to feeding hay with different non-structural carbohydrate content in control and polysaccharide storage myopathy-affected horses. *J Anim Physiol Anim Nutr (Berl)* 2011;95:798–807.
34. Williams ZJ, Bertels M, Valberg SJ. Muscle glycogen concentrations and response to diet and exercise regimes in Warmblood horses with type 2 polysaccharide storage myopathy. *PLoS One* 2018;13:e0203467.
35. Nutrient requirements of horses. In: National Research Council of the Academies. Washington, DC: The National Academies Press; 2007:114–117.
36. Pagan JD, Waldridge B, Whitehouse C, et al. Furosemide administration affects mineral excretion and balance in non-exercised and exercised Thoroughbreds. *J Equine Vet Sci* 2013;329.
37. Brown JC, Valberg SJ, Hogg M, et al. Effects of feeding two RRR-alpha-tocopherol formulations on serum, cerebrospinal fluid and muscle alpha-tocopherol concentrations in horses with subclinical vitamin E deficiency. *Equine Vet J* 2017;49: 753–758.
38. Pagan JD, Perry L, Wood L, et al. Form of α-tocopherol affects vitamin E bioavailability in Thoroughbred horses, in 1st Nordic Feed Science Conference, Uppsala, Sweden 2010; 112–113.
39. Borgia LA. Resistance training and the effects of feeding carbohydrates and oils on healthy horses and horses with polysaccharide storage myopathy. In: College of Veterinary Medicine. Pro Quest, Ann Arbor MI: University of Minnesota; 2010.
40. MacLeay JM, Valberg SJ, Pagan JD, et al. Effect of diet on Thoroughbred horses with recurrent exertional rhabdomyolysis performing a standardised exercise test. *Equine Vet J Suppl* 1999:458–462.
41. Finno CJ, McKenzie E, Valberg SJ, et al. Effect of fitness on glucose, insulin and cortisol responses to diets varying in starch and fat content in Thoroughbred horses with recurrent exertional rhabdomyolysis. *Equine Vet J Suppl* 2010:323–328.
42. Groff LP, Pagan JD, Hoekstra, K, et al. Effect of preparation method on the glycemic response to ingestion of beet pulp in Thoroughbred horses, in *Proceedings*. Equine Nutr Physiol Soc Symp 2001;125–126.
43. Pagan JD, Rotmensen T, Jackson, SG. Responses of blood glucose, lactate and insulin in horses fed equal amounts of grain with or without added soybean oil. In: Pagan JD, ed. *Advances in equine nutrition.* Nottingham, UK: Nottingham University Press; 1998:93–96.
44. Geor RJ, Harris, PA, Hoekstra, et al. Effect of corn oil on solid-phase gastric emptying in horses, in *Proceedings*. Forum Am Coll Vet Intern Med 2001;853.
45. Vervuert IC, M. Factors affecting glycaemic index of feeds for horses, in *Proceedings*. Eur Equine Nutr Health Congress; 2006.
46. Valberg SJ, Geor R, Pagan JD. Muscle disorders: Untying the knots through nutrition. In: Pagan JD, ed. *Advances in equine nutrition III.* Nottingham, UK: Nottingham University Press; 2005:473–483.
47. Pagan JD, Phethean E, Whitehouse C, et al. A comparison of the nutrient composition of European feeds used at the 2010 and 2018 FEI World Equestrian Games. *J Equine Vet Sci* 2019;103.
48. Prince A, Geor RJ, Harris PA, et al. Comparison of the metabolic responses of trained Arabians and Thoroughbreds during high- and low-intensity exercise. *Equine Vet J* 2010; 34:95–99.
49. Crandell, KM. Trends in feeding the American endurance horse. In: Pagan JD, ed. *Advances in equine nutrition III.* Nottingham, UK: Nottingham University Press; 2005:181–184.
50. Zhang S, Zeng X, Ren M, et al. Novel metabolic and physiological functions of branched chain amino acids: A review. *J Anim Sci Biotechnol* 2017;8:10.
51. Graham-Thiers PM, Kronfeld DS. Amino acid supplementation improves muscle mass in aged and young horses. *J Anim Sci* 2005;83:2783–2788.

[a]MicroSteed® Ration Evaluation Software, Kentucky Equine Research, Versailles, KY 40383.
[b]Feed XL Nutrition Software, available at feedxl.com.
[c]Equi-Analytical, Ithaca, NY 14850.
[d]Elevate® WS, Kentucky Performance Products, Versailles, KY 40383.
[e]Nano-E®, Kentucky Equine Research, Versailles, KY 40383.
[f]Re-Leve®, Kentucky Equine Research, Versailles, KY 40383.
[g]Nano-Q10™, Kentucky Equine Research, Versailles, KY 40383.

Dietary Support of the Immune System in the Performance Horse

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1. Introduction

Exercise is widely recognized as a stressor, causing neuroendocrine and hormonal changes that impact immune response.[1] While moderate intensity exercise performed regularly can benefit host defense mechanisms, acute bouts of high-intensity exercise or prolonged strenuous activity can result in immunosuppression, primarily of the innate immune system.[2] Not surprisingly, exercise training has been associated with increased susceptibility to viral infection.[3] Heavily campaigned performance horses are also confronted with environmental stressors (e.g., frequent transport over long distances, concentrated stabling at show and racetrack facilities) that further elevate exposure to airborne pathogens and increase disease risk.[4]

Nutrition plays a supportive role in immunity and host defense.[5,6] Various amino acids (e.g., glutamine, arginine, methionine, cysteine) and minerals (e.g., zinc and selenium [Se]) are critical to the formation, proliferation, and functional activity of immune cells and other components of the immune system. Vitamins A, D, E, and C are also important to immune cell function, as well as mitigation of reactive oxygen species generated by highly metabolic immune cells participating in host defense. Polyunsaturated fatty acids, acting via their conversion to eicosanoids, are responsible for directing many activities associated with inflammation and immune response. Even dietary fiber, a heterogenous group of oligo- and polysaccharides, supports and directs immune cell activities locally within the gastrointestinal tract and systemically. Deficiencies or imbalances of these nutrients generally result in compromised immune function and decreased disease resistance. Therefore, a balanced diet is critical to maintain immuno-surveillance and to mount an appropriate immune response to infection or trauma. Additionally, some nutrients possess immuno-stimulatory or modulatory effects when supplemented to the diet above established requirements.

Can the horse's immune system be improved through his feed bucket? Possibly. The field of nutritional immunology, where interactions between diet and immune function are investigated, is a relatively young science, with concentrated research efforts occurring mostly in the last 30 years. Comparatively, the application of immuno-nutrition to the feeding of horses is only in its infancy. While we are not yet in a position to provide proscriptive diets that will enhance immunity of disease-susceptible horses, there is some evidence for specific nutrients that may someday prove useful for improving host defense. This paper highlights re-

NOTES

search on nutrients that have been fed to the horse with the specific intent to modulate immune function, including the need to meet key vitamin and mineral requirements, the use of omega-3 fatty acids to modulate inflammation, and prebiotics and other functional fibers to maintain gut health.

2. Meet the Horse's Vitamin and Mineral Requirements

Several vitamins and minerals support the immune system, either through their role as antioxidants (e.g., vitamins E and C and Se) or by contributing to the body's natural defenses by strengthening epithelial barriers, cell-mediated immunity, and/or antibody production (e.g., vitamins D, E, C and A, and Se and zinc).[6] Diets deficient in these micronutrients result in impaired immune function and increased susceptibility to infection, which in some cases has been used as a metric for determining daily requirements.[7] Therefore, ensuring that the horse's diet contains adequate levels of vitamins and minerals is key to maintaining host defense. Research in humans and animals has shown that some micronutrients also have immuno-modulatory effects when supplemented above requirements,[5] but strong evidence to support this in horses is unavailable.

Vitamin E works in concert with vitamin C, Se, and glutathione to protect oxidation of cell membrane lipids. Reactive oxygen species are generated during exercise with heightened muscle metabolism and are also produced by highly metabolic immune cells, including superoxide radicals and hydrogen peroxide produced by phagocytes as part of the oxidative burst. Although the formation of reactive oxygen species can serve an essential purpose (e.g., killing of pathogens, attracting immune cells to the site of infection or trauma), they can also damage membrane lipids, proteins, and DNA if left unchecked, which can alter cell viability and impair immune response.

Vitamin E is the most widely studied vitamin in equine nutrition, with most research focusing on its ability to mitigate oxidative stress in exercising horses. Natural sources of vitamin E (RRR-α-tocopherol) have shown an advantage over synthetic forms (e.g., all rac-α-tocopherol acetate) for raising circulating vitamin E levels and reducing oxidative response in horses in training.[8,9] However, there is scant evidence that feeding vitamin E above current requirements (1.8 to 2 IU/kg body weight [BW] for moderate to heavy work) will improve antioxidant defenses in otherwise-healthy horses.[7] In horses with neurological disease[10] or myopathies,[11] higher rates of vitamin E supplementation are warranted. However, practitioners are cautioned against excessive vitamin E supplementation ($>$10$\times$ National Research Council [NRC] requirements, or 20 IU/kg BW in exercising horses), as there has been speculation that it may interfere with the absorption of other fat-soluble vitamins.[12]

Outside of its function as an antioxidant, investigations into the immunomodulatory role of vitamin E are limited in the horse. Most studies utilized non-exercising populations and compared immune responses in horses fed vitamin E above established requirements to those receiving vitamin E–deficient diets. For example, higher antibody titers to tetanus and influenza virus vaccination were observed in horses fed 78 IU vitamin E/kg dry matter (1.5$\times$ NRC requirement), either alone or with added Se compared with an unsupplemented diet deficient in both vitamin E (18 IU/kg dry matter) and Se (0.03 mg/kg dry matter).[13] Older horses supplemented with 7500 IU all-rac-α-tocopherol (resulting in a total vitamin E intake estimated at 7750 IU/day, 15$\times$ NRC requirement) exhibited greater neutrophil and monocyte bacterial-killing capacity and greater antibody response to an annual booster vaccination program compared with those fed a vitamin E–deficient diet (250 IU/day, about half the NRC requirement).[14] Bondo and Jensen[15] reported higher immunoglobulin (Ig) IgG and IgM in mare milk and higher IgM in serum of neonatal foals when mares were supplemented with 2500 IU RRR-α-tocopherol (along with basal diet, about 4 to 5$\times$ NRC requirements for gestating mares) compared with an unsupplemented diet that was deficient in vitamin E (170 to 320 IU). The three studies discussed above highlight the importance of vitamin E to immune function in horses; however, because supplemented horses were compared with those fed diets deficient in vitamin E, they do not provide clear evidence that vitamin E has immunomodulatory effects when fed above requirements. More research in this area is needed before appropriate recommendations can be given.

The trace mineral, Se, is also important to a properly functioning immune system, in part because of its role as an antioxidant. The current NRC[7] requirement for Se in performance horses is 0.1 mg/kg dry matter intake, or 1 to 1.25 mg/day for an average 500-kg horse. Several studies in horses have highlighted detriments to both innate and acquired immunity in horses with low (depleted) Se status and/or when minimum Se requirements are not met by the diet.[16–19]

Recent studies have also evaluated whether feeding Se above the current NRC requirement can further improve immune response. Brummer et al[19] performed a detailed immunological analysis on sedentary horses receiving a Se-adequate diet (0.12 mg/kg dry matter) or diets containing 3$\times$ the NRC requirement (0.3 mg/kg dry matter, with additional Se provided as either sodium selenite or Se yeast) for 29 weeks. *In vivo* and *ex vivo* responses to a novel vaccine (ovalbumin) and a vaccine horses had previously been exposed to (equine influenza) were not affected by level or source of Se intake. Lymphocyte proliferation and gene expression of cytokines in response to non-specific mitogen stimulation also did not differ between those fed Se at or above the current NRC requirements nor by dietary Se source. Oxidative and inflammatory responses were also evaluated in this same group of unfit horses in response to a mild bout of exercise (4.4 km walk/trot).[20] Although there was a transient elevation of whole blood glutathione peroxidase after exercise in horses receiving 0.3 mg/kg dry matter as Se-yeast, measures of oxidative stress and pro-inflammatory cytokine expression were unaffected by Se source or feeding rate. In another study, horses unaccustomed to exercise were subjected to a 2-hour (26-km) submaximal exercise bout after 5 weeks of Se intakes of either 0.1 or 0.3 mg/kg dry matter (additional Se was supplied as sodium selenite).[21,22] Higher Se intake resulted in increased glutathione peroxidase activity and less lipid peroxidation following exercise but did not alter other measures of antioxidant status or reduce muscle damage.[21] Diets containing 0.3 mg Se/kg dry matter also resulted in less post-exercise leukocytosis and greater lymphocyte viability after *ex vivo* exposure to hydrogen peroxide than diets containing 0.1 mg Se/kg dry matter.[22] The exercise bout was stressful enough to suppress lymphocyte proliferation and alter lymphocyte mRNA cytokine expression; however, this was not attenuated with Se intake above the NRC requirement. Collectively, these studies show that feeding Se above established requirements is not likely to greatly enhance antioxidant status or improve immunocompetence when vitamin E requirements are also concurrently being met.

Vitamin C is a part of the water-soluble antioxidant system where it traps peroxyl radicals and regenerates other antioxidants, including vitamin E. Healthy horses can synthesize vitamin C (ascorbic acid) from glucose in the liver; thus, no requirement has been established.[7] It is presumed endogenous synthesis of vitamin C is sufficient to meet the needs of healthy horses; however, strenuous exercise and respiratory disease, such as airway inflammation has been shown to reduce circulating ascorbic acid concentrations,[23,24] suggesting some groups may benefit from vitamin C supplementation.

Despite the popularity of supplementing performance horses with vitamin C, research has not demonstrated a clear benefit in reducing oxidative stress.[25–27] Based on current research, it is difficult to tease out the contribution of vitamin C to antioxidant defense because it has typically been supplemented as part of a mixture of antioxidants.

Similarly, investigations on other immune-related outcomes in response to vitamin C are limited to its supplementation as part of an antioxidant mixture. Ralston[28] supplemented a small group of weanling horses with a mixture of vitamins E (800 IU) and C (5 g) or placebo beginning 5 days after the animals had been transported over long distance (2400 miles, 38 hours). Adequate responses to a routine 5-way booster vaccination were noted in 4/5 vitamin-supplemented weanlings and only 1/5 placebo weanlings. Within the 5-week period following transportation, 4/5 placebo weanlings showed signs of illness (nasal discharge, cough, fever) meriting antibiotic treatment. The number of vitamin-supplemented weanlings that developed illness was not reported. Supplementation with a combination of vitamin E (2500 to 3000 IU), an ascorbic acid derivative (5 g), and Se (1 to 2.5 mg) did not improve neutrophil count in bronchoalveolar lavage fluid nor lung function in heaves-affected horses in clinical remission.[29,30] However, one of these studies[30] did observe greater exercise tolerance and lower scores for airway inflammation assessed by endoscopy in asthma-affected horses receiving the supplement compared with placebo. Nogradi et al[31] observed a reduction in bronchoalveolar lavage neutrophils and significant improvements in respiratory performance in a small number of asthma-affected horses receiving an oral supplement containing small quantities of docosahexaenoic acid (DHA; 1.5 to 3 g), vitamin C (2 to 4 g), methylsulfonylmethane (MSM), and "mushroom complex." Differences in outcomes between these studies might relate to whether the horses were in remission[29,30] or had active airway inflammation.[31] Taken together, the findings from these studies suggest that a mixture of antioxidants may be useful for modulating immune responses in stressed horses; however, the specific role of vitamin C alone on immune function in horses remains unclear. Toxicity from excess ascorbic acid has not been reported in horses; no side effects were reported in horses supplemented with 20 mg/kg BW (10 g/day for a 500-kg horse) for 8 months.[32] In other species, high oral doses can reduce the body's own synthesis of vitamin C, so abrupt cessation of ascorbic acid supplementation should be avoided.

3. Immunomodulation with Omega-3 Fatty Acids

In addition to serving as a calorie source, some dietary fats play an immunomodulatory role in the body. More specifically, fatty acids belonging to the omega-3 and omega-6 families are part of the inflammatory cascade and exert direct effects on immune cells.[33,34]

Similar to all mammals, horses require a dietary source of the omega-6 fatty acid, linoleic acid (LA; 18:2n-6) and the omega-3 fatty acid α-linolenic acid (ALA; 18:3n-3) because they lack the enzymes to synthesize them. LA and ALA can be oxidized for energy or incorporated into cell membranes where they contribute to membrane fluidity, but otherwise have very few direct biological effects. Rather, the dietary essentiality of LA and ALA is based on their role as precursors for the biosynthesis of longer-chain omega-6 and omega-3 fatty acids that help regulate many biological processes in the body. ALA is the "parent" omega-3 fatty acid and can be elongated and desaturated by the horse to form eicosapentaenoic acid (EPA; 20:5n-3) and DHA (22:6n-3). In the omega-6 family, LA competes for the same elongase and desaturase enzymes to form arachidonic acid (ARA; 20:4n-6). These long-chain polyunsaturated fatty acids are known to have significant effects on inflammation and immune responses, attributed in part to their ability to give rise to various eicosanoids (prostaglandins, prostacyclins, leukotrienes, and thromboxanes) and other potent biological mediators (isoprostanes, neuroprostanes, lipoxins, resolvins, and protectins). ARA, EPA, and DHA can also alter cell receptor signaling, gene expression, and protein synthesis, ultimately impacting the biological response to trauma and infection. Both omega-6 and omega-3 fatty acids contribute to normal inflammatory and immune responses, but the relative abundance of omega-6 versus omega-3 fatty acids in cell membranes can sway the final outcome. In simplistic terms, eicosanoids derived from ARA stimulate stronger pro-inflammatory responses, whereas those originating from EPA produce weaker inflammatory reactions. It must be emphasized, however, that it is really the balance of the different eicosanoids and mediators produced that generates the final biological response.

Research on omega-3 fatty acid supplementation in humans and other species has demonstrated a reduction in inflammation and positive impacts on innate and acquired immunity through modification of the expression of key cell surface proteins and modulation of the production of reactive oxygen species, eicosanoids, and cytokines.[33,34] By comparison, research in horses has revealed variable outcomes with either ALA (via flaxseed or flax/linseed oil) or EPA and DHA (via fish oil, marine algae, or seal blubber) addition to the diet. In some studies ARA-derived eicosanoids and pro-inflammatory cytokine production from *ex vivo* stimulated equine immune cells have been reduced,[35–39] whereas other studies have observed no effect of omega-3 fatty acid supplementation on inflammatory mediators.[36,37,40] Use of an intradermal injection of phytohemagglutanin A to evaluate a coordinated inflammatory response *in vivo* revealed an earlier response in yearling horses supplemented with either flaxseed or fish oil compared with nonsupplemented controls.[40] Linseed oil supplementation also failed to improve markers of inflammation and clinical response to endotoxin administration *in vivo*.[41] Function of immune cells has also been variable in response to omega-3 fatty acid enriched diets. Although often shown to be suppressed by omega-3 fatty acid intake in humans,[34] *ex vivo* mitogen-stimulated lymphocyte proliferation and the ability of neutrophils to phagocytize and oxidize bacteria were not affected in horses supplemented with flax or fish oil.[39,40,42] One study even reported an increase in lymphocyte proliferation in neonatal foals born to mares supplemented with linseed oil.[43] Conflicting observations have also been made on the impact of omega-3 fatty acid supplementation on acquired immunity in horses. Omega-3 fatty acid supplementation has been shown to increase[39] or have no impact[36,42] on antibody production in response to antigen or vaccination administration. Interestingly, the higher antibody response to tetanus vaccination in yearlings fed fish oil was similarly elevated in yearlings supplemented with corn oil (rich in omega-6) compared with non-supplemented controls.[39]

Owners and trainers have interest in feeding omega-3 fatty acids to horses with (or to prevent) osteoarthritis and other inflammatory disorders; but again, strong research support for this application is lacking. Lesion size in *Culicoides* hypersensitive horses showed a trend to be reduced when fed linseed oil compared with corn oil[44] and with flaxseed compared with bran supplementation.[45] Supplementation with EPA and DHA has shown variable effects on systemic or synovial inflammatory markers in healthy sedentary or exercised horses,[46–50] but did show a trend to reduce markers of joint inflammation in response to experimentally-induced synovitis.[51] In the only study conducted in arthritic horses, supplementation with EPA and DHA for 90 days resulted in fewer white blood cells and a trend for reduced inflammatory markers in synovial fluid, but no improvement in lameness.[52] In a small number of horses with recurrent airway obstruction (asthma), supplementation with seal blubber oil (a source of long-chain omega-3 fatty acids) did not improve pulmonary function or clinical signs over that seen with sunflower oil (a source of omega-6 fatty acids).[53] In contrast, a reduction in neutrophils recovered in bronchoalveolar lavage, 60% improvement in cough score, and 48% reduction in respiratory effort was reported in 4 horses with inflammatory airway disease after treatment with an oral supplement containing small quantities of DHA (1.5 to 3 g), along with vitamin C (2 to 4 g), MSM, and "mushroom complex."[31] The American College of Veterinary Internal Medicine has since recommended omega-3 fatty acids (1.5 g DHA/day or 3 mg/kg BW) for the treatment of inflammatory airway disease.[54] It is worth noting, however, that this level of omega-3 fatty acid supplementation is substantially lower than the daily intakes (50 to 75 mg total omega-3 per kg BW) shown to confer anti-inflammatory or immuno-modulatory benefits in many of the equine research trials described above.

Although the dose of omega-3 fatty acids may be responsible for some of the disparities between studies, the differing outcomes are likely heavily influenced by the horse's health status, the omega-3 source, and basal diet. Based on work in horses and other species, individuals are most likely to respond to omega-3 fatty acid supplementation when they are suffering from chronic inflammation, and when supplemented with the longer-chain omega-3 fatty acids EPA and DHA (from fish oil or marine algae) compared with ALA (from flax). Further, unlike a traditional Western diet for humans, it must be recognized that the horse already consumes a diet naturally high in omega-3 fatty acids. Forages, although low in total fat (2% to 3%), contain a significant portion of that fat (39% to 56%) as the omega-3 fatty acid, ALA.[55,56] In healthy horses, omega-3 intake from fresh grass or hay may be sufficient to offset the higher omega-6 fatty acid content from cereal grains, soybean meal, rice bran, and common vegetable oils included in today's equine rations. In fact, even accounting for the lower availability of fat from forages, most equine rations will still possess a better ratio of omega-6 to omega-3 than the ideal 5:1 to 10:1 recommended for humans.[57]

Collectively, research findings in horses suggest that omega-3 fatty acids can modulate immune response, particularly that of inflammation, but more research is needed to verify the practical value of using omega-3 fatty acids to attenuate inflammation and pain in horses with chronic inflammatory diseases (e.g., osteoarthritis, asthma). Future research should also examine the benefits of omega-3 fatty acid supplementation during periods of physiological stress (e.g., transport, exercise, weaning), immuno-insufficiency (e.g., neonatal foals, senior horses), as well as other pro-inflammatory states (e.g., equine metabolic syndrome, pituitary pars intermedia dysfunction). Additionally, more research is needed to determine the appropriate amount of omega-3 fatty acids needed to influence immunity, as well as the potential importance of omega-6 to omega-3 fatty acid ratio in equine diets. Lastly, it is worth noting that omega-6 fatty acids are not the "bad guy" of equine nutrition, and in some cases (as highlighted above), LA has even been shown to promote positive immune responses in horses. Claims that excess omega-6 intake promotes inflammation remains an active area of debate in humans,[58] as well as horses.

4. Use of Prebiotic and Functional Fibers to Maintain Gut Health

Over 70% of the immune system is associated with the gastrointestinal tract. In fact, the gut serves as one of the most important first lines of defense against infection by pathogens. Therefore, it comes as no surprise that some components of the diet can influence immunity by affecting the microbial ecology of the gut and/or interacting with the gut-associated mucosal immune system.[59]

Some types of dietary fiber (carbohydrates that cannot be digested by the horse's own enzymes) have been shown to positively affect health by 1) supporting the colonization of beneficial commensal bacteria in the gut (which are themselves an important barrier to pathogens); 2) supporting gut epithelial tissue through the production of short-chain fatty acids such as butyrate; 3) binding to pathogens, thus blocking them from attaching to the intestine; and 4) interacting directly and indirectly with immune cells associated with the gut mucosa to modulate the immune system (both locally in the gut, and systemically throughout the body).[59] These unique fibers are generally referred to as prebiotics. Although not all prebiotics are fibers, most are oligosaccharides (fibers consisting of 2 to 20 sugar units), including fructooligosaccharides (FOS), galactooligosaccharides (GOS), and xylooligosaccharides. Additional fibers that are thought to have prebiotic-like effects include mannanoligosaccharides (MOS), beta-glucans, and pectin. These fibers are abundant in mare colostrum and milk.[60] They can also be found in the cell walls of yeast, some cereal grains (e.g., oats, barley, wheat), and forages, though often in the form of longer-chain polysaccharides. Enzymatic feed technologies have been used to create oligosaccharides from raw feedstocks and fiber-rich coproducts for use in animal diets. Additionally, microbial fermentation of hemicellulose and other fibers in the gastrointestinal tract can liberate shorter-chain mannan and arabinoxylan oligosaccharides that subsequently exert immunomodulatory effects, in addition to generating short-chain (volatile) fatty acids as an energy source for the animal.[61]

Early work on prebiotic supplementation in horses focused on changes on gut microbial populations and improvements in digestion. More recently, investigations have explored the impact of prebiotics and prebiotic-like fibers on immune function. Shifts in cytokine production by cells, as well as increased immune cell viability were observed by Vendrig et al.[62] in an *in vitro* model of inflammation where immune cells isolated from horses were incubated with GOS, GOS+FOS, or GOS+FOS+acidic-oligosaccharides and then stimulated with bacterial lipopolysaccharide. Work in broodmares has shown higher IgA concentrations in colostrum and foal serum when mares were supplemented with MOS isolated from yeast[63] and whole-cell killed yeast containing MOS and beta-glucans.[64] Additionally, whole-cell killed yeast–supplemented mares and their foals had lower fecal IgA and IgG, suggesting a downregulation or quieting of the inflammatory gut immune response.[64] Although not fed in the diet, broodmares receiving weekly intramuscular injections of a yeast-derived beta-glucan in late gestation had higher IgG, IgG(T), and IgM in colostrum and their foals had higher IgG(T) in serum and improved neutrophil function.[65] In contrast, oral consumption of beta-glucan (170 mg/kg BW) supplied to mature, sedentary horses in the form of a high beta-glucan oat variety or a concentrated oat beta-glucan powder did not mitigate changes in leukocyte populations or alter lymphocyte or neutrophil function, nor mucosal IgA in response to a 12-hour head-elevation challenge.[66] Older horses receiving a proprietary yeast-derived prebiotic were reported to have lower tumor necrosis factor alpha and interferon gamma (in serum, and gene expression by lymphocytes stimulated *ex vivo*) compared with unsupplemented controls.[67] A follow-up study utilizing the same prebiotic showed an increased response to influenza vaccination in aged horses.[68] These findings show potential for prebiotics to counteract age-associated inflammation and immunosenescence in older horses.

Collectively, prebiotics have demonstrated some promise in horses that may have compromised or insufficient immunity; however, additional investigation is needed to ascertain which prebiotics are effective and in which scenarios their use is most appropriate. In the meantime, emphasizing a fiber-based diet (e.g., high quality forages, beet pulp, soybean hulls) should contribute to a healthier gastrointestinal tract.

5. Conclusions

The application of immuno-nutrition to the horse is a relatively new area of study. As horse owners seek complementary and holistic methods to maintain the health of their horses, interest in nutrients that positively impact the immune system is gaining momentum. All nutrients are important for supporting host defense; thus, it is important to ensure minimum nutrient requirements are being met. For most healthy performance horses, this means selecting high-quality forages and appropriately formulated concentrates. Some nutrients (e.g., omega-3 fatty acids, vitamin C) have also demonstrated their ability to modify immune function in some populations when fed above requirements. Supplementing the diets of healthy horses with these immunomodulating nutrients is not likely to be of benefit—their immune system is already functioning well and cannot be further "improved." However, in horses with compromised immunity (e.g., strenuous training/competition, foals, weaning, senior horses, osteoarthritis, asthma, and endocrine disorders), supplementation of the diet with immunomodulating nutrients may help mitigate or reverse perturbations of the immune system. There is still much to learn on this topic in horses, including a greater understanding of synergistic (or antagonistic) effects between nutrients.

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Declaration of Ethics

The Author has adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Author has no conflicts of interest.

References

1. Peak JM, Neubauer O, Walsh NP, et al. Recovery of the immune system after exercise. *J Appl Physiol* 2017;122: 1077–1087.
2. Raidal SL, Love DN, Bailey GD, et al. Effect of single bouts of moderate and high intensity exercise and training on equine peripheral blood neutrophil function. *Res Vet Sci* 2000;68:141–146.
3. Folsom RW, Littlefield-Chabaud MA, French DD, et al. Exercise alters the immune response to equine influenza virus and increases susceptibility to infection. *Equine Vet J* 2001;33:664–669.
4. Art T, Lekeux P. Exercise-induced physiological adjustments to stressful conditions in sport horses. *Livestock Prod Sci* 2005;92:101–111.
5. Calder PC, Field CJ, Gill HS. *Nutrition and immune function*. New York, NY: CABI Publishing; 2002.
6. Klasing KC. Nutrition and the immune system. *Br Poultry Sci* 2007;48:525–537.
7. NRC. *Nutrient requirements of horses*. 6th rev ed. Washington, DC: National Academies Press; 2007.
8. Duberstein KJ, Pazdro R, Lee KC, et al. Effect of supplemental vitamin E form on serum α-tocopherol levels and blood oxidative stress parameters in response to a novel exercise challenge. *J Equine Vet Sci* 2017;57:61–66.
9. Fagan MM, Harris P, Adams A, et al. Form of vitamin E supplementation affects oxidative and inflammatory response in exercising horses. *J Equine Vet Sci* 2020;91:103103.
10. Finno CJ, Valberg SJ. A comparative review of vitamin E and associated equine disorders. *J Vet Intern Med* 2012;26: 1251–1266.
11. Valberg SJ. Muscle conditions affecting sport horses. *Vet Clin Equine* 2018;34:253–276.
12. Williams CA, Carlucci S. Oral vitamin E supplementation and oxidative stress, vitamin and oxidant status in intensely exercising horses. *Equine Vet J* 2006;36(Suppl):617–621.
13. Baalsrud KJ, Øvernes G. The influence of vitamin E and selenium supplements on antibody production in horses. *Equine Vet J* 1986;18:472–474.
14. Petersson KH, Burr DB, Gomez-Chiarri M, et al. The influence of vitamin E on immune function and response to vaccination in older horses. *J Anim Sci* 2010;88:2950–2958.
15. Bondo T, Jensen SK. Administration of RRR-α-tocopherol to pregnant mares stimulates maternal IgG and IgM production in colostrum and enhances vitamin E and IgM status in foals. *J Anim Physiol Anim Nutr* 2011;95:214–222.
16. Knight DA, Tyznik WJ. The effect of dietary selenium on humoral immunocompetence of ponies. *J Anim Sci* 1990;68: 1311–1317.
17. Montgomery JB, Wichtel JJ, Wichtel MG, et al. Effects of selenium source on measures of selenium status and immune function in horses. *Can J Vet Res* 2012;76:281–291.
18. Brummer M, Hayes S, McCown SM, et al. Selenium depletion reduces vaccination response in horses. *J Equine Vet Sci* 2011;31:266.
19. Brummer M, Hayes S, Adams AA, et al. The effect of selenium supplementation on vaccination response and immune function in adult horses. *J Anim Sci* 2013;91:3702–3715.
20. Brummer M, Hayes S, Harlow BE, et al. Effect of selenium status on the response of unfit horses to exercise. *Comp Exer Physiol* 2012;8:203–212.
21. White SH, Johnson SE, Bobel JM, et al. Dietary selenium and prolonged exercise alter gene expression and activity of antioxidant enzymes in equine skeletal muscle. *J Anim Sci* 2016;94:2867–2878.
22. Bobel J, Warren LK, White S. Exercise-induced suppression of lymphocyte function is unaffected by a higher level of dietary selenium. *J Anim Sci* 2012;90(Suppl 3):414.
23. Marlin DJ, Fenn K, Smith N, et al. Changes in circulatory antioxidant status in horses during prolonged exercise. *J Nutr* 2002;132:1622S–1627S.
24. Kirschvinka N, Smith N, Fievez, et al. Effect of chronic airway inflammation and exercise on pulmonary and systemic antioxidant status of healthy and heaves-affected horses. *Equine Vet J* 2002;34:563–571.
25. Williams CA, Kronfeld DS, Hess TM, et al. Antioxidant supplementation and subsequent oxidative stress of horses during an 80-km endurance race. *J Anim Sci* 2004;82:588–594.
26. Deaton CM, Marlin DJ, Roberts CA, et al. Antioxidant supplementation and pulmonary function at rest and exercise. *Equine Vet J* 2002;34(Suppl):58–65.
27. de Moffarts B, Kirschvinka N, Art T, et al. Effect of oral antioxidant supplementation on blood antioxidant status in trained Thoroughbred horses. *Vet J* 2005;169:65–74.

28. Ralston S. Effect of vitamin supplementation post-transportation in weanlings, in Proceedings. *Equine Sci Soc Symp* 2001;17:131.
29. Deaton CM, Marlin DJ, Smith NC, et al. Antioxidant supplementation in horses affected by recurrent airway obstruction. *J Nutr* 2004;134:2065S–2067S.
30. Kirschvinka N, Fievez L, Bougnet V, et al. Effect of nutritional antioxidant supplementation on systemic and pulmonary antioxidant status, airway inflammation and lung function in heaves-affected horses. *Equine Vet J* 2002;34:705–712.
31. Nogradi N, Couetil LL, Messick J, et al. Omega-3 fatty acid supplementation provides an additional benefit to a low-dust diet in the management of horses with chronic lower airway inflammatory disease. *J Vet Intern Med* 2015;29:299–306.
32. Snow DH, Gash SP, Cornelius J. Oral administration of ascorbic acid to the horse. *Equine Vet J* 1987;9:30–33.
33. Calder PC. Polyunsaturated fatty acids and inflammation. *Prostaglandins Leukot Essent Fatty Acids* 2006;75:197–202.
34. Calder PC. Marine omega-3 fatty acids and inflammatory processes: Effects, mechanisms and clinical relevance. *Biochem Biophys Acta* 2015;1851:469–484.
35. Hall JA, Van Saun RJ, Wander RC. Dietary (n-3) fatty acids from menhaden fish oil alter plasma fatty acids and leukotriene B synthesis in healthy horses. *J Vet Intern Med* 2004; 18:871–879.
36. Hall JA, Van Saun RJ, Tornquist SJ, et al. Effect of type of dietary polyunsaturated fatty acid supplement (corn oil or fish oil) on immune responses in healthy horses. *J Vet Intern Med* 2004;18:880–886.
37. Henry MM, Moore JN, Feldman EB, et al. Effect of dietary α-linolenic acid on equine monocyte procoagulant activity and eicosanoid synthesis. *Circ Shock* 1990;32:173–188.
38. Morris DD, Henry MM, Moore JN, et al. Effect of dietary α-linolenic acid on endotoxin-induced production of tumor necrosis factor by peritoneal macrophages in horses. *Am J Vet Res* 1991;52:528–532.
39. Vineyard KR, Warren LK, Kivipelto J. Effect of high fat diets and fat source on immune function in yearling horses. *J Anim Sci* 2008;86(E-suppl 2):376.
40. Vineyard KR, Warren LK, Kivipelto J. Effect of dietary omega-3 fatty acid source on plasma and red blood cell membrane composition and immune function in yearling horses. *J Anim Sci* 2010;88:248–257.
41. Henry MM, Moore JN, Fisher JK. Influence of an ω-3 fatty acid-enriched ration on in vivo responses of horses to endotoxin. *Am J Vet Res* 1991;52:523–527.
42. Vineyard KR, Warren LK, Kivipelto J. Effect of fish oil supplementation on neutrophil function and antibody production in yearling horses, in *Proceedings*. Equine Sci Soc Symp 2007;20:13–14.
43. Gobesso AAO, Centini TN, Gonzaga IVF, et al. Study of the lymphocyte proliferation of neonate foals from mares supplemented with linseed oil and soybean oil. In: *Forages and grazing in horse nutrition*. EEAP Publication No. 132. Wageningen, Nethererlands: Wageningen Academic Publishers; 2012, 503–505.
44. Friberg CA, Logas D. Treatment of Culicoides hypersensitive horses with high-dose n-3 fatty acids: A double-blinded crossover study. *Vet Dermatol* 1999;10:117–122.
45. O'Neill W, McKee S, Clarke AF. Flaxseed (Linum usitatissimum) supplementation associated with reduced skin test lesional area in horses with Culicoides hypersensitivity. *Can J Vet Res* 2002;66:272–277.
46. Hess T, Braun S, Herkelman K. The effects of various levels of docosahexaenoic acid on inflammatory markers in conditioned horses during lactate threshold tests. *J Equine Vet Sci* 2019;72:64–71.
47. Lucia JL, Coverdale JA, Arnold CE, et al. Effect of omega 3 polyunsaturated fatty acids (PUFAs) on markers of inflammation in young horses in training. *J Equine Vet Sci* 2009; 29:297–298.
48. Pritchett KB, Leatherwood JL, Vandergrift B, et al. Influence of omega-3 polyunsaturated fatty acid supplementation on plasma prostaglandin E2 production in young exercising horses. *J Equine Vet Sci* 2015;35:416–417.
49. Ross-Jones T, Hess T, Rexford J, et al. Effects of omega-3 long chain polyunsaturated fatty acid supplementation on equine synovial fluid fatty acid composition and prostaglandin E2. *J Equine Vet Sci* 2014;34:779–783.
50. Woodward AD, Nielsen BD, O'Connor CI, et al. Supplementation of dietary long-chain polyunsaturated omega-3 fatty acids high in docosahexaenoic acid (DHA) increases plasma DHA concentration and may increase trot stride lengths in horses. *Equine Compar Exerc Physiol* 2007;4:71–78.
51. Ross-Jones T, McIlwraith CW, Kisiday JD, et al. Influence of an n-3 long-chain polyunsaturated fatty acid-enriched diet on experimentally induced synovitis in horses. *J Anim Physiol Anim Nutr* 2016;100:565–577.
52. Manhart DR, Scott BD, Gibbs PG, et al. Markers of inflammation in arthritic horses fed omega-3 fatty acids. *Prof Anim Sci* 2009;25:155–160.
53. Kohl-Parisini A, van den Hoven R, Leinker S, et al. Effects of feeding sunflower oil or seal blubber oil to horses with recurrent airway obstruction. *Can J Vet Res* 2007;71:59–65.
54. Couetil LL, Cardwell JM, Gerber V, et al. Inflammatory airway disease of horses—Revised consensus statement. *J Vet Intern Med* 2016;30:503–515.
55. Warren LK, Kivipelto J. Effect of season, forage maturity and grazing on the fatty acid composition of bahiagrass pasture. *J Anim Sci* 2007a;85(Suppl 1):141.
56. Warren LK, Kivipelto J. Fatty acid content of grass and legume hays commonly fed to horses. *J Anim Sci* 2007b; 85(Suppl 1):140–141.
57. Warren LK, Vineyard KR. Fat and fatty acids. In: Geor RJ, Harris PA, Coenen M, eds. *Equine applied and clinical nutrition*. New York, NY: Elsevier; 2013.
58. Fritsche KL. Too much linoleic acid promotes inflammation—Doesn't it? *Prostaglandins Leukot Essent Fatty Acids* 2008;79:173–175.
59. Cummings JH, Antoine JM, Azpiroz F, et al. PASSCLAIM—Gut health and immunity. *Eur J Nutr* 2004; 43(Suppl 2):II/118–II/173.
60. Karav S, Salcedo J, Frese SA, et al. Thoroughbred mare's milk exhibits a unique and diverse free oligosaccharide profile. *FEBS Open Bio* 2018;8:1219–1229.
61. Tiwari UP, Fleming SA, Abdul Rasheed MS, et al. The role of oligosaccharides and polysaccharides of xylan and mannan in gut health of monogastric animals. *J Nutr Sci* 2020; 9(e21):1–9.
62. Vendrig JC, Coffeng LE, Fink-Gremmels J. In vitro evaluation of defined oligosaccharide fractions in an equine model of inflammation. *BMC Vet Res* 2013;9:147–156.
63. Spearman K, E Ott. The effect of MOS supplementation on the immune response of mares and their foals. *J Anim Sci* 2004;82(Suppl 1):61.
64. Hansen LPB, Bobel JM, Warren LK. Effect of maternal supplementation with a killed whole-cell yeast on passive transfer and foal mucosal immunity. *J Equine Vet Sci* 2017; 52:90–91.
65. Krakowski L, Krzyzanowski J, Wrona Z, et al. The effect of nonspecific immunostimulation of pregnant mares with 1,3/1,6 glucan and levamisole on the immunoglobulins levels in colostrum, selected indices of nonspecific cellular and humoral immunity in foals in neonatal and postnatal period. *Vet Immunol Immunopathol* 1998;68:1–11.
66. Bobel JM, Di-Lernia MR, Abbott JR, et al. Influence of oat β-glucan on neutrophil function and lymphocyte subsets in response to stress. *J Equine Vet Sci* 2015;35:402.
67. Adams AA, Vineyard KR, Gordon ME, et al. The effect of n-3 polyunsaturated fatty acids (DHA) and prebiotic supplementation on inflammatory cytokine production and immune responses to vaccination in old horses. *J Equine Vet Sci* 2015;35:407–408.
68. Adams AA. Immunosenescence and how it affects care of the older horse, in *Proceedings*. Am Assoc Equine Pract 2016;62:481–490.

Effects of Low-Dust Forages on Racehorses' Airway Health

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1. Introduction

Mild equine asthma is associated with dust exposure. The purpose of the study was to compare respirable dust exposure and bronchoalveolar lavage (BAL) fluid cytology between racehorses fed dry hay, steamed hay, and haylage.

2. Materials and Methods

Thoroughbred racehorses (n = 73) were randomly assigned to be fed hay, steamed hay, or haylage for 6 weeks. A BAL was performed at baseline and after 3 and 6 weeks. Differential cell counts were performed on cytospin preparations. Respirable dust was measured gravimetrically at the horse's breathing zone on 2 occasions. Mixed models were constructed to examine the effect of forage assignment upon BAL fluid cytology and respirable dust. Adjusted P-values $< .05$ were considered significant.

3. Results and Discussion

Airway cytology data were obtained from 69 horses at week 3 (hay = 24, steamed hay = 21, haylage = 24) and 53 horses at week 6 (hay = 17, steamed hay = 18, haylage = 18). Feeding steamed hay (0.056 ± 0.018 mg/m^3) or haylage (0.053 ± 0.016 mg/m^3) reduced horses' exposure to respirable dust compared to feeding hay (0.078 ± 0.037 mg/m^3; $P < .05$). Horses eating haylage had a lower proportion of BAL fluid neutrophils at week 3 ($P = .025$) and 6 ($P = .003$) compared to baseline and to hay at week 6 ($P = .04$). Horses eating haylage exhibited a decrease in mast cell proportions only at week 3 ($P = .008$). Steamed hay and haylage reduced respirable dust exposure, while only haylage significantly decreased airway inflammation.

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Research Abstract—for more information, contact the corresponding author

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Declaration of Ethics

The Authors have adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

Dr. Couëtil is a consultant for Boehringer Ingelheim Animal Health US, Inc. The other authors have no conflicts of interest.

Role of Dietary Pro-Resolving Lipid Mediators in Resolution of Equine Asthma

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Feeding haylage improves airway inflammation beyond that due to reduced dust exposure, although the mechanism remains unclear. Authors' addresses: Department of Veterinary Clinical Sciences, College of Veterinary Medicine (Olave, Ivester, Couëtil), Department of Basic Medical Sciences, Lynn Hall, 625 Harrison Street (Robinson), School of Health Sciences, College of Health and Human Sciences, 550 Stadium Mall Drive (Park), Purdue University, West Lafayette, IN 47907; e-mail: colaveol@purdue.edu. *Corresponding and presenting author.

1. Introduction

Omega-3 polyunsaturated fatty-acid (Ω-3)-derived pro-resolving lipid mediators (PRLMs) promote inflammation resolution by increasing neutrophil apoptosis and clearance. The authors hypothesized that horses eating low-dust high-Ω-3 forage (haylage) will present a faster resolution of airway inflammation than low-dust low-Ω-3 forage (hay pellets) and that PRLMs would increase apoptosis efferocytosis of neutrophils.

2. Materials and Methods

Mild asthmatic horses previously eating hay were fed pellets (low Ω-3, $n = 10$) or haylage (high Ω-3, $n = 9$) for 6 weeks. Bronchoalveolar lavage (BAL) was performed at baseline, week 3, and week 6. Dust exposure was measured. Apoptosis of circulating neutrophils and efferocytosis by alveolar macrophages were quantified by flow cytometry. Mixed models were constructed to examine the effect of forage on BAL cytology and PRLM treatments on neutrophil apoptosis and efferocytosis. $P < 0.05$ was considered significant.

3. Results and Discussion

Dust exposure was higher with hay feeding ($P < 0.01$) and equivalent between haylage and pellets ($P = 0.9$). BAL neutrophil proportions decreased significantly in horses fed haylage (baseline: 11.8 ± 2.4%; week 6: 2.5 ± 1.1%; $P = 0.0017$) but not in those that were fed pellets (baseline: 12.1 ± 2.3%; week 6: 8.5% ± 1.7%; $P = 0.28$). At week 6, horses eating haylage had lower BAL neutrophil proportions than those eating pellets ($P = 0.014$). PRLM treatments did not affect neutrophil apoptosis or efferocytosis ($P > 0.9$). Only horses fed haylage displayed resolution of airway inflammation despite similar dust exposure to those fed pellets. This improvement was not associated with an effect of PRLMs on neutrophil apoptosis or efferocytosis.

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Research Abstract—for more information, contact the corresponding author

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Declaration of Ethics

The Authors have adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

Dr. Couëtil is a paid consultant for Boehringer Ingelheim. The other authors have no conflicts of interest.

Effects of Supplements Containing Turmeric and Devil's Claw on Equine Gastric Ulcer Scores and Gastric Juice pH

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Supplements containing turmeric (TUM) and devil's claw (DC) did not cause or worsen gastric ulcers or alter health parameters after 28 days of feeding. Authors' addresses: Equine Health Studies Program, Department of Veterinary Clinical Sciences, School of Veterinary Medicine, Louisiana State University, Baton Rouge, LA 70803 (St. Blanc, Banse, Retif, Arana-Valencia, Keowen, Garza, Liu, Andrews); SmartPak Equine, 40 Grissom Road #500, Plymouth, MA 02360 (Gray); email: mstbla2@lsu.edu. *Corresponding and presenting author.

1. Introduction

Supplements containing turmeric (TUM) and devil's claw (DC) are commonly fed to horses to decrease inflammation and pain. The purpose of this study was to determine whether feeding a supplement containing these botanicals caused worsening of gastric ulcer scores, decreased body weight, increased gastric juice pH, or altered blood parameters in horses.

2. Materials and Methods

Twelve Thoroughbred horses with equine gastric ulcer syndrome (EGUS) scores > 0 were assigned to either the treatment (TUM/DC supplement) or control (supplement without TUM/DC) group. The supplements were fed daily for 28 days. Gastroscopy was performed on days 0, 14, and 28. The EGUS, non-glandular ulcer number and severity (NGS), and glandular number and severity scores were recorded. Body weight, gastric juice pH, packed cell volume, total protein, and blood analyzer values were evaluated on days 0 and 28. A mixed ANOVA model was used with significance set at $P < .05$.

3. Results

Mean EGUS and NGS scores were significantly lower in both treatment and control groups by day 14 and 28 when compared with day 0. Only two horses in the treatment group had glandular lesions, which resolved by day 14 and remained resolved by day 28. Blood parameters, body weight, and gastric juice pH did not change.

4. Discussion

The supplements did not cause worsening of squamous ulcers. Further investigation in more horses with glandular pathology is needed to determine its effect on these lesions.

Research Abstract—for more information, contact the corresponding author

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Declaration of Ethics

The Authors have adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

SmartPak Equine contributed materials and funding for this research and has donated to the Louisiana State University Foundation in the past. Lydia Gray is an employee of SmartPak Equine and was involved in study design and review. SmartPak Equine is currently involved in the commercialization and distribution of the supplement described in this study.

How to Interpret History and Physical Examination Findings of a Horse with an Acute Abdomen in the Field

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1. Introduction

While the majority of horses and foals with colic respond to medical management,[1–3] early identification of those with a strangulating obstruction is imperative. The goals should be to manage the majority of horses/foals medically, without delaying surgery in those with a strangulation thereby maximizing the likelihood of an uncomplicated recovery and successful return to their intended use. Careful consideration of the patient history and detailed physical examination can help with early identification of an intestinal strangulation or at least prompt the use of additional diagnostic tests.

2. Signalment and History

Knowing the patient signalment and obtaining a detailed history provides information that can be used to formulate a differential diagnosis list for the horse with colic, develop a treatment regimen, and devise a colic prevention plan. Recording the history as part of the medical record is also important to provide accurate information for referral, for reference in the case of future colic episodes, and as part of a preventative medicine program.

3. Signalment

While gas colic is by far the most common diagnosis across most age, breed, and sex categories,[1,2] the signalment is critical for forming a differential diagnoses list. Gas colic can be defined clinically by horses with mild-to-moderate pain that resolves spontaneously or with a single dose of an analgesic drug and accounts for about 70–80% of colic episodes.[1] Examples of diagnoses that should be considered for specific signalments include the following:

- Neonate: Meconium retention, enterocolitis, hypoxic-ischemic syndrome, jejunal intussusception or volvulus, intestinal atresia
- Geriatric horse: Strangulating pedunculated lipoma (small intestine or small colon), large colon impaction
- Pregnant mare: Uterine torsion; colonic displacement or volvulus, uterine artery hemorrhage, large colon impaction, parturition or abortion, pregnancy-related discomfort
- Postpartum mare: Large colon volvulus, postpartum hemorrhage, jejunal ischemia as-

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sociated with a mesenteric rent, small colon injury, uterine involution
- Colt or stallion: Inguinal hernia, testicular torsion
- Miniature horse: Small colon fecalith, large colon impaction, trichobezoar
- Yearling: Ileocecal intussusception
- Weanling: Ascarid impaction, umbilical hernia with bowel entrapped

Signalment is also important because it may direct the history taking process 1) if you are presented with a mare showing colic signs, the reproduction status requires investigation; 2) if you have an older horse, underlying diseases should be considered; and 3) in the case of a neonate, questions pertaining to parturition, passive transfer of maternal antibodies, and clinical signs shown by other foals on the farm should be asked.

4. Obtaining the Patient History

Obtaining a thorough and accurate yet succinct patient history (Table 1) involves asking a few initial key questions of the owner/caregiver, keeping the owner/caregiver focused on answering the questions thoroughly and concisely during an often stressful situation, and then recognizing areas of the patient's history that require a more in-depth discussion that may take place following the physical examination. Having a standardized history sheet for horses with colic can assist in obtaining a complete history with each case.

While history taking is traditionally incorporated into the first part of the patient evaluation, it is important to recognize that the entire history does not need to be obtained prior to examining the patient. However, there are a few very pertinent historical facts that may alter your initial approach to patient care and are typically obtained over the telephone prior to arrival on the farm including specific signs being demonstrated by the patient, duration of colic signs, and reproductive status of mares (initial history).

The owner/caregiver should be able to describe specifically the signs being shown by the horse or foal. The term, "colic," is often used to describe any equine patient that is not quite normal. Recumbency and signs of dull demeanor and inappetence are often described as colic. While these signs may be associated with colic, other disease processes should also be considered. Persistent recumbency is more typical of a horse with neurological disease, severe laminitis, trauma with musculoskeletal injury, debility, or shock from other causes. Dull demeanor and inappetence can be associated with any systemic disease process (e.g., colitis, pleuropneumonia, hepatic or renal disease, anaplasma) as well as problems of the head and neck regions.

Signs specific for the horse with colic include pawing at the ground, flank staring, kicking at the abdomen, and rolling. If the horse is not showing any of these signs, it is likely to have another problem rather than colic. Colic signs are often described as mild, moderate, or severe:

- Mild colic signs include intermittent flank staring and kicking at the abdomen, inappetence, lying down, and occasional rolling.

Table 1. Pertinent History-Taking Questions for Equine Colic Cases[45]

Initial history
- What specific signs is your horse showing?
- What is the duration of time over which your horse has been showing these signs? Have the signs changed over this time?
- What is the reproductive status of the horse?

Appetite, water consumption, defecation, urination
- Has the horse's appetite and water consumption been within normal limits?
- Has the horse urinated or defecated recently? When was the last time? What was the consistency of feces?

Management
- What is the duration of time the horse has been under the current ownership?
- What is the horse's current feeding regimen? Dental care?
- What is the horse's water source?
- Is the horse stalled or on pasture?
- What is the horse's exercise regimen?
- What is the intended use of the horse?
- Has there been any change in diet, water source, housing, or exercise regimen?
- Has the horse traveled recently? Where and when?
- What is the horse's vaccination and deworming history?

Medical history
- Has the horse had signs of colic previously? Previous colic surgery?
- Does the horse have any other medical problems?
- Is the horse currently being treated with any medication? Has any medication been administered for this episode of colic?
- Has the horse had a previous surgical procedure?
- Are the other horses on the farm healthy?
- Does the horse have any stable vices such as crib biting or windsucking?

Specific for Mares
- Is the mare pregnant (Yes/No)?
- Days of gestation? Estimated due date?
- Have there been any problems during this pregnancy (Yes/No)?
  - If yes, what problems?
- Have there been problems with previous pregnancies (Yes/No)?
  - If yes, what problems?
- Number of previous pregnancies/foals?
- Has the mare recently foaled (Yes/No)? When?
- Was parturition normal (Yes/No)?
  - If no, what were the problems?
- Did the mare pass her placenta normally (Yes/No)?
- Was the foal normal (Yes/No)?
  - If no, what were the problems?
- Has the mare had previous colic associated with pregnancy or the periparturient period (Yes/No)?
  - If yes, what was the cause?

- Moderate signs include more persistent rolling but the horse can be distracted and remains standing when walked. The horse may be sweating.
- Severe signs of colic are persistent rolling and thrashing, with difficulty keeping the horse standing when it is walked. The horse is generally covered in sweat and often has multiple abrasions to its head, tuber coxae, and limbs.

Clinical signs shown by the horse should also be interpreted with regard to any analgesic medication the owner may have administered. The change in clinical signs over time should also be noted e.g., horses with large colon volvulus may have a history of several hours of mild-to-moderate colic that has recently become markedly more severe and horses with gastric or cecal rupture may have had a history of variable degrees of pain that has progressed to no further signs of pain and shock (sweating, muscle fasciculations, reluctance to move).

While the owner/caregiver can rarely give an accurate time of when the colic signs actually began, they should be able to tell you 1) when the signs were first observed, and 2) when the horse or foal was last observed to be normal. Knowledge of at least an approximate duration of signs is important when performing a differential diagnosis list (e.g., mild colic for 24 hours may indicate a large colon impaction whereas a strangulating lesion is typically associated with an acute onset of severe pain). Duration of colic is also vital for determining a diagnostic and treatment plan including the use of diagnostic tests such as transabdominal ultrasonographic and radiographic examination in horses with recurrent colic, route of fluid therapy, and whether or not to refer the horse.

Knowledge of a mare's reproductive status is critical because management of colic in periparturient mares can be particularly challenging from a diagnostic and therapeutic perspective.

A more detailed history can then be obtained once the degree of pain and enough information to have an initial impression of the patient status has been gathered. The detailed history can provide information pertaining to the likely cause of the current colic episode as well as identify potential management factors to change to prevent future colic.

5. Appetite, Water Consumption, Defecation, and Urination

Whether or not the horse has been eating, drinking, defecating, and urinating can provide an overall impression of general wellbeing of the patient. This information may not be available if the horse resides at pasture, particularly if the horse is at pasture with other horses. The owner/caregiver should be asked about the horse's recent feed intake, whether or not the horse's appetite has been normal, and whether or not the horse has been drinking an acceptable volume of water. Nutritional needs of horses are extremely variable and observation of body condition score is likely the best way to determine the adequacy of nutrition. Whether the horse's appetite has changed and any associated changes in body condition as well as the period of time over which this has occurred are important to note. Water consumption is variable and dependent on the body weight of the horse, ambient temperature, type of feed, activity level, and pregnancy or lactation status. Typically an adult horse will consume 35–70 L of water a day or about 7%–15% of their body weight. Horses require 2–3 L of water per kg of dry feed intake. The last observed defecation amount and consistency should be noted. Normal fecal output in an adult horse is 6–8 piles of soft to firm formed feces a day. Whether or not the horse has been observed to urinate or there were several wet areas in the stall should be determined and used to assess hydration status and renal function.

6. Management

Type of feed provided, method of feeding, frequency of feeding, and if there has been any change in feeding regimen should be ascertained and may be related to the colic signs.[4]

Specific hay types have been associated with certain causes of colic: Coastal Bermuda grass hay, which is fed in the Southeastern United States, has a strong association with ileal[5] and possibly cecal impactions; enterolithiasis has been associated with feeding alfalfa hay[6–8]; and poor-quality hay and hay in round bales has been associated with colic.[9] Other examples of relationship between feed type and colic include the association between colic and feeding large amounts of concentrate (e.g., >2.5 kg/day dry matter),[10,11] which alter the contents of the colon and may increase tympany and colonic displacements[12]; equine gastric ulcer syndrome and high concentrate diets[13]; and sand colic has been associated with feeding on the ground in areas with sand or gravel. Horses typically graze for about 18 hours each day and management practices of many horses do not necessarily mimic the horses' natural grazing habits. Many studies on colic have found an association between colic and less pasture time.[9,11,14] Alteration in diet and feeding practices may be necessary to manage colic in some horses. In several studies an association between change in feed or feeding regimen and signs of colic has been identified.[9,10,11,14,15] The incidence of colic is also higher during the spring and possibly autumn months, which tend to be associated with a change in feed particularly for pasture-fed horses.[15,16] Lack of dental care has been associated with colonic impactions.[14]

Access to ponds is associated with a decreased risk of colic compared to other water sources.[17] Lack of access to water is also associated with colic.[18] Owners should be aware of the potential consequences of a freezing water source during the winter months.

The water source may not necessarily freeze but become cold during the cooler months; water temperature was found to affect consumption during cold but not hot weather.[19,20] During cold weather, horses with only warm water available drink a greater volume each day than if they have only icy cold water available; however, if they have a choice between warm and icy water, they drink almost exclusively from the icy water and drink less volume than if they have only warm water available. While the higher incidence of impactions occurring during the winter months[15] may be associated with housing and diet, inadequate water intake during these months may also be a contributing factor. Mineral content of water should also be considered in areas where horses are predisposed to enterolithiasis.[10,11] All horses should have a readily available source of fresh, palatable water available and water intake monitored when possible.

An increase in the number of hours in a stall and decrease in exposure to pasture and recent change in exercise regimen increased the risk for colic and simple colonic obstruction and distention.[9,14] Horses that are housed for 19–24 hours a day are at a particular risk for colic compared to horses at pasture.[9,10,14,17] Pasture access and duration of access, however, have been associated with risk of equine grass sickness in non-US geographical regions.[21]

Recent transportation has been associated with colic. Horses that had a history of travel in the previous 24 hours had an increased risk of simple colonic obstruction and distention compared to horses that had not been transported.[14] Stress, change in diet/water consumption, and possibly restricted movement are likely related to the association between travel and colic. There has also been an association between transportation and salmonellosis. Transportation had a major role in reactivating *Salmonella* sp. infection in carrier ponies[22] and horses with a travel time to the hospital >1 hour were at an increased risk for shedding salmonella compared to horses with a shorter travel time.[23]

Knowledge of where the horse has previously resided as well as when and for how long the horse was in that region may help with diagnosis. While there may not be an association between geographical region and occurrence of colic,[16] specific types of colic tend to occur in different regions:

- Enterolithiasis is particularly common in California.[7,8]
- Ileal impaction is associated with horses residing in the southeastern United States.[5]
- Sand colic occurs in horses residing in regions with sandy soil such as Arizona, California, Florida, New Jersey, and Delaware.
- Duodenitis-proximal jejunitis is geographically variable with California having a lower incidence compared to other regions and the disease seeming to occur with greater severity in the southeastern compared to the northeastern United States.[24,25]

History of anthelmintic therapy including the anthelmintic(s) used, frequency of administration, and results of monitoring of parasite burden need to be obtained. While historically *Strongylus vulgaris* (large red worm) was associated with colic, with the development of ivermectin-based anthelmintics the role of *S. vulgaris* in colic has diminished.[4] *Anaplocephala perfoliata* (tapeworms) have been associated with gas colic, ileal impaction, ileocecal, cecocecal, and cecocolic intussusceptions, and cecal impaction[4,26] and treatment with praziquantal tartrate or pyrantel pamoate (double dose) should be part of the anthelmintic regimen. Cyathostomes (small red worms) have been associated with cecal and large colon lesions[4,27,28] and *Parascaris equorum* (round worms) have been associated with intestinal obstruction, rupture, peritonitis, intussusception, or abscessation in foals.[4,29] Monitoring of resistance of these parasites to routinely used anthelmintics is recommended on large farms. Horses that were not treated with an ivermectin- or moxidectin-based anthelmintic within the previous 12 months[12] or were not on a regular deworming program[6] were predisposed to colic and horses recently administered an anthelmintic were at a decreased risk of colic.[9] Recent anthelmintic administration, however, within 7–8 days was associated with colic[10] and ascarid impactions.[29] Vaccination history is also important particularly in cases where it may not be clear that the horse is showing signs of colic.

7. Medical History

Horses that have had previous colic surgery and previous episodes of colic are predisposed to colic.[10,11,14,16–18] Horses with a large colon volvulus and displacement necessitating surgical correction were significantly more likely to colic after surgery if they had more than one episode of colic prior to the one necessitating surgery.[30,31] The specific diagnosis and procedure performed during a previous colic surgery often provides an indication of the cause of colic e.g., colonic displacements and large colon volvulus have a tendency to recur and horses having had small intestinal or small colon surgery are predisposed to adhesions. Often owners/caregivers may be aware of previous colic or colic surgery but with no knowledge of the specific lesion. Owners/caregivers should be encouraged to keep records of the horses under their care so that this information is readily available to the attending veterinarian. The frequency and severity of previous colic episodes should be recorded. Recurrent colic warrants a more in-depth diagnostic work up, albeit not necessarily on an emergency basis.

Knowledge of current or recent medication including dose rate, route, and frequency of administration that the horse is or was receiving is critical so that treatment can be continued should the horse become hospitalized; drug toxicity that may be manifest as colic can be identified; and treatment for colic with potentially toxic drugs does not result in toxicity from overdosing.

There are certain causes of colic associated with a particular medical history. Acute colitis should be considered in horses with a history of antimicrobial drug administration. Horses with colitis can initially show signs of colic that progress to dull demeanor and diarrhea. Colitis should be considered particularly in horses with a fever. Cecal impaction should be considered in horses with a history of recent surgery or stall confinement for an injury. Recent lameness has been associated with colonic impaction.[14] Right dorsal colitis should also be considered in a horse presenting for colic and diarrhea with a history of nonsteroidal anti-inflammatory drug use.

Whether or not the owner has administered any medication for the current episode of colic, including the route of administration, dose rate, and frequency, should be noted.

Knowledge of recent medical problems of other horses stabled at the same location may be useful to determine a diagnosis and assist with recommendations for prevention and treatment.

Stable vices, such as crib biting or windsucking, have been recently associated with colonic colic and epiploic foramen entrapment.[32]

8. Physical Examination

Physical examination, along with obtaining a thorough patient history, remains the cornerstone of good veterinary medicine. Information obtained during physical examination of the colic patient is used to confirm that the horse has gastrointestinal disease and determine the severity and possible cause, direct analgesic and fluid therapy, make decisions with regard to medical or surgical treatment, and provide the owners with some indication of prognosis. Meticulous medical records are necessary so that trends over time can be observed, all abnormal findings can be noted, and information can be accurately and completely communicated if referral is necessary. Should the horse have recurrent colic, comparison of physical examination findings on each occurrence can be made. Examining the colic patient begins with making several initial observations. Physical examination should begin with a rapid assessment of the patient's cardiovascular stability. Once a rapid patient assessment is performed and the horse is determined to be cardiovascularly stable or unstable, the physical examination can be completed. Of note is that when using various physical examination findings for patient assessment, observation of trends over time and use of multiple indices is more useful than the use of one index at one point in time.

9. Initial Observation

Patient examination begins with a careful 30–60-second observation. Particular attention should be paid to the horse's body condition. Poor body condition may be an indication of an underlying disease process, inadequate nutrition, or poor dentition. Demeanor or attitude is described as bright, alert, and responsive; quiet and alert; dull, or obtunded. Horses with colic are generally bright and alert. On the other hand, horses with colitis, proximal enteritis, or peritonitis, including gastrointestinal rupture, tend to have a dull demeanor. Abnormal demeanor should also be considered with some neurological diseases or toxicity. Assessment of demeanor should take into consideration recent sedative/analgesic drug administration. Evidence of inappropriate sweating can be an indication of severe pain or shock. Abdominal distention when mild can be difficult to assess unless the veterinarian is familiar with the horse's normal abdominal contour. Moderate-to-severe abdominal distention is more easily discernible and is generally an indication of a large intestinal obstruction. One exception is a small intestinal mesenteric root volvulus. Asymmetry of abdominal distention can provide some evidence of the type of lesion (e.g., when the horse is standing squarely, horses with a nephrosplenic entrapment may have more distention on the left side and cecal tympany or impaction may result in more apparent distention on the right side of the abdomen). Abrasions occurring on the head, tuber coxae, and limbs are an indication that the horse at least at some point was showing signs consistent with severe abdominal pain. A strangulating obstruction should be considered in any horse with abrasions, even very small abrasions, associated with colic. Occasionally, a horse will be examined for an apparent primary laceration, unbeknown to the owner/caregiver and veterinarian that the horse sustained the injury during an episode of colic. Therefore, when evaluating a horse with trauma of unknown origin, colic should be considered as a potential cause and warrants careful observation.

The degree of pain should be assessed. Signs of abdominal pain may be observed initially; however, horses with mild colic are often easily distracted and may not demonstrate signs when being restrained. Once an initial physical examination is completed, it is recommended to allow the horse to be unrestrained in a stall for a brief period so that the signs of colic can be carefully observed, prior to administration of sedation if the horse is not particularly painful. It is often during this observation period that it is determined if the horse truly has colic (more common) or has other disease process such as neurological disease.

Severity of pain along with degree of abdominal distention, and frequency of intestinal borborygmi can be used to evaluate the colic severity.[33,34] Moderate-to-severe colic observed during the initial

Table 2. Assessment of the Cardiovascular System[46]

Cardiovascular Status	Clinical Signs
Normal	Bright, alert, and responsive Heart rate <48 beats/minute Mucous membranes pink, moist, CRT <2 seconds Warm extremities Good jugular refill Good pulse quality
Mild dehydration	Bright or quiet, alert, and responsive Heart rate <48 beats/minute but if painful up to 60 beats/minute Mucous membranes pink, tacky, CRT 2–3 seconds Warm extremities Good jugular refill Good pulse quality
Moderate dehydration and hypovolemia	Quiet but alert and responsive Heart rate 62–76 beats/minute Mucous membranes variable color, tacky to dry, CRT ~3 seconds Cooler extremities Slow jugular refill Pulse quality variable
Severe dehydration and hypovolemia (shock)	Dull mentation or moribund Heart rate 80–120 beats/minute Dry, injected/toxic (endotoxemia), or pale (hemorrhage) mucous membranes with a CRT >3 seconds Cool extremities Poor jugular refill Peripheral pulses difficult to palpate

CRT, capillary refill time.

examination, persistent colic, and return of colic signs following provision of analgesia is associated with the need for surgery.[33] Although poorly documented, older horses (late teens and older) tend to less readily and less dramatically demonstrate colic signs compared to younger horses (yearlings and 2–3-year-olds) and foals and this should be taken into consideration.

10. Rapid Assessment of Cardiovascular Status

The cardiovascular status of the horse can be assessed quickly and thoroughly to determine the severity of disease and the need for emergency resuscitation with intravenous fluids (Table 2). The cardiovascular status of the patient can be rapidly assessed by obtaining a heart rate and examining the oral mucous membrane color, moistness, and capillary refill time (CRT). Jugular vein filling, pulse quality, and extremity temperature can provide more specific information with regard to hydration, vascular volume, and tissue perfusion. Note that a nasogastric tube should be passed immediately in any horse with a heart rate >60 beats/minute because it can be an indication of pending gastric rupture. Older foals and weanlings tend to have a variable heart rate that is slightly higher than that of an adult; however, the heart rate should be within the adult range by 6 months of age. Tachycardia is generally an indication of pain or shock. In colic patients, tachycardia up to 60 beats/minute can be associated with pain alone. Once the heart rate is >70 beats/minute, the horse is likely to have some degree of shock. Shock is defined as insufficient oxygen delivery to the cell leading to inadequate cellular ATP production and depletion of ATP supply. Failure of the energy (ATP)-dependent Na^+/K^+ pump ultimately results in cell death. Tachycardia is one compensatory mechanism associated with sympathetic stimulation to increase cardiac output and oxygen delivery to the tissues. Because of its association with pain and shock, heart rate has a strong association with prognosis for horses with colic.[35–40] Heart rate along with packed cell volume (PCV) and blood lactate and plasma creatinine concentrations are a good indication of the degree of shock, likelihood of postoperative complications, and prognosis for survival. Alpha-2 agonists (i.e., xylazine and detomidine) cause a reflex bradycardia and heart rate measurements should be interpreted in light of recent medication. The effects of the alpha-2 agonists should have subsided within 1–2 hours of administration. Tachycardia that is inconsistent with other clinical findings (e.g., a horse with a heart rate of 90 beats/minute and no other clinical indication of pain or shock) may be associated with an arrhythmia. An electrocardiogram should be obtained. Arrhythmias are uncommon in colic patients but may include ventricular tachycardia or atrial fibrillation.

Normal mucous membranes should be pale pink and moist. The CRT time should be <2 seconds. Injected membranes that are bright pink to red with or without a toxic line are usually associated with endotoxemia. Severely injected red to purple mucous membranes are generally associated with gastrointestinal tract rupture, colitis, or an extensive and prolonged strangulating obstruction. Abnormal mucous membranes have been used in models to estimate colic severity score.[41] Tachycardia with pale mucous membranes may be an indication of hemorrhage. Mucous membranes should be moist. Tacky mucous membranes are an indication of mild-to-moderate dehydration (i.e., loss of total body water with loss of water from the interstitial tissue) and may be corrected with either enteral or intravenous fluids. Dry mucous membranes are associated with moderate to severe dehydration. Dry mucous membranes may be observed in horses with a prolonged duration of colic or causes of colic in which a large volume fluid is lost into the gastrointestinal tract. Severe dehydration should be treated with intravenous fluids. Prolonged CRT is observed in horses with hypovolemia and poor tissue perfusion and is an indication for intravenous fluid therapy.

Jugular refill time is measured by holding off the jugular vein in the lower neck and observing the time taken to fill the vein. Jugular refill time should be <2 seconds in a well-hydrated horse. Poor jugular refill (>3 seconds) is generally associated with more serious causes of colic and indicates hypovolemia and the need for intravenous fluids.

Extremities (distal limbs, ears, nose) should be warm to the touch. Cool extremities generally represent poor tissue perfusion as a result of peripheral vasoconstriction to maintain circulation of vital organs. Ambient temperature should be taken into consideration when evaluating extremity temperature.

The pulse can be palpated in the facial artery and should be easily palpated, regular, and strong. With signs of hypovolemia and poor cardiac output the pulse quality will deteriorate to become barely palpable. During the hyperdynamic phase of shock bounding pulses may be palpated.

11. Evaluation of the Gastrointestinal Tract

The gastrointestinal tract is evaluated initially by ausculting the four abdominal quadrants for borborygmi. Normal borborygmi have a constant low-grade rumbling associated with gas and fluid moving through the gastrointestinal tract. Horses that have been inappetent or had feed withheld usually have hypomotile borborygmi. An absent of borborygmi is generally associated with the need for abdominal surgery[41] and typically noted in horses with strangulating intestinal obstructions. Hypermotile intestinal borborygmi can occur with mild-to-moderate colitis. Disparity in intestinal borborygmi between the left and right side of the abdomen may be used to identify the lesion site (e.g., intestinal borborygmi may be decreased on the left side in a horse with a nephrosplenic entrapment and the right side in a horse with a cecal impaction). Sand accumulation can be auscultated in some horses on the ventral abdomen caudal to the xiphoid process and is similar to the sound produced if a paper bag were partially filled with sand and slowly rotated.[42,43] The gastrointestinal function is also assessed based on historical information and observation. The horse's appetite, fecal output and consistency, and degree of abdominal distention are used with auscultation of borborygmi to complete the initial assessment of gastrointestinal function.

12. Rectal Temperature

Rectal temperature should be performed prior to abdominal palpation per rectum to obtain an accurate measurement. Rectal temperature should be within normal limits for horses (99–101°F [37.2–38.3°C]) and foals (100–102°F [37.8–38.9°C]) with colic. Reasons for a high rectal temperature are hyperthermia (an elevated body temperature due to failed thermoregulation) or fever (elevation of temperature above the normal range due to an increase in the body temperature regulatory set-point). Fever is responsive to treatment with anti-inflammatory drugs and is typically more common in horses with colic. Colitis, enteritis, peritonitis, or a respiratory tract infection should be suspected in horses with pyrexia particularly if the rectal temperature is >102°F (38.9°C). Horses do not typically develop pyrexia associated with stress or pain. Endotoxemia, however, does produce a fever and, therefore, a mild fever may be observed in horses with colic, particularly those with strangulating obstructions.

13. Respiratory Rate and Evaluation of the Respiratory System

Normal respiratory rate should be 8–12 breaths/minute. Normal respiration in the adult horse is barely visible by observing the nares or thorax/abdomen. Horses with pain, fever, shock, or respiratory tract disease will have a high respiratory rate. The most common reason for a high respiratory rate in a horse with colic is pain. Nostril flare will be observed and is a subtle yet important indication of pain particularly in stoic patients (e.g., geriatric horses). Respiratory rate has been associated with prognosis for short-term survival in a few retrospective studies[35,36,38,41] but is more likely an indication of pain necessitating intensive medical or surgical treatment.

Horses with shock are usually severely tachypneic. Marked abdominal distention can cause inadequate ventilation and tachypnea in an effort to exchange adequate air with a decrease in diaphragm compliance. Trocharization may be indicated in such cases.

Fever can lead to a high respiratory rate. Tachypnea with respiratory rates >40 breaths/minute and even >100 breaths/minute has been observed in febrile horses administered an alpha-2 adrenergic agonist (i.e., xylazine or detomidine).[44] Tachypnea was observed for at least 1–5 minutes following drug administration and was also associated with a likely unrelated antipyretic effect.[44] While the response of febrile horses to sedation with xylazine or detomidine can be dramatic, it does not appear to negatively impact the health of the patient.

Occasionally, a horse or foal showing signs of colic will have underlying respiratory tract disease. A thorough examination of the respiratory system should be performed in these horses. Complete evaluation of the respiratory system involves examination of the nares for discharge and odor; history of a cough; ability to elicit a cough with tracheal palpation; percussion; and thoracic and tracheal auscultation without and then with a rebreathing bag to identify wheezes/crackles and areas with poor air movement. The response to the rebreathing examination should be assessed with most horses not becoming distressed during the examination and having a normal respiratory rate within 1–3 breaths following removal of the bag. Distress, coughing, and prolonged recovery should be considered abnormal and warrants further diagnostic tests. Thoracic ultrasonographic and radiographic examination and transtracheal wash to obtain a sample for cytology and bacterial culture and sensitivity testing can be performed if signs are localized to the thorax.

14. Digital Pulses

Laminitis is uncommon in horses with colic and is a relatively rare postoperative complication, the exception being horses with colitis, enteritis, or peritonitis, and those developing a high fever. However, horses with a previous history of laminitis do anecdotally appear to be predisposed. Digital pulses should be palpated on the initial examination and the hoof temperature and any signs of lameness noted to establish a baseline to which future assessments can be compared.

Obtaining a detailed history and performing a thorough physical examination, not the least of which are some careful observations of the patient, should help with the decision to continue with medical management, pursue additional diagnostic tests in the field, or refer for further evaluation and treatment.

Acknowledgments

Declaration of Ethics

The Author has adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Author has no conflicts of interest.

References

1. Tinker MK, White NA, Lessard P, et al. Prospective study of equine colic incidence and mortality. *Equine Vet J* 1997;29:448–453.
2. Proudman CJ. A two year, prospective survey of equine colic in general practice. *Equine Vet J* 1992;24:90–93.
3. Mackinnon MC, Southwood LL, Burke MJ, et al. Colic in equine neonates: 137 cases (2000–2010). *J Am Vet Med Assoc* 2013;243:1586–1595.
4. Archer DC, Proudman CJ. Epidemiological clues to preventing colic. *Vet J* 2006;172:29–39.
5. Little D, Blikslager AT. Factors associated with development of ileal impaction in horses with surgical colic: 78 cases (1986–2000). *Equine Vet J* 2002;34:464–468.
6. Cohen ND, Vontur CA, Rakestraw PC. Risk factors for enterolithiasis among horses in Texas. *J Am Vet Med Assoc* 2000;216:1787–1794.
7. Hassel DM, Langer DL, Snyder JR, et al. Evaluation of enterolithiasis in equids: 900 cases (1973–1996). *J Am Vet Med Assoc* 1999;15:233–237.
8. Hassel DM, Aldridge BM, Drake CM, et al. Evaluation of dietary and management risk factors for enterolithiasis among horses in California. *Res Vet Sci* 2008;85:476–480.
9. Hudson JM, Cohen ND, Gibbs PG, et al. Feeding practices associated with colic in horses. *J Am Vet Med Assoc* 2001;219:1419–1425.
10. Cohen ND, Gibbs PG, Woods AM. Dietary and other management factors associated with colic in horses. *J Am Vet Med Assoc* 1999;215:53–60.
11. Tinker MK, White NA, Lessard P, et al. Prospective study of equine colic risk factors. *Equine Vet J* 1997;29:454–458.
12. Lopes MA, White NA 2nd, Crisman MV, et al. Effects of feeding large amounts of grain on colonic contents and feces in horses. *Am J Vet Res* 2004;65:687–694.
13. Buchanan BR, Andrews FM. Treatment and prevention of equine gastric ulcer syndrome. *Vet Clin N Am Equine Pract* 2003;19:575–597.
14. Hillyer MH, Taylor FG, Proudman CJ, et al. Case control study to identify risk factors for simple colonic obstruction and distension colic in horses. *Equine Vet J* 2002;34:455–463.
15. Archer DC, Pinchbeck GL, Proudman CJ, et al. Is equine colic seasonal? Novel application of a model based approach. *BMC Vet Res* 2006;2:27.
16. Traub-Dargatz JL, Kopral CA, Seitzinger AH, et al. Estimate of the national incidence of and operation-level risk factors for colic among horses in the United States, spring 1998 to spring 1999. *J Am Vet Med Assoc* 2001;219:67–71.
17. Cohen ND, Matejka PL, Honnas CM, et al. Case-control study of the association between various management factors and development of colic in horses. Texas Equine Colic Study Group. *J Am Vet Med Assoc* 1995;206:667–673.
18. Reeves MJ, Salman MD, Smith G. Risk factors for equine acute abdominal disease (colic): Results from a multi-centre case-control study. *Prev Vet Med* 1996;26:285–301.
19. Kristula MA, McDonnell SM. Drinking water temperature affects consumption of water during cold weather in ponies. *Appl Anim Behaviour Sci* 1994;41:155–160.
20. McDonnell SM, Kristula MA. No effect of drinking water temperature on consumption of water during hot summer weather in ponies. *Appl Anim Behaviour Sci* 1996;49:149–163.
21. McCarthy HE, Proudman CJ, French NP. The epidemiology of equine grass sickness—A literature review (1909–1999). *Vet Rec* 2001;149:293–300.
22. Kim LM, Morley PS, Traub-Dargatz JL, et al. Factors associated with Salmonella shedding among equine colic patients at a veterinary teaching hospital. *J Am Vet Med Assoc* 2001;218:740–748.
23. Owen RA, Fullerton J, Barnum DA. Effects of transportation, surgery, and antibiotic therapy in ponies infected with Salmonella. *Am J Vet Res* 1983;44:46–50.
24. Edwards GB. Duodenitis-proximal jejunitis (anterior enteritis) as a surgical problem. *Equine Vet Educ* 2000;12:318–321.
25. Freeman DE. Duodenitis-proximal jejunitis. *Equine Vet Educ* 2000;12:322–332.
26. Proudman CJ, French NP, Trees AJ. Tapeworm infection is a significant risk factor for spasmodic colic and ileal impaction colic in the horse. *Equine Vet J* 1998;30:194–199.
27. Uhlinger C. Effects of three anthelmintic schedules on the incidence of colic in horses. *Equine Vet J* 1990;22:251–254.

28. Mair TS, Sutton DGM, Love S. Caecocaecal and caecocolic intussusceptions associated with larval cyathostomosis in four young horses. *Equine Vet J* 2000;32:77–80.
29. Southwood LL, Ragle CA, Snyder JR, et al. Surgical treatment of ascarid impactions in foals and horses, in *Proceedings*. Equine Colic Res Symp 2002;112–113.
30. Southwood LL, Bergslien K, Jacobi A, et al. Large colon displacement and volvulus in horses: 495 cases (1987–1999), in *Proceedings.* Equine Colic Res Symp 2002;32–33.
31. Southwood LL. Acute abdomen. *Clin Tech Equine Pract* 2006;5:112–126.
32. Archer DC, Freeman DE, Doyle AJ, et al. Association between cribbing and entrapment of the small intestine in the epiploic foramen in horses: 68 cases (1991–2001). *J Am Vet Med Assoc* 2004;15:562–564.
33. Grulke S, Olle E, Detilleux J, et al. Determination of a gravity and shock score for prognosis in equine surgical colic. *J Vet Med A Physiol Pathol Clin Med* 2001;48:465–473.
34. Southwood LL, Gassert T, Lindborg S. Colic in geriatric compared to mature nongeriatric horses. Part 1: Retrospective review of clinical and laboratory data. *Equine Vet J* 2010;42:621–627.
35. Dukti S, White NA. Prognosticating equine colic. *Vet Clin North Am Equine Pract* 2009;25:217–231.
36. Furr MO, Lessard P, White NA. Development of a colic severity score for predicting the outcome of equine colic. *Vet Surg* 1995;24:97–101.
37. Garcia-Seco E, Wilson DA, Kramer J, et al. Prevalence and risk factors associated with outcome of surgical removal of pedunculated lipomas in horses: 102 cases (1987–2002). *J Am Vet Med Assoc* 2005;226:1529–1537.
38. Henneke DR, Potter GD, Kreider JL, et al. Relationship between condition score, physical measurements and body fat percentage in mares. *Equine Vet J* 1983;15:371–372.
39. Proudman CJ, Edwards GA, Barnes J, et al. Modelling long-term survival of horses following surgery for large intestinal disease. *Equine Vet J* 2005;37:366–370.
40. Mair TS, Smith LJ. Survival and complication rates of 300 horses undergoing surgical treatment of colic. Part 1. Short-term survival following a single laparotomy. *Equine Vet J* 2005;37:296–302.
41. White NA, Elward A, Moga KS, et al. Use of web-based data collection to evaluate analgesic administration and the decision for surgery in horses with colic. *Equine Vet J* 2005;37: 347–350.
42. Ragle CA, Meagher DM, Schrader JL, et al. Abdominal auscultation in the detection of experimentally induced gastrointestinal sand accumulation. *J Vet Intern Med* 1989;3: 12–14.
43. Granot N, Milgram J, Bdolah-Abram T, et al. Surgical management of sand colic impactions in horses: a retrospective study of 41 cases. *Aust Vet J* 2008;86:404–407.
44. Kendall A, Mosley C, Bröjer J. Tachypnea and antipyresis in febrile horses after sedation with a2-agonists. *J Vet Intern Med* 2010;24:1008–1011.
45. Southwood LL. Patient signalment and history. In: Southwood LL, ed. *Practical guide to equine colic*. Ames, IA: Wiley-Blackwell; 2013:1–11.
46. Southwood LL. Physical examination. In: Southwood LL, ed. *Practical Guide to Equine Colic*. Ames, IA: Wiley-Blackwell; 2013;12–21.

How to Safely and Effectively Perform Abdominal Palpation per Rectum

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1. Introduction

A critically important component of the examination of a horse with acute abdominal pain is abdominal palpation per rectum. Although only 25–35% of the equine abdomen is palpable per rectum, rectal examination findings play an important role in the diagnosis of the underlying cause of colic signs and often contribute to a decision for the need for surgical exploration when combined with other clinical findings. Abdominal palpation per rectum should be performed in all horses presenting to a veterinarian for assessment of acute abdominal pain, unless circumstances such as size or temperament place the horse or veterinarian at unnecessary risk of injury. In addition to the acute abdominal patient, horses with a history of persistent or recurrent colic, chronic diarrhea, chronic weight loss, or fever of unknown origin are good candidates for a thorough abdominal examination per rectum.[1]

Certain conditions may be definitively diagnosed via palpation per rectum, such as feed impaction at the pelvic flexure, herniation of small intestine through the inguinal canal in a stallion, and uterine torsion. There are many others conditions whose diagnosis can be facilitated by palpation per rectum, including, but not limited to, gas distention of the large colon or cecum, left dorsal colonic displacement (nephrosplenic entrapment), right dorsal colonic displacement, cecal impaction, small intestinal distension, ileal impaction, perirectal masses, and intra-abdominal masses. Although most experienced clinicians feel confident in their diagnosis based on palpation per rectum, numerous studies have identified a marginal degree of accuracy between preoperative or antemortem diagnosis and the definitive diagnosis. For example, a study evaluating cases of inguinal hernia reported that 13 of 27 cases were missed during the initial evaluation,[2] and in a study of 59 cases of surgically treated nephrosplenic entrapment, 34 had lesions other than or in addition to nephrosplenic entrapment.[3] Similarly, cecal impaction is a frequently missed diagnosis, with only 14 of 48 horses correctly diagnosed on initial examination.[4]

The key points in this review of abdominal palpation per rectum in the horse with colic include recommendations for preparation and technique for optimizing diagnostic capabilities and safety, description of normal anatomic structures, and abnormal palpation findings for specific conditions.

2. Preparation and Technique

The most critical component of transrectal palpation is proper restraint to ensure a safe procedure for the

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patient, the examiner, and the handler. Consequences of inappropriate or inadequate restraint could include a catastrophic iatrogenic rectal tear for the patient and bodily harm to the examiner. It is important to have an experienced handler, standing on the same side as the examiner, and ideally, the horse is restrained within stocks. Horses exhibiting unrelenting pain or those resistant to palpation should be properly sedated for the examination with an α-2 agonist, such as xylazine HCl[a] (0.3–0.6 mg/kg intravenous [IV]) or detomidine HCl[b] (10–15 μg/kg IV) in combination with butorphanol[c] (0.01–0.02 mg/kg IV). The addition of butorphanol is optimal for the safety of the examiner to lessen the potential to be kicked. The use of a nose twitch may also be applied by an experienced handler if further restraint is needed. If palpation feels restricted despite sedation due to peristaltic activity, excessive gas distension, or generalized tension within the rectum, a low or therapeutic dose of N-butylscopolammonium bromide[d] (0.15–0.3 mg/kg IV) can be administered to promote relaxation of the smooth muscle of the gastrointestinal tract, temporarily abolishing peristalsis and rectal pressure. Even at the low dose, the effect is profound, occurring within 1 minute of administration, and potentially lessens the risk of iatrogenic injury to the rectum in addition to improving the diagnostic capability of the examination by allowing a greater exploration of the abdominal cavity with reduced resistance from straining. Some veterinarians prefer to use a 50- to 60-ml dose of topical 2% lidocaine HCl[e] in the rectum; however, this has been shown to be inferior to N-butylscopolammonium bromide for rectal relaxation.[5] The author occasionally uses a 60-ml volume of lidocaine infused directly into the terminal rectum of horses that exhibit muscular stenosis of the anal sphincter during examination by using a catheter-tipped syringe but prefers N-butylscopolammonium bromide to improve diagnostic capabilities. Ideally, an attempt at palpation prior to administering N-butylscopolammonium bromide will have occurred to both assess whether a dose is indicated (e.g., straining is present) and to get a more accurate representation of the degree of colon distension present, as in the author's experience, N-butylscopolammonium bromide markedly "softens" the feel of a distended viscus. Also recall that it will increase heart rate and blood pressure and the impact on heart rate will persist for up to an hour.[6]

To begin the examination, apply a rectal sleeve that is liberally lubricated with carboxymethylcellulose. The hand and arm should be gently advanced into the rectum and distal descending (small) colon as far as possible while complying with any peristaltic contractions, sometimes requiring backing out in part to avoid excessive pressure on the rectal wall. Be particularly wary of any explosive movements, such as those associated with a cough or an agitated horse resistant to palpation. As much fecal material as possible, if present, should be evacuated prior to beginning the palpation, and fecal characteristics should be noted as they may assist in diagnosis. Deep extension of the arm into the abdomen will allow for a more thorough exploration.

A strategic and consistent approach to palpation will reap the greatest benefits for identification of gastrointestinal lesions, keeping in mind that many horses will present limitations based on the degree of distension or lack of relaxation. First, begin with identification of the left kidney and associated nephrosplenic ligament and proximal border of the spleen normally present against the left body wall. Next, examine the right dorsal quadrant, paying particular attention to the vertically oriented ventral band of the cecum and its location in relation to the large colon. Then, examine the right ventral and left ventral abdomen for the presence of normal and abnormal visceral distention and position. Last, palpate the more caudal structures within the pelvic canal as the arm is extracted. A thorough examination will, in most instances, provide information about the segment of intestine involved and the severity of the condition, with a definitive diagnosis possible in several instances, when evaluated in context with other clinical findings.

3. Normal Anatomy

Structures that are expected to be palpable in the normal horse include the caudal pole of the left kidney, lying in the left dorsal abdomen, with its associated nephrosplenic ligament, extending from the ventrolateral aspect of the left kidney toward the hilus of the spleen on its axial, visceral surface. The dorsocaudal border of the spleen is palpable as well and should feel smooth with sharp borders. The descending colon with its distinctive fecal balls and mobility will often be the most prominent feature in the normal horse within the left dorsocaudal abdominal quadrant. Centrally along the dorsum, the descending aorta may be palpable, and its quadrification into the left and right internal and external iliac arteries should be identified. The ventral band of the cecum is a key landmark in the right dorsal to central abdomen, recognizable by its vertical orientation in the abdomen and extending from the right caudodorsal body wall cranioventrally toward midline, with the cecum primarily filling the right dorsal and ventral quadrants. Full extension of the arm into the abdomen is often necessary to identify this landmark. A small amount of gas is normally palpable within the cecum, but there should be no tension on the ventral band and content should be very soft or fluidy. The duodenum courses caudal to the cecal base and is not often palpable in the absence of pathology or distension, as with the rest of the small intestine. The pelvic flexure, or at least components of the left ascending colon, should be palpable within the left ventral quadrant, containing soft digesta in some instances. The pelvic flexure is recognized by its diameter, presence of soft digesta, and smooth surface charac-

Table 1. Common Conditions and Expected Findings on Transrectal Palpation in Horses with Acute Abdominal Disease

Abnormal Condition	Expected Findings
SI obstruction	Nonspecific small intestinal distention is an indication of either a functional or mechanical obstruction. One or more loops of fluid- or gas-distended SI will be evident as slippery and smooth tubular structures generally between 4–8 cm in diameter. A distended or thickened duodenum may be palpable as a horizontally positioned loop in the dorsal and central to right abdomen as it courses around the base of the cecum.
Ileal impaction	Generalized SI distention is palpable in 96% of cases with 25% having a palpable impaction.[7] This may be evident as a firm, tubular structure in the center of the abdomen just medial to the cecum.
Herniation of SI through an inguinal ring	Generalized SI distention may be present. A taut band of mesentery and associated SI will be palpable coursing into an inguinal ring, just cranial to the brim of the pelvis. Pain may often be elicited with traction on the mesentery or ileocecal band/cecum. Palpation of the scrotum should be performed on every stallion with acute, severe colic.
Intussusception	Jejunojejunal intussusception results in generalized SI distention with rare ability to palpate the intussusception as a markedly thickened, edematous tubular structure in the caudal abdomen. Ileocecal intussusception is difficult to palpate but, in rare circumstances, may be identified as a turgid, tubular mass in the RD abdomen within the cecum.[1]
Duodenitis/proximal jejunitis	Proximal enteritis will most commonly have evidence of generalized SI distention, unless early in the disease process. The duodenum may more likely be palpable in these cases and occasionally may have a slightly thickened feel. Degree of distention of SI typically is not as severe as with strangulating SI obstructions.
LC impaction secondary to SI obstruction	With any form of SI obstruction, the LC ingesta will often become dehydrated secondary to loss of fluid input from the SI. In this case, the colon will feel firm but often has a distinctive feel with prominent taenia and haustra and a more uneven firm surface reminiscent of a “shrink-wrapped” feel of desiccated ingesta. This is commonly misinterpreted as a primary LC impaction, resulting in delays in appropriate treatment for SI disease.
LC primary impaction of the pelvic flexure	With impaction of the pelvic flexure, the colon will feel enlarged with doughy to firm contents within the smooth, pelvic flexure, usually extending into the adjacent dorsal or ventral left colons. The colon will be stretched and smooth, unlike the feel of desiccated content secondary to SI obstruction.
LC primary impaction of the RD colon	RD colon impaction likely represents the most common area of LC obstruction, but its diagnosis is presumptive in most cases. As the RD colon is beyond reach during rectal palpation in all but the smallest horses with the largest impactions, the diagnosis is based on clinical findings, history, and absence of fecal output. Expected findings are a lack of abnormalities.
LCV	LCV is most commonly characterized by extreme large colon distension, sometimes to the point of not being able to extend the arm into the abdomen beyond the wrist. Colonic wall thickening may be appreciated and associated with venous congestion and edema. Taenia may course horizontally as the colon expands to fit within a limited space. However, early LCV may not have distention present with limited distinguishing features on palpation. It is often unnecessary and unsafe to palpate the LCV patient due to unrelenting pain dictating a clear need for surgery or euthanasia. Ultrasonographic examination can facilitate a rapid diagnosis by the detection of colonic wall edema in the ventral abdomen.
LDD—nephrosplenic entrapment	The primary characteristic of a LDD is palpation of most of the colon on the left side of the abdomen, combined with the ability to follow the taenia of the colon cranially and dorsally on the left, coursing lateral to the left kidney. The proximal border of the spleen will remain against the left body wall but will be displaced ventrally. When severe colon distention is present, diagnosis may be more difficult and palpation of the left kidney and spleen may be obscured by the colon.
RDD	RDD may occur in a few configurations but, by definition, requires movement of the left ventral and dorsal colon to a location on the right, lateral to the cecum. In many instances, the left colon will exhibit a 180-degree volvulus and the prominent taenia and haustra of the left ventral colon will be evident dorsally and traveling cranially on the right side of the abdomen. If colon distention does not obscure identification of the ventral band of the cecum, a more definitive diagnosis can be made when the ventral band is identified medial to the large colon. It is common to palpate distended colon with taenia horizontally positioned and traveling cranially to the right, or on occasion, the pelvic flexure will be immediately identifiable within the pelvic inlet. Following the colon from the pelvic flexure will reveal its track to the right body wall, lateral to the ventral band of the cecum.

Table 1. (*continued*)

Abnormal Condition	Expected Findings
Enterolithiasis—LC	Obstructive enterolithiasis of the LC is often characterized by a lack of any abnormalities on transrectal palpation. History and clinical signs are critical in these cases to consider this diagnosis in the absence of abnormalities on palpation. When complete obstruction occurs within the transverse colon, large colon and cecal distention will be evident.
Enterolithiasis—SC	Obstructive enterolithiasis involving the descending or SC is most commonly characterized by progressive abdominal distention with gas due to both cecal and large colon gas accumulation. A baseball-sized enterolith may be palpable within the SC in rare circumstances.
SC fecalith	SC fecaliths can occasionally be identified upon rectal palpation as very firm, fecal impactions within the SC accompanied commonly by extensive SC, LC, and cecal gas distention. The SC can be distinguished by its small diameter and presence of characteristic mesenteric and antimesenteric taenia.
SC impaction	A true SC impaction does not consist of firm, stacked fecal balls but, rather, is a pathologic impaction secondary to SC inflammation. It is nearly always preceded by an episode of diarrhea that subsequently becomes desiccated, resulting in a firm, tubular segment of variable length. Careful palpation will identify the antimesenteric taenia that distinguishes SC from the pelvic flexure or SI. The other distinctive finding in many of these cases is edema of the rectal wall with a fragile feel to the wall.
Cecal distension	The cecum may become distended with fluid and/or gas as either a primary (impaction/dysfunction) or secondary process. A fluid-filled cecum will be characterized by a tight ventral band, often pulled ventral and slightly toward the left. When severe, gas-distended cecum may be difficult to differentiate from LC distention, but they often occur concurrently.
Cecal cupula impaction	True cecal impactions with dried digesta frequently affect the cecal cupula (cranial aspect of the cecal base) and are palpable as a large diameter, digesta-filled, indentable viscus in the RD to central abdomen. They can sometimes be distinguished from LC impactions by their diameter and identification of the vertically oriented ventral cecal band over the caudal surface. As the cecum is attached to the dorsal body wall, palpation may help distinguish a cecal impaction from a LC impaction as the hand cannot pass dorsally along the surface of the distended cecum.[4]
Cecal dysfunction	Cecal dysfunction most commonly follows elective procedures, often including NSAID use. Early signs may consist of increased tension in the ventral cecal band.
Perirectal mass	Perirectal masses commonly present for colic secondary to a rectal impaction and subsequent tenesmus. A thorough, circumferential palpation of the perirectal region will facilitate diagnosis, as it is easy to bypass the region during palpation and fail to recognize the mass.
Ruptured viscus	The findings on rectal palpation for horses with a ruptured GI tract will depend, in part, on the location of the rupture along with the duration and degree of gas present in the peritoneal cavity. If a moderate quantity of gas is present, this will eliminate the normal negative pressure within the peritoneal cavity, providing unusually free movement of the arm during palpation. Other common findings are emphysema or a gritty texture on serosal surfaces. These findings will be accompanied by signs of septic shock in all instances.
Intra-abdominal abscess	A large, extraluminal mass may be palpable in the central abdomen, sometimes arising from mesenteric lymph nodes. Alternatively, they may be secondary to small perforations of bowel and be located in variable locations. Diagnosis may be facilitated by transrectal ultrasound along with history and other diagnostic findings.

Abbreviations: SI, small intestine; LC, large colon; RD, right dorsal; RDD, right dorsal displacement; LDD, left dorsal displacement; LCV, large colon volvulus; SC, small colon; NSAID, nonsteroidal anti-inflammatory drug; GI, gastrointestinal.

terized by the absence of distinct taenia and haustra, which is an anatomical feature of the ventral colon. It is not abnormal to be unable to identify the pelvic flexure, as it will undergo some natural movement in the abdomen and may be indistinct if lacking digesta. Colonic tenia in the left abdominal region should course cranially and remain on the left side of the abdomen, to the left of the ventral cecal band. Other palpable structures include uterus and ovaries in the mare, inguinal rings in the stallion, and the bladder, particularly when distended with urine. The mesenteric root may sometimes be palpable but only when under some degree of tension under abnormal conditions.

4. Abnormal Anatomy

Table 1 describes characteristic findings identified upon palpation per rectum that are associated with a variety of conditions causing colic. Illustrations and animated clips of many of these conditions can enhance palpation skills through visualization of anatomy and can be viewed in The Glass Horse: Equine Colic,[e] developed at the University of Georgia (https://www.sciencein3d.com/products.html).

There are several conditions that may be incorrectly diagnosed based on transrectal palpation. These are worth mentioning, as an incorrect diagnosis can often result in delays in definitive treatment, ultimately affecting prognosis. The first of these is a diagnosis of large colon impaction when there is a small intestinal obstruction (often strangulating obstruction). Small intestinal obstruction results in sequestration of fluid in the stomach and small intestine with desiccation of colonic contents, which is exacerbated by dehydration and hypovolemia. The result is a "shrink-wrap" feel, with undulations on the surface of the colon, rather than a stretched taut viscus typical of large colon impactions. Another commonly missed diagnosis is cecal impaction, as it is sometimes mistaken for a large colon obstruction but can have much more serious consequences (e.g., rupture) and require considerably more extensive therapy for resolution. Due to the dorsal mesenteric attachment, it is not possible to pass your hand over a distended cecum. You can, however, pass your hand over the top and to the lateral side of a displaced colon. The third condition that is commonly misdiagnosed is masses of the perirectal region. All horses exhibiting tenesmus or presenting with a rectal impaction should have a thorough examination of the rectum and perirectal region for the presence of masses, such as perirectal abscessation or neoplasia. Studies have also indicated marginal accuracy of palpation per rectum upon initial presentation for both inguinal hernia and nephrosplenic entrapment.

5. Summary

Transrectal palpation is a critical component of the diagnostic examination in the acute colic patient. The procedure can be performed safely when using the tools available, from facilities and skilled handlers to pharmacologic assistance. In combination with history and other clinical findings, it can sometimes provide a definitive diagnosis but commonly will assist in determining the severity of the disease process and contribute to information regarding the need for surgical intervention. A thorough knowledge of normal and expected abnormal anatomy is critical for the successful use of transrectal palpation as a valuable diagnostic tool in the colic patient.

Acknowledgments

Declaration of Ethics

The Author has adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Author has no conflicts of interest.

References and Footnotes

1. Ethell MT, Dart AJ, Hodgson DR, et al. Alimentary system. In: Rose RJ, Hodgson DR, ed. *Manual of equine practice*, 2nd ed. Philadelphia, PA: W.B. Saunders, 2000;273–339.
2. Schneider RK, Milne DW, Kohn CW. Acquired inguinal hernia in the horse: a review of 27 cases. *J Am Vet Med Assoc* 1982;180:317–320.
3. Gillen AM, Munsterman AS, Hanson R. Evaluation of phenylephrine and exercise with or without trocarization for treatment of suspected nephrosplenic entrapment in horses. *J Am Vet Med Assoc* 2019;254:1448–1453.
4. Plummer AE, Rakestraw PC, Hardy J, et al. Outcome of medical and surgical treatment of cecal impaction in horses: 114 cases (1994–2004). *J Am Vet Med Assoc* 2007;231: 1378–1385.
5. Luo T, Bertone JJ, Greene HM, et al. A comparison of N-butylscopolammonium bromide and lidocaine for control of rectal pressure, in *Proceedings*. Am Assoc Equine Pract 2005;51:191–194.
6. Morton AJ, Varney CR, Ekiri AB, et al. Cardiovascular effects of N-butylscopolammonium bromide and xylazine in horses. *Equine Vet J Suppl* 2011:117–122.
7. Parks AH, Doran RE, White NA, et al. Ileal impaction in the horse: 75 cases. *Cornell Vet* 1989;79:83–91.

[a]Rompun, Bayer HealthCare, LLC, Shawnee Mission, KS 66216.

[b]Dormosedan, Zoetis, Parsippany, NJ 07054.

[c]Torbugesic, Zoetis, Parsippany, NJ 07054.

[d]Buscopan, Boehringer Ingelheim Vetmedica Inc., St. Joseph, MO 30096.

[e]The Glass Horse: Equine Colic, Science in 3D, Inc., Watkinsville, GA 30677.

How to Perform a Diagnostic FLASH

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1. Introduction

Doctor of medicine surgeons and criticalists, and later small animal criticalists, were the first to introduce the idea of localized sonograms, which was formally added to the literature in the 1990s. The goal was to perform fast sonograms in trauma situations that would decrease the time from presentation to an emergency room to the decision to take the patient to surgery or to perform computerized tomography. A protocol was designed that could be performed by clinicians without advanced imaging training. The sonograms could be performed simultaneously with other emergency procedures and were rapid, inexpensive, noninvasive, and nonradiating. This technique is called Focused Assessment with Sonography in Trauma (FAST). A 4-window protocol was designed and successfully tested prospectively. Currently, many variations of the procedure exist, titrated to different clinical situations, and a considerable effort has been placed in defining the diagnostic accuracy and structure of these protocols. In 2011, a group of equine clinicians from the University of Liege in Belgium[1] published the use of Fast Localized Abdominal Sonography of Horses (FLASH). In this study, 7 windows were described and reported an acceptable diagnostic ability of this protocol for detecting small intestinal obstructions and the need for exploratory laparotomy. Detection of small intestinal strangulations is perhaps one of the highlights of this protocol (Fig. 1).

It is important to remember that sonographic evaluation is only a small part of the assessment of a horse with acute colic. It is a useful tool, but not all horses with acute colic need an abdominal sonogram, and there are many other parts of the evaluation of the horse with acute colic that need to be considered. Signalment, history, and physical examination give the clinician the most important information, and diagnostic aids complete the assessment. These data are filtered through the clinician's brain to establish a diagnosis, or differential diagnosis list, a prognosis, and a therapeutic plan. This cycle can be repeated as many times as needed depending on the progression of the horse.

The ideal instrument used to perform a sonogram in a horse with colic is a large convex probe. Portable or ultraportable machines are able to obtain diagnostic images for these scans. Many current ultraportable machines have built-in software that allows remote assistance (telemedicine/teleconsulting), and this is likely to become a commonly used tool in the near future as this technology becomes easier to use in all types of equipment. Spraying

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Fig. 1. Distended thickened nonmotile small intestine imaged in the inguinal region of a horse with a strangulating small intestinal lesion.

alcohol or using warm water is sufficient to obtain an adequate image for a FLASH in most horses. The goal is to perform the scan in less than 10 minutes.

The seven windows of the original FLASH are ventral window, gastric window, left middle third window, splenorenal window, right middle third window, duodenal window, and thoracic window. The concept of having a fixed tested protocol with known specificity and sensitivity is ideal. A slight modification of this protocol has been developed to fit the sonogram within a typical colic work-up and makes it faster and potentially more specific. The protocol and goals of each window are in the following sections.

Nephrosplenic Window

The probe is placed between the dorsal and middle thirds of the abdomen at the level of the 17th intercostal space or paralumbar fossa. In normal horses, the left kidney is seen medial to the spleen (Fig. 2A). Visualization of the left kidney in this window virtually rules out nephrosplenic entrapment. In the images in this manuscript, dorsal or cranial is to the right.

The diagnosis of a nephrosplenic entrapment is the main goal of the nephrosplenic window. A nonvisible kidney is not pathognomonic for nephrosplenic entrapment. Horses with left dorsal displacements without entrapment (e.g., left colon is gas filled and positioned dorsal and sometimes lateral to the spleen but not in the nephrosplenic space). Some horses appear to have a colon dorsal to the spleen without colic signs. In horses with a nephrosplenic entrapment, the left kidney is not visible and the colon is seen dorsal to the spleen in the paralumbar fossa; and in the caudal intercostal spaces, the dorsal edge of the spleen is not visible, the spleen and stomach are displaced ventrally, and, in many cases, a mesenteric vessel is visible adjacent to the medial border of the spleen (Fig. 2B and C). The latter sonographic sign is the consequence of most entrapments presenting a 180-degree rotation of the colon that makes the medial colonic vessels visible.[2]

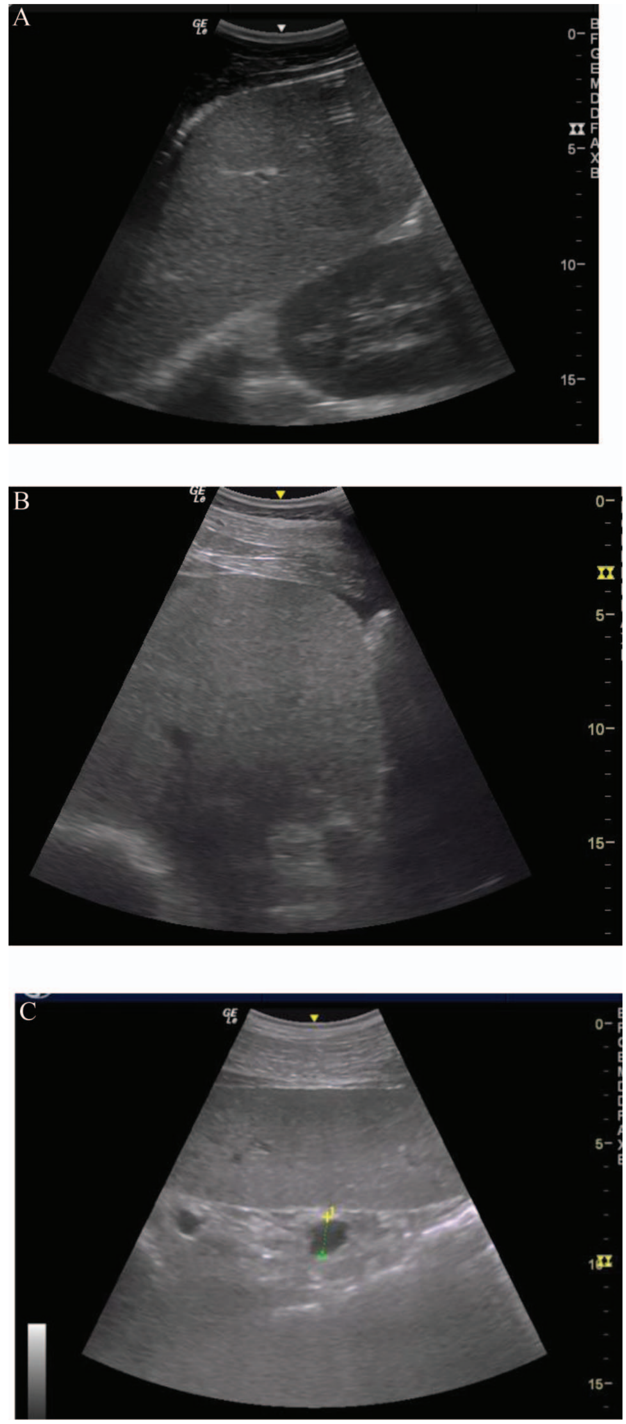

Fig. 2. A, Normal nephrosplenic window. Spleen is imaged superficially, and the left kidney is seen along the medial border of the spleen. B and C, Nephrosplenic window of a horse with a nephrosplenic entrapment. The colon is dorsal and obscuring the dorsal border of the spleen. Also note that no kidney is visualized. In image C, mesenteric vessels can be seen along the medial border of the spleen supporting a colon displacement.

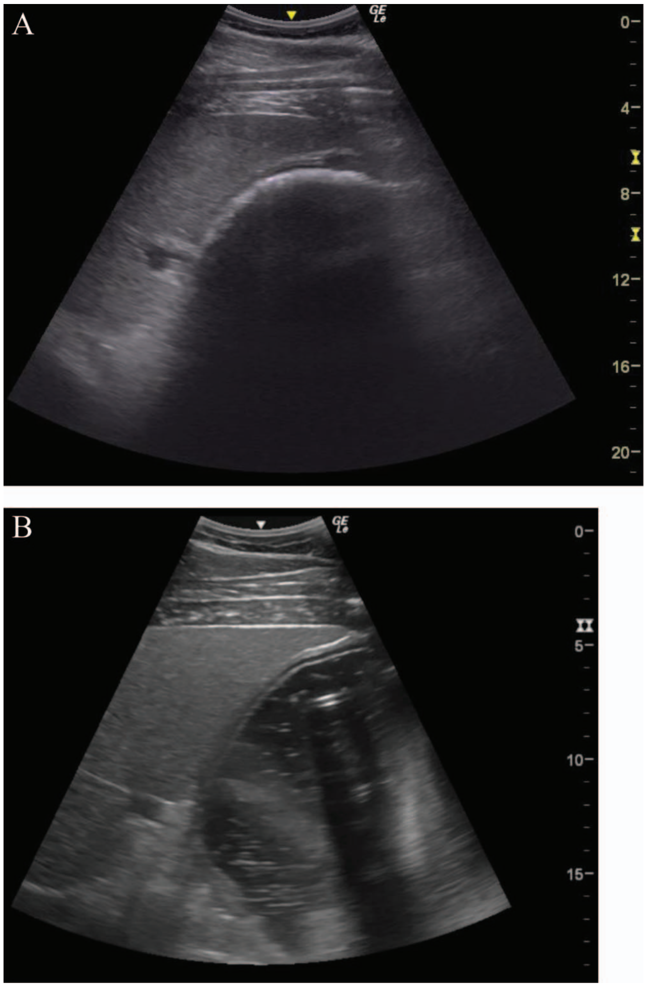

Fig. 3 A, This image shows a normal gastric window. The stomach can be seen adjacent to the spleen and there is ingesta within the gastric lumen. B, This image shows a fluid-filled stomach with a nasogastric tube in place.

Gastric Window

For this window, the probe is placed in the 10th intercostal space in the mid abdomen and moved cranially and caudally. At this point, a stomach tube has likely been or is simultaneously being passed. The sonogram helps decide the degree of gastric distension. In some cases in which reflux is not obtained, a sonogram shows distension with ingesta or that the tube is not in the stomach. In these cases, this visual helps the clinician realize that further lavage or repositioning of the tube is necessary. Fig. 3 provides an example of a normal gastric window. The splenic vein and the "double contour sign" (parallel hyperechoic interfaces between hypoechoic layers) gastric wall help determine that the gastrointestinal viscus observed is the stomach. The echogenicity helps determine the gastric contents. Echoic contents casting a complete shadow are consistent with ingesta, as shown in Fig. 3A. Fig. 3B shows a fluid-filled stomach. Also note that a stomach tube is visible in this image as a double hyperechoic echo casting an acoustic shadow. Hyperechoic contents casting a dirty acoustic shadow or showing a mirror image artefact are consistent with gas. The number of intercostal spaces and the shape of the stomach can assist in determining the degree of gastric distension. The stomach can be followed cranially by scanning across intercostal spaces. A normal stomach can occupy 3–7 intercostal spaces depending on when and what the horse has eaten. A stomach wall should appear rounded (Fig. 3A and B). A stomach that becomes flattened is consistent with gastric distension. An enlarged stomach filled with ingesta and flattened against the abdominal wall raises concerns about a gastric impaction. Ultrasound does not allow a characterization of the consistency of ingesta, and the remaining examination findings and, particularly, results of gastric lavage are necessary to make a diagnosis. There can be intermittently collapsed, motile loops of small intestine with normal wall thickness between the spleen and the stomach in normal horses. If there is distended thickened small intestine between the spleen and stomach, a gastrosplenic entrapment may be suspected. The appearance of a thickened stomach wall can also be suggestive of gastritis or gastric edema.

Ventral Window

This view is split into two different windows.

Cranioventral Abdomen

The probe is placed in the most ventral aspect of the abdomen (cranioventral) and then moved caudally. In a normal horse, sacculated large intestine is typically observed. This window is useful to see increased free peritoneal fluid, distended or thickened small intestine, and thickened large intestine. The cranioventral window is often used to determine if and where abdominocentesis will be performed and with which length/gauge needle or cannula. The abdominal muscles can be seen meeting at the linea alba. The thickness of the abdominal wall can be measured to determine the length of needle/cannula. For example, if the wall thickness measures 1 cm, then the needle/cannula will need to be 0.5 cm longer than this measurement, as the tissues are compressed by the ultrasound probe and the peritoneal lining will be deformed by the tip of the needle or cannula before penetration.

Inguinal Area

The probe is placed in the right and left inguinal areas and as far caudal as possible. Some horses may kick when the probe is placed in this area. It is particularly useful to assess the presence of distended or thickened small intestine. In normal horses, small intestine can be intermittently dilated or collapsed. A wall thickness of 3 mm is considered normal, although when transiently dilated, the

Fig. 4. Moderately distended compressible nonthickened small intestine in a horse with an ileal impaction.

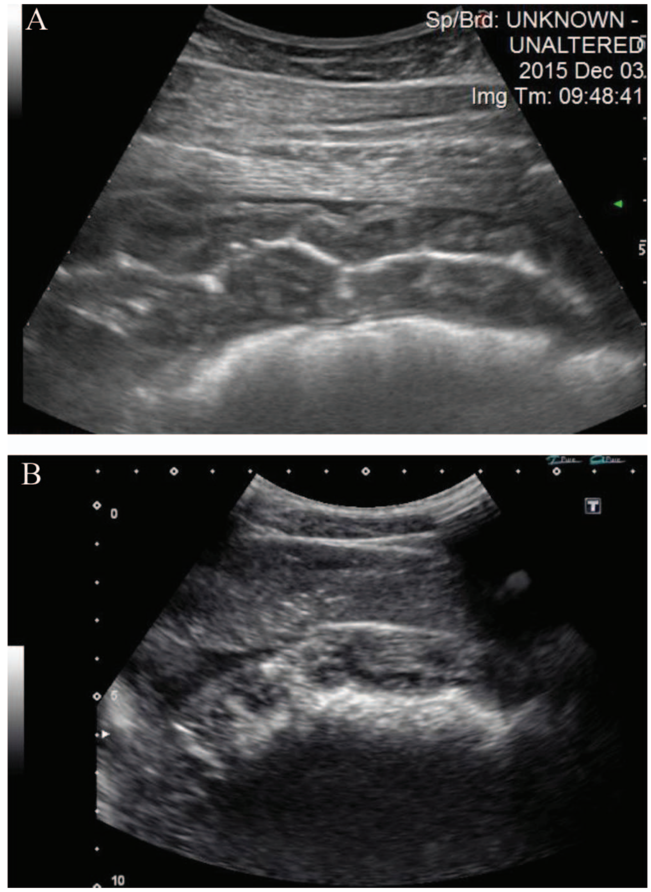

Fig. 5. A, Thickened large colon in a horse with a large colon volvulus. B, Thickened large colon in a horse with salmonellosis.

thickness is expected to decrease. The motility of a normal small intestine is continuous.

The most relevant findings in a ventral window are as follows:

- Distended thickened nonmotile small intestine (Fig. 1). This sonographic finding is second only to "pain nonresponsive to analgesia" as an indication for exploratory laparotomy (and close to serosanguinous peritoneal fluid with increased lactate concentration). The normal small intestine is usually collapsed. Mildly distended small intestine can be seen with fasting or hypomotility. Sedation may decrease motility and typically does not cause significant distension. Functional obstruction (ileus) or mechanical obstruction like an ileal impaction (Fig. 4) causes moderate or marked distention, and sedimentation of digesta occurs over time. Thickened nonmotile distended small intestine is typically caused by a strangulating obstruction necessitating surgical correction. Enteritis could cause this appearance, but the thickening tends to be mild and diffuse in cases of enteritis. The remaining clinical presentation can help in differentiation.
- Thickened large intestine. The presence of thickened large intestine needs to be placed into the clinical context and several differential diagnoses considered. Large colon volvulus and colitis are the most common differential diagnoses for a horse with thickened large intestine. Inflammatory bowel disease (IBD)/ lymphoma, a displacement with obstruction of venous return, and rare large intestinal infiltrative diseases are other differentials.[3] The literature can be somewhat misleading for the diagnosis of large colon volvulus. In a horse with acute colic and severely thickened colon in the ventral abdomen, a colon volvulus is the most likely diagnosis, but this finding is not pathognomonic.[4,5] Fig. 5 compares the sonographic appearance of a horse with a large colon volvulus and another horse with severe colitis (salmonellosis). The absence of sacculations in the ventral window has been suggested as a sign of volvulus. Because the ventral colon is sacculated and the dorsal colon is not, seeing nonsacculated colon ventrally has been suggested to be a sign of a 180-degree rotation. Colonic distension associated with a displacement or impaction or in horses with a colon fuller than average can cause the ventral colon to become nonsacculated, and this finding cannot be relied upon for the diagnosis of large colon volvulus. Paying attention to the layering pattern may help rank the differential diagnoses, but this type of detailed sonogram is difficult to perform in emergency situations, and their discussion is beyond the description of FLASH.
- Increased fluid. Peritoneal fluid echogenicity can vary between peritonitis, hemoabdomen,

Fig. 6. Free fluid with hyperechoic particles in the ventral abdomen in a horse with ruptured stomach.

transudate, and ruptured viscus. Fluid with spontaneous contrast (smoke) is characteristic of hemoperitoneum, whereas hypoechoic fluid can be consistent with transudate or modified transudate. Fig. 6 shows a sonogram of a horse with large particles suggestive of intestinal rupture. In such cases, pneumoperitoneum can often be seen accompanying the echoic fluid in horses with intestinal rupture.

- Hyperechoic contents casting a complete shadow are suggestive of sand. This may take some attention and experience to recognize. The colon may become flattened against the ventral abdomen if the volume is large enough to make the ventral colon lose its normal haustrations. In Fig. 7, the sonographic image and radiograph show a mare that presented with chronic diarrhea diagnosed with sand enteropathy that responded to a course of psyllium and magnesium sulfate. In cases of sand impaction, the colon will be flattened and distended, and in cases of enteropathy, the wall can be thickened, hypervascular, or have an altered layering pattern. The sensitivity of ultrasound to detect sand is high, but its ability to assess the amount of sand is poor. Radiographs are better than ultrasound at determining the amount of sand and the clinical relevance of the sonographically visible sand.[6]

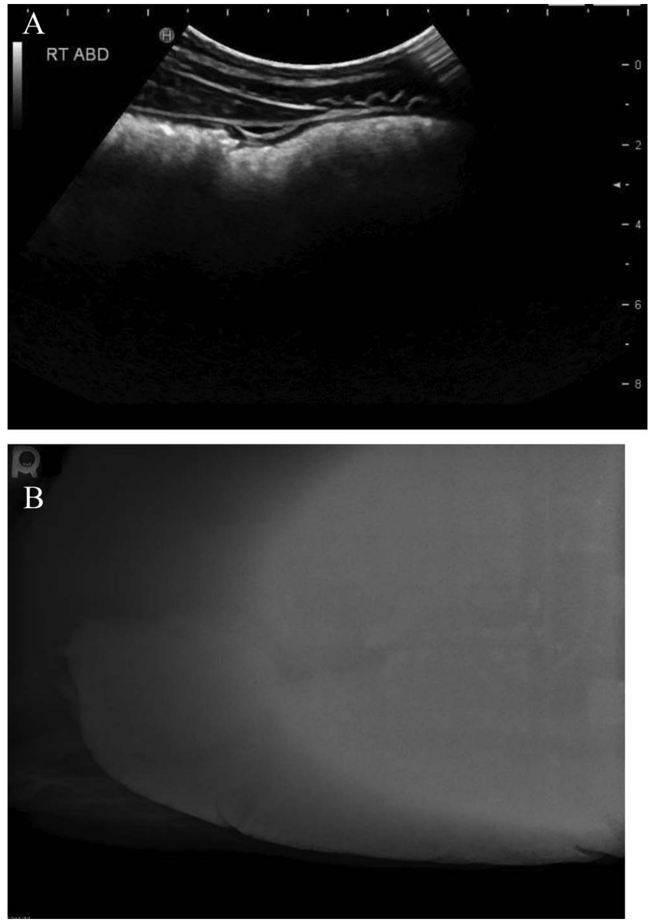

Fig. 7. A, Sonogram of the ventral abdomen showing hyperechoic contents. B, Corresponding abdominal radiograph of a horse with a sand impaction.

Left Middle Third Window

The FLASH protocol says "freely move the probe in the left mid abdomen." Freely moving the probe is not recommended in a protocol that should be specific and fast. The probe should be moved from the diaphragm to the costochondral junction in 3 intercostal spaces in the mid abdomen (usually 15–13 intercostal space [ICS]). Spleen and stomach or spleen and colon are often seen in this window. This window is key for diagnosing nephrosplenic entrapments. The colon remains dorsal to the spleen, the dorsal edge of the spleen is not visible, and, in many cases, a colonic vessel is seen adjacent to the medial aspect of the spleen, which is indicative of a 180° rotation of the entrapped colon, as shown in Fig. 2.

Duodenal Window

The duodenum can be imaged ventral to the right kidney and medial to the right liver lobe. Fig. 8A shows the normal appearance of the duodenum medial to the right lobe of the liver, and Fig. 8B shows the appearance ventral to the right kidney. The duodenum can be distended in cases of mechanical or functional obstruction of the small intestine. The duodenum can be thickened in cases of duodenitis or IBDs. Sedation will affect motility, and the presence of a nasogastric tube can introduce air. The appearance of the duodenum is rarely specific for the cause of acute colic.

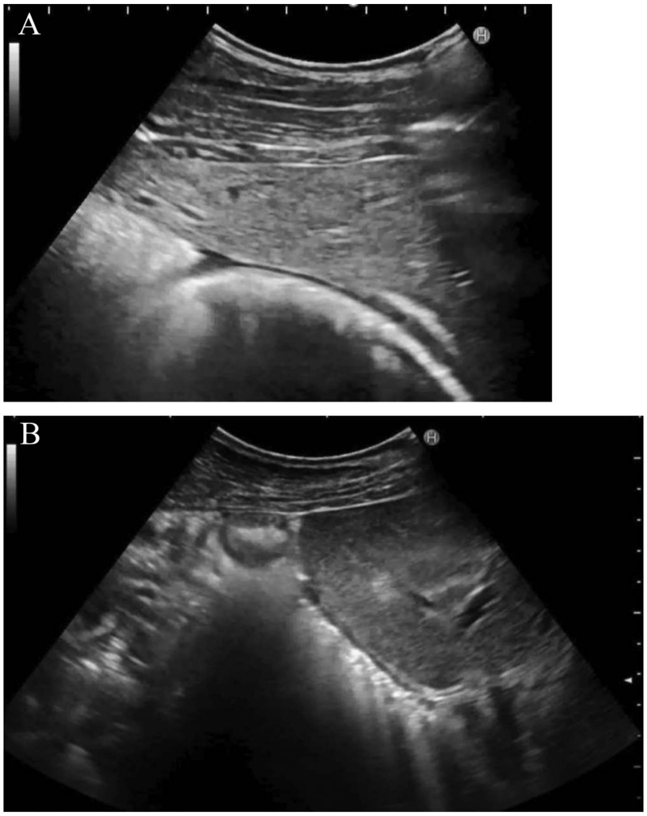

Fig. 8. Sonogram of the duodenal window. A, The duodenum can be imaged between the right lobe of the liver and the right dorsal colon in the right side of the screen. The transition between right dorsal colon (right) and right ventral colon (left) can also be observed. B, The duodenum is ventral (to the left) and adjacent to the right kidney.

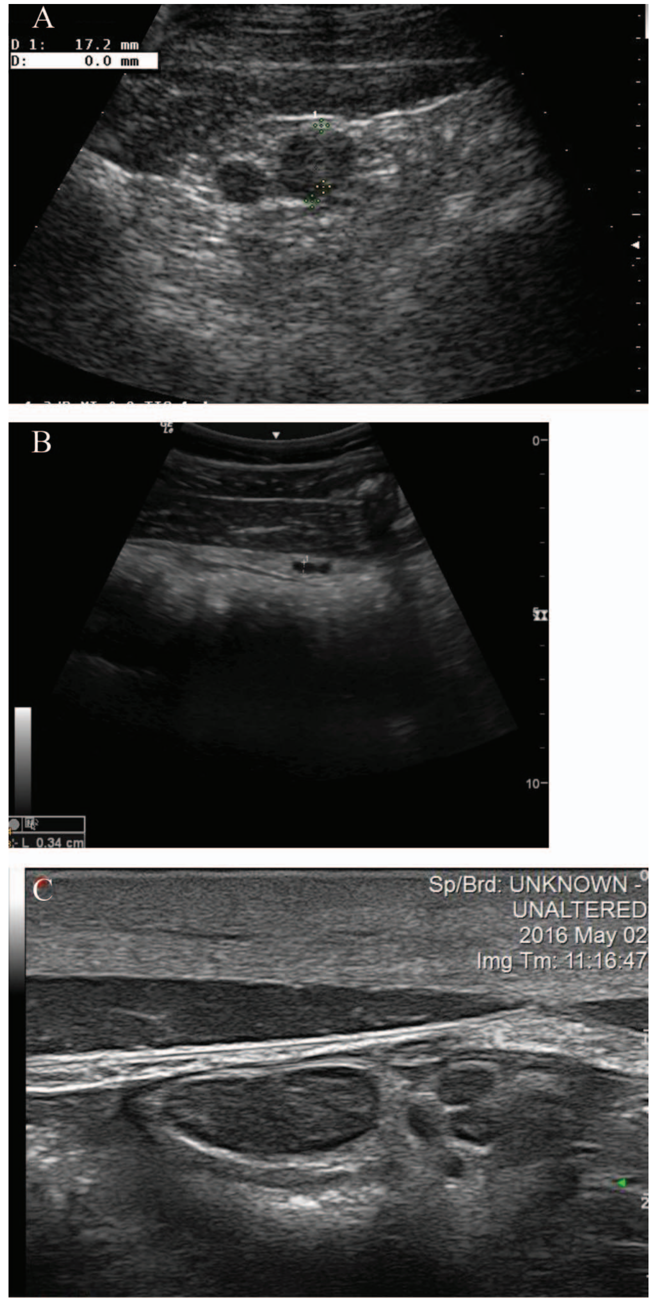

Fig. 9. A, Displaced and distended mesenteric vessels in a horse with right dorsal displacement of the large colon. B, Normal lateral cecal band. C, Lateral cecal band of a horse with peritonitis and mesenteric lymphadenopathy.

Right Middle Third Window

The FLASH protocol says "freely move the probe in the right mid abdomen." Freely moving the probe is not recommended in a protocol that should be specific and fast. The probe is moved from the diaphragm to the costochondral junction in 3 intercostal spaces in the mid abdomen (usually 14–12 ICS). It is useful to image displaced mesenteric vessels. Fig. 8 demonstrates that the diaphragm, the right lobe of the liver, and, medial to it, the right dorsal and ventral colon and duodenum can all be identified. When the probe is moved in a ventral direction, you can identify the remaining right ventral colon and cecum.

With the exception of the vessels in the lateral cecal band, there should be no vessels adjacent to the abdominal wall. If vessels in the right middle third window are observed, this can be indicative of a right dorsal colonic displacement or a large colon volvulus. In cases of large colon volvulus, the colon will likely be thickened. In Fig. 9, mesenteric vessels are seen and the colon wall thickness is normal; this horse had a right dorsal displacement.[7] If there is distended thickened small intestine between the right lobe of the liver and the colon, an epiploic foramen entrapment should be suspected. The lateral cecal band is added in this window to differentiate it from a colonic vessel. The lateral cecal band has a small vein, an artery, and lymphoid tissue. Lymph nodes are small and even hard to see in normal horses. The cecal band is normally located more caudal and ventral than displaced colonic mesenteric vessels. Lymphoid tissue larger than the vein is consistent with mesenteric lymphadenopathy, which may be reactive (e.g., inflammatory) or neoplastic peritonitis, colitis, and/or lymphoma, which are the most common causes for mesenteric lymphadenopathy in the adult horse. A normal cecal band and the appearance of a cecal band in a horse with severe lymphadenopathy caused by peritonitis are shown in Fig. 9B and C.

Thoracic Window

The probe is in the level of the ventral thorax in the 6th intercostal space. Normal horse lung and diaphragm can be imaged moving while the horse breathes. In many horses, pericardial fat can be seen in this location. If a cause of acute colic is not identified on the abdominal FLASH windows, it is important to rule out pleurodynia secondary to pleuropneumonia with this thoracic window. In horses with pleuropneumonia, variable amounts of pleural fluid and a hypoechoic wedge-shaped lung consistent with consolidation are often seen. Diaphragmatic hernias with fluid, small intestine, or the liver in the chest are also readily identifiable. Herniation of the large intestine is more difficult to identify, as gas-filled large intestine can display similar hyperechoic echoes to the lung.

In summary, abnormalities that are likely to be identified in a FLASH are as follows: nephrosplenic entrapment/left dorsal displacements; fluid distension of the stomach; abnormal peritoneal fluid suggestive of ruptured viscus; hemorrhage or peritonitis; thickened ventral colon, more commonly suggestive of large colon volvulus or colitis; abnormal duodenum suggestive of obstruction, ileus, duodenitis, or IBD; displaced mesenteric vessels suggesting right dorsal displacement or volvulus; mesenteric lymphadenopathy; or thoracic disease (pleural effusion or hernia). Pathologies that are unlikely to be identified are the ones that will have abnormalities outside the seven FLASH windows and the ones for which advanced training and more thorough and extensive characterization are needed to recognize. Examples of such etiologies include intussusceptions, disease of the urinary tract or liver, masses outside the windows, or some impactions.

FLASH is not a quick abdominal ultrasound. It is a specific protocol developed for specific patient population: the adult horse with acute colic. The major potential limitation of the FLASH protocol is lower sensitivity than complete sonogram performed by a specialist, but this limitation is typically accepted in favor of an easy-to-learn, shorter, stall-side examination that targets high-yield windows. As for all sonograms, FLASH should be interpreted in light of signalment, history, physical examination, and other diagnostic aids. More about the diagnostic accuracy of this protocol will be learned, but currently, only the ability to detect small intestinal obstructions and the need for exploratory laparotomy have been tested. FLASH is a very useful technique for evaluating the horse with acute colic but cannot replace a full abdominal ultrasonographic evaluation for horses with a clinical presentation different than acute colic.

Acknowledgments

Declaration of Ethics

The Authors have adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Authors have no conflicts of interest.

References

1. Busoni V, De Busscher V, Lopez D, et al. Evaluation of a protocol for fast localised abdominal sonography of horses (FLASH) admitted for colic. *Vet J* 2011;188:77–82.
2. Manso-Díaz G, Bolt DM, López-Sanromán J. Ultrasonographic visualisation of the mesenteric vasculature in horses with large colon colic. *Vet Rec* 2019;186:491.
3. Biscoe EW, Whitcomb MB, Vaughan B, et al. Clinical features and outcome in horses with severe large intestinal thickening diagnosed with transabdominal ultrasonography: 25 cases (2003–2010). *J Am Vet Med Assoc* 2018;253:108–116.
4. Pease AP, Scrivani PV, Erb HN, et al. Accuracy of increased large-intestine wall thickness during ultrasonography for diagnosing large-colon torsion in 42 horses. *Vet Radiol Ultrasound* 2004;45:220–224.
5. Abutarbush SM. Use of ultrasonography to diagnose large colon volvulus in horses. *J Am Vet Med Assoc* 2006;228:409–413.
6. Korolainen R, Ruohoniemi M. Reliability of ultrasonography compared to radiography in revealing intestinal sand accumulations in horses. *Equine Vet J* 2002;34:499–504.
7. Grenager NS, Durham MG. Ultrasonographic evidence of colonic mesenteric vessels as an indicator of right dorsal displacement of the large colon in 13 horses. *Equine Vet J Suppl* 2011;(39):153–155.

How and When to Consider Advanced Diagnostic Procedures in the Field: Point-of-Care Lab Data and Abdominocentesis

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1. Introduction

Use of abdominocentesis and point-of-care monitors that measure blood lactate and blood glucose can be invaluable aids in field assessment of the acute or chronic colic patient. In those patients with a clear need for referral for surgical intervention, these diagnostics may provide helpful prognostic information for the owner, but a balance between time required to perform an abdominocentesis and the need for rapid surgical intervention must also be considered. In those patients for which referral is not a viable financial option, or in cases of longer-standing disease processes of undetermined etiology, these diagnostics can be particularly helpful to guide therapy or decide on euthanasia to end patient suffering.

The key points in this review are indications for abdominocentesis and point-of-care laboratory data (lactate and glucose concentrations) for primary care of the colic patient. A technique summary for abdominocentesis will be provided. Clinical scenarios for field colic cases benefiting most from these diagnostics will be discussed.

2. Abdominocentesis

Technique

Restraint

Before beginning abdominocentesis, proper restraint of the patient is essential to limit the potential for injury to the examiner. Horses should be properly sedated for the procedure with an α-2 agonist such as xylazine HCl[a] (0.3–0.6 mg/kg IV) or detomidine HCl[b] (10–15 μg/kg IV) in combination with butorphanol[c] (0.01–0.02 mg/kg IV). The use of a nose twitch may also be applied by an experienced handler if further restraint is needed. The veterinarian performing abdominocentesis should always stand forward toward the horse's right front leg and reach caudally to limit the potential to be kicked from a hind limb during the procedure. The handler should stand on the same side as the examiner.

Choosing a Location and Aseptic Preparation

Aseptic technique is essential for abdominocentesis due to entry into a body cavity. Ideally, a brief ultrasonographic examination of the proposed region for abdominocentesis should be performed to

NOTES

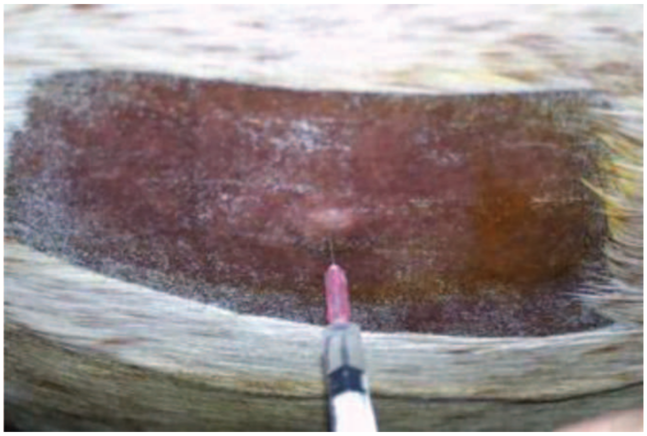

Fig. 1. Local anesthesia with 2.5 mL 2% lidocaine prior to abdominocentesis.

optimize a location and limit the potential for enterocentesis or inadvertent puncture of the spleen. A good starting point for application of the ultrasound probe is in the most cranioventral abdomen, just to the right of midline, behind the xiphoid process and just caudal and axial to the deep pectoral muscles. A measurement of the depth of the body wall at the proposed site of abdominocentesis can also be readily performed with any ultrasound probe to assist with determination of which supplies are needed for successful entry into the peritoneal cavity. Once the location for abdominocentesis has been optimized via ultrasound, clipping of hair followed by a sterile prep of the area should be performed. Local anesthesia using a 25-gauge, 5/8" needle with 2.5–3 mL of 2% lidocaine solution can then be applied to the subcutaneous tissue, following a track vertically to the depth of the needle, through the external rectus fascia (Fig. 1). This step may not be necessary depending on the supplies used for abdominocentesis.

Ultrasonographic findings favorable for abdominocentesis are free peritoneal fluid at the site, although fluid acquisition may be successful in the absence of sonographically evident peritoneal fluid accumulation. Other ultrasonographic features to look for when free fluid is limited, is the presence of visibly mobile viscera. The presence of large colon haustra (sacculations) indicates the absence of heavy colonic content (e.g., sand or gravel) making the risk of enterocentesis lower. Lastly, avoid the spleen to limit the potential for blood contamination.

Choosing Supplies

There are generally 4 options to obtain a sample of peritoneal fluid. These include an 18-gauge, 1.5" needle, an 18-gauge, 3.5" spinal needle, a teat cannula, and a bitch catheter. If abdominal ultrasound was used to determine the depth from the skin surface to the peritoneal cavity and that distance was equal to or less than 2.5 cm, the 18-gauge, 1.5" needle may be sufficient. Body walls thicker than 2.5 cm require one of the alternative options. The risk for penetrating a viscus is believed to be lower with the more blunt-ended teat cannula and bitch catheter, and the proper use of these blunt instruments results in a higher likelihood of obtaining a diagnostic sample. Abdominocentesis using a teat cannula or bitch catheter is also slightly more difficult and time consuming. Use of needles is contraindicated when taut, fluid-filled loops of small intestine are immediately adjacent to the body wall or palpated per rectum as inadvertent puncture or laceration of small intestine is likely to result in septic peritonitis.

Technique with Needles

Following site selection and aseptic preparation, the 18-gauge needle is inserted through the skin, subcutaneous tissues, and external rectus fascia using sterile gloves to handle the needle. The needle should then be advanced a few millimeters at a time, with a spin of the needle to encourage fluid movement. The 1.5" needle will often need to be inserted to its full length prior to entering the peritoneal cavity. Occasionally, a vacuum effect due to the negative pressure within the abdomen will prevent fluid from exiting via the needle, and insertion of a second needle immediately adjacent to the first may allow flow of peritoneal fluid. Alternatively, a small volume 2–3 mL of air may be injected through the needle using a sterile 3-mL syringe. It may be difficult to discern whether the tip of the needle has reached the peritoneal cavity. Gentle movement of the needle hub is common when within the peritoneal cavity due to movement of intestinal viscera against the tip of the needle. Fluid should be collected into an ethylenediaminetetraacetic acid (EDTA) blood collection tube unless a septic process is suspected where samples should be collected in both EDTA and sterile red top tubes. Lactate concentration can be measured from EDTA or heparinized tubes.

Technique with Teat Cannula or Bitch Catheter

The following supplies are required following aseptic preparation and local anesthesia prior to initiating abdominocentesis: sterile #15 scalpel blade, sterile 3×3 or 4×4 gauze, teat cannula or bitch catheter, and collection tubes (EDTA $\pm$ red top tube) (Fig. 2). Following site selection, aseptic preparation and application of local anesthetic, a stab incision is made through the skin, subcutaneous tissue, and external rectus fascia by the examiner wearing sterile gloves. Avoid injury to small vessels in the skin. In overweight horses, this may require deep insertion of the #15 blade beyond the primary cutting edge. The external rectus fascia is palpable with the tip of the blade and should be recognized and then penetrated to a depth of 0.5 cm before extracting the blade (Fig. 3). The teat cannula or bitch catheter should be pushed through the center of a sterile

Fig. 2. Supplies required for abdominocentesis with a teat cannula or bitch catheter.

gauze pad prior to insertion to protect the sample from blood contamination arising from the skin and subcutaneous tissues. A second sterile swab may be used to blot the stab incision site and the instrument is inserted through the skin. The tip of the instrument can then be used to find the opening created through the dense, external rectus fascia, and the cannula is inserted through this layer and through the rectus abdominus muscle. A palpable "pop" may be recognized as the instrument is further inserted through the internal rectus abdominus fascia and a final "pop" may be associated with the peritoneum. Pain is often elicited upon tenting and puncture of the peritoneum. Fluid flow should be anticipated at this point when present. It is critical to guard the placement by gripping the instrument with sterile gloves near the body wall to ensure the instrument is not forced rapidly into the peritoneal cavity, potentially risking viscus penetration. Keep in mind that the peritoneum will tent away from the blunt-ended instrument, so it may need to be inserted several inches beyond the measured thickness of the body wall before the peritoneum is penetrated. Many standard stainless steel bovine teat cannulas are only 8 cm (3.6") in length, so if the body wall is relatively thick, a longer bitch catheter is more likely to yield a fluid sample. Failure to penetrate the peritoneum is a common reason for not obtaining a sample. Maintenance of the teat cannula/bitch catheter perpendicular to the body wall is important to limit the potential for dissection retroperitoneally or through the rectus abdominus muscle. If uncertain of the position of the cannula, a sterile 6-mL syringe may be firmly attached to the end of the cannula and 5 mL of air may be rapidly injected and then aspirated. When in the peritoneal cavity, most air will escape into the abdomen and only a small amount will be retrieved (<2 mL). Lastly, be wary of very firm surfaces with little give to them such as sand or a very firm impaction. If unsure of the safety of the procedure, consider repeating ultrasound of the region to find an optimal location.

Potential complications to abdominocentesis include enterocentesis, splenic puncture and hemorrhage, and omental herniation in foals.[1] Prevalence of enterocentesis is estimated to be between 2% and 5% with secondary complications in 0.5% of cases.[2] In the instance of enterocentesis, the author will initiate broad-spectrum antimicrobial therapy for 1–3 days.

Indications for Abdominocentesis

Abdominal paracentesis is a useful diagnostic aid to assess for the presence of intestinal injury from distention or ischemia in the acute or chronic colic. It has further indications in other processes such as peritonitis or to search for intra-abdominal neoplasia. With reference to colic in the field setting, it is appropriate for particular circumstances. As it is a relatively invasive procedure, it is not appropriate for an initial evaluation of a patient showing mild-to-moderate colic signs that is likely to respond to medical therapy. For horses sent to referral hospitals where the need for surgical intervention is unclear, it is considered a routine part of the minimum database. In horses with a surgical option, it serves as a helpful guideline for nonstrangulating obstructions to determine whether further attempts at analgesia and medical therapy are indicated, or to ensure minimal injury is present prior to therapeutic procedures such as exercise or rolling. Other indications are assessment for the presence of a strangulating obstruction versus an inflammatory condition such as enteritis or colitis. In the field setting, the indications for abdominocentesis in the acute colic are when gastrointestinal rupture is sus-

Fig. 3. Image demonstrating insertion of the #15 scalpel blade through the locally anesthetized skin, subcutaneous tissue, and the external rectus fascia.

pected, and when a strangulating obstruction is suspected but the horse is not eligible for referral and surgery due to financial or personal decisions by the owner. It is critical to obtain a definitive diagnosis in these two scenarios to support the indication for euthanasia and alleviate the suffering of the horse. For horses with suspected gastrointestinal rupture, an ultrasound examination is highly valuable prior to abdominocentesis to ensure the presence of septic peritonitis with increased free peritoneal fluid. A third scenario where it could be helpful is when the horse has a nonstrangulating obstruction that is not responsive to initial medical therapy, and the owners are unwilling to refer. Abdominocentesis may be helpful in guiding progression of disease and in determining how long attempts at medical therapy should persist. Lastly, abdominocentesis may be indicated in atypical or chronic cases to help guide diagnosis or the need for referral.

Interpretation of Peritoneal Fluid Findings

The most practical method of peritoneal fluid analysis in the field colic consists of 3 simple assessments. Color is one of the most reliable methods for distinguishing nonstrangulating from strangulating disorders, with a serosanguinous color associated more commonly with strangulating disorders (Fig. 4).[3] The second practical method is assessment of total protein using a refractometer along with general assessment of opacity. Normal peritoneal protein concentration is 0.8–1.2 g/dL, and higher concentrations (e.g., >2.0 g/dL) suggest inflammation or injury to the intestine or peritoneal cavity.[4] It is important to assess protein levels with a minimum volume of 1–2 mL of fluid as EDTA additives can falsely elevate refractive protein values.[5] Lastly, a point-of-care lactate meter can be helpful to distinguish nonstrangulating from strangulating obstructions through assessment of the peritoneal fluid lactate to blood lactate ratio. A peritoneal fluid to blood lactate ratio of >2.0 is 64% sensitive and 72% specific for the detection of small intestinal strangulating obstructions. Serial lactate assessments of peritoneal fluid increase both sensitivity and specificity to detect strangulating obstructions.[6] Serosanguinous fluid color is 90% sensitive and 61% specific for small intestinal strangulating obstructions,[7] so the combination may be of particular value in decision making in the field colic. Further assessments in a laboratory setting that could be pursued include nucleated cell count, cytologic evaluation, glucose, pH, D-dimers, and creatine kinase. When a septic peritonitis or gastrointestinal rupture is suspected, some of these additional assessments can be valuable. Horses with gastrointestinal rupture may have peritoneal fluid with a gross appearance of particulate material or a green or brown hue to the fluid or supernatant after centrifugation, but commonly will have a serosanguinous appearance. Cytologic examination can be highly informative to identify the presence of mixed extracellular bacterial populations with or without plant material.

Fig. 4. Serosanguinous fluid from a horse with a strangulating obstruction.

3. Point-of-Care Lab Data: Lactate Meter

As the majority of data collected on point-of-care laboratory data has derived from referral centers, more studies are needed to determine their usefulness in the primary care setting. However, the point-of-care lactate meter has become an affordable and readily available option for field practitioners. Blood lactate can give you an immediate idea of severity of a disease process with regard to circulatory and intestinal compromise, but by itself, does not distinguish between strangulating and nonstrangulating obstructions.[7] It can serve as a useful guideline for fluid therapy needs in any acutely ill horse with hypovolemia,[8,9] and can be a helpful early prognostic indicator in horses with large colon volvulus.[10] In a study of horses with large colon volvulus, blood lactate concentrations greater than 7 mmol/L were associated with a 30% survival rate.[10] Normal blood lactate lies between 0.6 and 1.5 mmol/L.[9] As described above, use of a peritoneal fluid to blood lactate ratio as well as serial peritoneal fluid (PF) lactate assessment increase the sensitivity and specificity of lactate for the detection of strangulating obstructions and thus the acute need for surgery. Always keep in mind that blood lactate values in ponies presenting with a primary complaint of gastrointestinal disease have higher admission lactate concentrations (2.8 mmol/L vs 1.6 mmol/L) than adult horses, to avoid overestimating the severity of disease in that population.[11]

4. Point-of-Care Lab Data: Glucometer

Hyperglycemia is common in horses with colic and can be easily and affordably measured using a handheld glucometer, providing additional evidence toward severity of a disease process. Approximately 50% of horses with colic admitted to referral hospitals have blood glucose concentrations >135 mg/dL, and extreme hyperglycemia (>180 mg/dL) has been associated with surgical colic, strangulating obstructions, and decreased short- and longer-term survival.[12,13] Hyperglycemia may occur acutely as part of the stress response to a severe gastrointestinal obstruction, but also occurs secondary to glucose dysregulation and insulin resistance that develops with progressive disease.[14] Glucose can be a valuable adjunct to peritoneal fluid analyses when a septic peritonitis is suspected such as with presence of cloudy peritoneal fluid. Peritoneal fluid glucose concentrations less than 30 mg/dL have been shown to be highly specific for septic peritonitis as well as a peritoneal fluid glucose to blood glucose difference of greater than 50 mg/dL.[15] It also should be noted that the correlation between hand held glucometers to plasma chemistry analyzers can vary, and it is important to ensure calibration for each new reagent lot is performed, and that test strips are properly stored with regard to temperature and humidity recommendations.[16]

Although less widely utilized, point-of-care triglyceride analyzers have also been validated for use in horses, ponies, and donkeys,[17] and may provide valuable adjunctive data in horses with more chronic or insidious conditions, as hypertriglyceridemia is a relatively common complication in anorectic equids.

5. Summary

Abdominocentesis is valuable in horses managed in the field with acute colic where a decision for euthanasia must be made either when surgical intervention is not a financially viable option for the owners, or if gastrointestinal rupture is suspected and should be confirmed. Other scenarios where abdominocentesis may be helpful include recurrent colic, suspected peritonitis, and for serial assessment in horses with persistent nonstrangulating obstructions not amenable to referral, particularly if peritoneal fluid can be identified on ultrasonographic examination. A brief ultrasonographic examination at the site of abdominocentesis is highly recommended to recognize presence of peritoneal fluid and to avoid injury to viscera or enterocentesis. Interpretation of peritoneal fluid findings can be readily performed in the field by visual inspection and use of a refractometer and lactate meter.

Field assessment of horses with colic using a portable lactate meter and glucometer can provide valuable insight into severity of the disease process to guide therapy or the need for referral or euthanasia.

Acknowledgments

Declaration of Ethics

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Conflict of Interest

The Author has no conflicts of interest.

References and Footnotes

1. Desrochers AM, White NA. Diagnostic approach to colic. In: Blikslager AT, White NA, Moore JN, Mair TS, eds. *The equine acute abdomen*. 3rd ed. Hoboken, NJ: John Wiley & Sons, Inc; 2017;223–262.
2. Tulleners EP. Complications of abdominocentesis in the horse. *J Am Vet Med Assoc* 1983;182:232–234.
3. Weimann CD, Thoefner MB, Jensen AL. Spectrophotometric assessment of peritoneal fluid haemoglobin in colic horses: An aid to selecting medical vs. surgical treatment. *Equine Vet J* 2002;34:523–527.
4. Brownlow MA, Hutchins DR, Johnston KG. Reference values for equine peritoneal fluid. *Equine Vet J* 1981;13:127–130.
5. Estepa JC, Lopez I, Mayer-Valor R, et al. The influence of anticoagulants on the measurement of total protein concentration in equine peritoneal fluid. *Res Vet Sci* 2006;80:5–10.
6. Peloso JG, Cohen ND. Use of serial measurements of peritoneal fluid lactate concentration to identify strangulating intestinal lesions in referred horses with signs of colic. *J Am Vet Med A* 2012;240(10):1208–1217.
7. Shearer TR, Norby B, Carr EA. Peritoneal fluid lactate evaluation in horses with nonstrangulating versus strangulating small intestinal disease. *J Equine Vet Science* 2018;61:18–21.
8. Fielding CL, Magdesian KG. How to use venous blood lactate concentration to guide fluid therapy in adult horses, in *Proceedings*. Am Assoc Equine Pract 2015;51:2005.
9. Lumsden JH, Rowe R, Mullen K. Hematology and biochemistry reference values for the light horse. *Can J Comp Med* 1980;44:32–42.
10. Johnston K, Holcombe SJ, Hauptman JG. Plasma lactate as a predictor of colonic viability and survival after 360 degrees volvulus of the ascending colon in horses. *Vet Surg* 2007;36:563–567.
11. Dunkel B, Kapff JE, Naylor RJ, et al. Blood lactate concentrations in ponies and miniature horses with gastrointestinal disease. *Equine Vet J* 2013;45:666–670.
12. Hassel DM, Hill AE, Rorabeck RA. Association between hyperglycemia and survival in 228 horses with acute gastrointestinal disease. *J Vet Intern Med* 2009;23:1261–1265.
13. Hollis AR, Boston RC, Corley KT. Blood glucose in horses with acute abdominal disease. *J Vet Intern Med* 2007;21:1099–1103.
14. Toth F, Frank N, Chameroy KA, et al. Effects of endotoxaemia and carbohydrate overload on glucose and insulin dynamics and the development of laminitis in horses. *Equine Vet J* 2009;41:852–858.
15. Van Hoogmoed L, Rodger LD, Spier SJ, et al. Evaluation of peritoneal fluid pH, glucose concentration, and lactate dehy-

drogenase activity for detection of septic peritonitis in horses. *J Am Vet Med Assoc* 1999;214:1032–1036.
16. Wilkins PA. Advantages and potential pitfalls of point of care glucose and lactate monitoring, in *Proceedings*. Am Assoc Equine Pract 2007;53:356–359.
17. Pongratz MC, Junge HK, Riond B, et al. Validation of the Accutrend Plus point-of-care triglyceride analyzer in horses, ponies and donkeys. *J Vet Emerg Crit Care* 2016;26:682–690.

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How to Manage a Horse with Colic in the Field

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Medical management of colic in the field is initially centered on management of pain, which also becomes of critical importance to the decision to refer and on estimating the prognosis. Other components of medical management include decisions related to nasogastric intubation of laxatives and reasonable recommendations for fluid therapy. Rehydration can be accomplished with nasogastric administration of water (with or without electrolytes), or IV fluids, which can be given in the field, but are more typically reserved for in-hospital use. This presentation is intended to provide important points related to choices of analgesics and other medical therapies so that horses with colic can be optimally treated, while avoiding any delays on a potential decision to refer for advanced medical or surgical care. Author's address: Department of Clinical Sciences, North Carolina State University, 1060 William Moore Drive, Raleigh, NC 27607; e-mail: Anthony_Blikslager@ncsu.edu.

1. Introduction

Veterinarians are called on a frequent basis to evaluate horses that have developed colic. In many cases, the colic will have either resolved or require simple medical treatment by the time the veterinarian arrives. One factor that complicates the veterinary approach to colic is the frequent use of analgesics by horse owners and trainers. Although this is often under the direction of a veterinarian, this is not always the case, and can complicate case management. Subsequent to management of pain, other treatments for colic that need to be considered are use of nasogastric administered laxatives or fluids, as well as consideration as to the practicality of IV fluid therapy. The goal of this presentation is to present the rationale for the use of differing treatments available for management of colic.

2. Recognition of Colic

Owners have varying abilities to detect colic in their horses. Some owners only notice when the horse has severe colic, but many notice subtle changes in behavior that are not necessarily clear-cut signs of colic. These behavioral signs of colic are nonetheless important for the veterinarian to consider. As the field of pain management in veterinary medicine has dramatically changed in recent years, so has the veterinarians' ability to detect pain (Table 1).[1] When an owner calls to report that a horse has abnormal behavior, such as showing a lack of interest in feed, there is a reasonable likelihood that they have detected behavioral signs of pain, and the most likely cause of pain is colic. For example, horses with early signs of colic tend to stand toward the back of the stall, lose interest in observing other horses and people at the barn, and often will not finish a meal. At veterinary teaching hospitals, behavioral pain scores have been developed to detect subtle behavioral signs of pain that would typically be missed, and they have become a routine component of the monitoring of horses.[2] In addition, a description of an equine "pain face" has provided an

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Table 1. A Pain Scoring System Adapted to Detect Behavioral Signs of Pain That Can Be Used to Recognize Subtle Cases of Colic That May Initially Appear Normal. Behavioral Pain Scoring System

Behavior Category	Behavioral Score to be Assigned for Each Category			
	0	1	2	3
Gross pain	None	NA	Occasional	Continuous
Head position	Above withers	NA	At withers	Below withers
Ear position	Forward, frequent movement	NA	Slightly back, little movement	NA
Location	At door watching environment	Standing in middle, facing front of stall	Standing in middle, facing sides of stall	Standing in middle, facing back of stall
Spontaneous locomotion	Moves freely	Occasional steps	NA	No movement
Response to another horse	Ears forward, head up, moves to door	Ears forward, head up, no movement to door	Ear flick, no movement to door	No response
Response to open door	Moves to door	Looks at door	NA	No response
Response to approach	Moves to observer, ears forward	Looks at observer, ears forward	Moves away	Does not move, ears back
Lifting feet	Freely when asked	After mild encouragement	NA	Unwilling

Scores are added to give a total subjective pain score.
NA, not applicable.
Modified from Pritchett LC, Ulibarri C, Roberts MC, et al. Identification of potential physiological and behavioral indicators of post-operative pain in horses after exploratory celiotomy for colic. *Appl Anim Behav Sci* 2003;80:31–43, with permission from Elsevier.

additional level of subtlety when it comes to pain detection. This results from tensing of the musculature along the muzzle and above the eye.[3]

3. Initial Considerations

Ever since dipyrone was initially taken off the market in 1977, most horse farms have flunixin meglumine readily available and it has become common for trainers to administer non-steroidal anti-inflammatory drugs for colic without consulting the veterinarian. This is not necessarily in compliance with state veterinary practice acts. One approach is to ask the owner or trainer to at least call the practice to let the veterinarian know before treating a horse for colic so that treatment can be discussed. Owners and veterinarians need to be aware that a full dose of flunixin meglumine (1.1 mg/kg, IV) for treatment of colic is a potent analgesic and has duration of 8–12 hours. Use of flunixin meglumine at the currently recommended maximum dosage (1.1 mg/kg, q12h, IV) can make pain in horses that are in true need of intensive care more difficult to detect. This issue of “masking” of colic signs by owner or trainer administration of analgesics continues to be problematic, particularly when it delays further treatment. Dipyrone was successful because it was a mild analgesic and did not completely ameliorate pain in horses requiring surgery. Interestingly, this medication has recently become available on the market again, although it is labeled for treatment of pyrexia.[4]

4. Initial Examination

To shorten the time needed to examine a horse with colic, consider asking your receptionist to get the signalment, treatments given, effect of treatment, and duration of colic. Owners may be reluctant to admit to administering treatments, necessitating some skill in obtaining an accurate history. Therefore, it is important for the receptionist or the veterinarian to ask questions about administration of medications in a way that makes the owner feel comfortable about providing an accurate answer. Additional history, such as diet, de-worming schedule, and housing can be obtained after the horse has been attended to with some exceptions. For example, it is very helpful to know a horse’s forage diet in the Southeastern United States because of the prevalence of ileal impaction associated with coastal Bermuda hay.

On physical examination, the veterinarian can make a more accurate determination of the level of colic (mild, moderate, or severe). This may require having the horse in its normal environment such as a stall or paddock so the behavior is not inhibited by being handled. The next step is to assess the cardiovascular status of the horse. This is done by assessing the color of the gums, obtaining a capillary refill time, and taking the heart rate. It is preferable to take the pulse from the facial artery so that an assessment of pulse quality (“thready” or strong) can be made. However, the horse sometimes makes this difficult because it is in pain; at which time auscultatation of the chest is appropriate. If the horse is severely painful, obtaining the heart rate is important if possible because it has consistently been shown to be the best prognostic indicator.[5]

5. Initial Treatment of Pain

If a horse is actively showing signs of colic, and once the cardiovascular status has been obtained, this is the time to treat for pain. The author’s choice is xylazine (0.3 mg/kg; 150–200 mg) because it is short-acting (approximately 40 minutes), highly effective as an analgesic, and sedates the horse to facilitate the remainder of the examination.[6] A popular and effective addition to xylazine is butorphanol (5 mg, IV). If the veterinarian chooses to use flunixin meglumine (0.25–1.1 mg/kg, IV), it has a long duration of action (up to 12 hours), which makes it more difficult to determine if colic is recurrent while conducting a timely visit. Another medication that has become available is hyoscine butylbromide[a] (0.3 mg/kg, slowly IV). This is an excellent anti-spasmodic agent, but the product sold in the United States does not contain an analgesic (this product sold in Europe, also contains dipyrone [metamizole] and is the favored choice for initial treatment for colic in other countries). However, hyoscine butylbromide[a] can be given with nonsteroidal anti-inflammatory drugs available in the United States. Concerns on transient elevations in heart rate with hyoscine butylbromide[a] (approximately 20 minutes) become of less concern if the veterinarian has already checked the heart rate and administered an analgesic. If an initial dose of xylazine, particularly if administered with butorphanol, has no effect, the treatment can be repeated. However, it is important to realize that the necessity for a second treatment with an analgesic raises the index of suspicion that a horse needs referral. If pain continues, more potent sedatives such as detomidine (0.01–0.02 mg/kg; 5–10 mg, IV) can be used and can be repeated as needed if the horse remains painful. If repeated doses of detomidine are ineffective, the horse needs to be referred if at all possible. For owners that do not wish to refer, inability to control pain is an important factor in making the decision to euthanize a horse. Alternatively, for horses that respond well to an initial dose of xylazine, following completion of the remainder of the examination, flunixin meglumine (1.1 mg/kg, IV) is helpful as an anti-inflammatory and longer duration analgesic if it has not already been given. If colic does recur, the risk that surgery or intensive care is needed is increased. Therefore, the owner or trainer should be given explicit instructions to keep the horse in a stall, hold the horse off feed, and regularly monitor the horse for 24 hours for recurrence of pain. It is also helpful to ask the owner to assess fecal output. Many horses that arrive at referral hospitals after prolonged durations of colic have been treated on multiple occasions for colic, which can be improved upon if horses with the first recurrence of pain after analgesia are considered for referral. Nonetheless, considerations of expense, owner preference, and shipping are widely understood to complicate decision making.

6. Remainder of the Physical Examination

Once the horse is comfortable, the level of dehydration can be determined by tenting the skin on the neck, and looking at the appearance of the eye in the orbit. This can be deceiving in senior horses because of the loss of elasticity of the skin. Nonetheless, most horses can be practically defined as not dehydrated (skin tent, 2–3 seconds), 6% dehydrated (3–6-second skin tent), 8% dehydrated (6–8 second skin tent, some evidence of the eye sinking back into the orbit), or 10% dehydrated (prolonged skin tent, obvious sinking of the eye). The next component of the examination is auscultation of the chest to confirm heart rate (this may be affected by an alpha-2 agonist such as xylazine) and to briefly auscultate the lung fields. Auscultation of the abdomen at the paralumbar fossa as well as at a site on the lower flank for approximately 1 minute on each side is reasonable to classify gut sounds as absent, normal, or increased. Gut sounds may be reduced in response to alpha-2 agonists. The time required for this part of the examination provides a good opportunity to take the rectal temperature, and this should always be done prior to rectal palpation. A febrile horse with signs of colic is often associated with the early phases of enteritis or colitis, and some horses with colitis have severe abdominal pain.

Rectal palpation is a useful and practical means to determine the intestinal segment causing the cause of colic. Determining the position of the spleen is important. If it feels larger than normal, and pushed away from the body wall, the most frequent reason is that the colon is between the spleen and body wall. Phenylephrine (0.01 mg/kg over 20 minutes diluted in saline) and walking or jogging the horse can be helpful to vasoconstrict the spleen to help resolve possible colonic displacement on the left side of the abdomen.[7] Another critical component of the colic examination is nasogastric intubation. When horses have severe pain or tachycardia, the stomach tube should be passed early during the examination to relieve possible gastric distension.

Diagnostic ultrasound is becoming a common diagnostic modality and can be adapted to use rapidly in the field using a fast localized abdominal sonography for horses examination. This takes approximately 10 minutes to perform, and can be used to detect such findings as abdominal fluid, distended small intestine, and the appearance of the nephrosplenic space. This is particularly useful in regions of the abdomen beyond the reach of rectal palpation and can be used in conjunction with rectal palpation to provide as much information as possible in terms of localizing the cause of colic.

7. Laxative Treatment

Laxatives should be administered via nasogastric tube, and only when there is no evidence of gastric reflux. Additionally, if the veterinarian suspects a small intestinal obstruction, including ileal impaction, nasogastric laxatives or fluids are not indicated because of a lack of transit to the region of the impaction. If a horse is suspected of having a gastric impaction, multiple water lavages of the stomach are warranted. Although mineral oil (2 to 4 L/500 kg PO) is commonly used as a laxative, it has been shown that hydration of the colonic contents can be better achieved by administration of magnesium sulfate (1 g/kg in 4 L of water PO).[8] While sodium sulphate has been shown to result in greater colonic content hydration than magnesium sulphate, it also results in thirst and hypocalcemia, making magnesium sulphate preferable.[8] Access to feed should not be permitted but water should be freely available. For impactions that persist, aggressive enteral and/or intravenous fluid therapy should be instituted. One study demonstrated the increased efficacy of continuously administered enteral rehydration solution in softening colonic contents as compared with intravenous fluids, which are probably best suited to restoring the systemic extracellular fluid compartment.[9] In another study, investigators determined that administration of 8–10 L of isotonic enteral fluids every 2 hours in horses with either large colon impaction or large colon displacement successfully resolved impactions in 99% of cases and in excess of 80% of large colon displacements within 24-hours. The enteral fluid was practically simple to make, using 6 g NaCl and 3 g KCl/ L of tap water. made from water and electrolytes. In some cases, a less aggressive approach (5 L q 2–4 hours) is helpful to reduce impactions without causing colic or reflux associated with over-filling the stomach. If the impaction remains unresolved, the horse becomes uncontrollably painful, or extensive gas distention of the colon occurs, surgery is indicated.

8. Considerations for Fluid Therapy

Intravenous fluid therapy is typically more practical to reserve for referral hospitals because of the need for frequent monitoring by a knowledgeable technical staff. It is certainly possible to administer fluids in the field, but the time taken to place a catheter and a therapeutic volume of fluids should be carefully considered. Occasionally, catheter placement is also reasonable to enable horse owners to repeat treatment during shipping, particularly for a recurrently painful horse that has a long shipping time. For IV fluid therapy, once the degree of dehydration has been estimated, the percentage is multiplied by the horse's body weight to give the fluid deficit (e.g., 6% dehydration $\times$ 500 kg = 30 L). In the field, if fluids are going to be administered, the veterinarian should be prepared to give approximately 15–20 L, which corresponds to half the fluid deficit for an adult horse that is 6% to 8% dehydrated. This avoids any misconception by the owner that a small volume of fluids will make a difference.

9. Conclusions

Important considerations for optimal treatment of colic in the field are optimal use of available analgesics based on their potency and duration of action, as well as a knowledge of how well the horse can be monitored by the owner. Other considerations are the indicated usages of nasogastric laxatives, and the place of rehydration therapy. Importantly, field analgesia and fluid therapy are effective in the large majority of horses with colic. However, for those horses with breakthrough pain, particularly after potent analgesics including alpha-2 agonists (xylazine and detomidine) and opiates (butorphanol) should be carefully considered for referral. Additionally, management of pain but a lack of success at resolving conditions like large colon impactions over 1–2 days should be also be considered for referral.

Acknowledgments

Declaration of Ethics

The Author has adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Author has no conflicts of interest.

References and Footnote

1. Sellon DC, Roberts MC, Blikslager AT, et al. Effects of continuous rate intravenous infusion of butorphanol on physiologic and outcome variables in horses after celiotomy. *J Vet Intern Med* 2004;18:555–563.
2. van Loon JP, Van Dierendonck MC. Monitoring acute equine visceral pain with the Equine Utrecht University Scale for Composite Pain Assessment (EQUUS-COMPASS) and the Equine Utrecht University Scale for Facial Assessment of Pain (EQUUS-FAP): A scale-construction study. *Vet J* 2015;206: 356–364.
3. Gleerup KB, Forkman B, Lindegaard C, et al. An equine pain face. *Vet Anaesth Analg* 2015;42:103–114.
4. Morresey PR, White GW, Poole HM, et al. Randomized blinded controlled trial of dipyrone as a treatment for pyrexia in horses. *Am J Vet Res* 2019;80:294–299.
5. Proudman CJ, Dugdale AH, Senior JM, et al. Pre-operative and anaesthesia-related risk factors for mortality in equine colic cases. *Vet J* 2006;171:89–97.
6. Blikslager A. Managing pain associated with colic. *Comp Contin Educ Pract Vet* 2008;30:294–307.
7. Hardy J, Bednarski RM, Biller DS. Effect of phenylephrine on hemodynamics and splenic dimensions in horses. *Am J Vet Res* 1994;55:1570–1578.
8. Lopes MA, White NA 2nd, Donaldson L, et al. Effects of enteral and intravenous fluid therapy, magnesium sulfate, and sodium sulfate on colonic contents and feces in horses. *Am J Vet Res* 2004;65:695–704.
9. Lopes MA, Walker BL, White NA 2nd, et al. Treatments to promote colonic hydration: Enteral fluid therapy versus intravenous fluid therapy and magnesium sulphate. *Equine Vet J* 2002;34:505–509.

[a]Buscopan®, Boehringer Ingelheim Animal Health, Ltd., Duluth, GA 30096.

How and When to Refer the Horse with Colic That Is Not Responding to Medical Management

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1. Introduction

Referral of the horse with colic on an emergency basis is stressful for owners, caregivers and the veterinarians trying to do the best medically and financially for the horse and owner. Encouraging clients to have an emergency plan for their horse(s) and to be prepared will contribute to a favorable outcome. An emergency preparedness checklist for horse owners and caregivers includes knowing the following:

- Contact information for owner, if caregiver
- Horses/foals for which referral is an option
- Horses/foals for which surgery is an option
- Financial outlay that can be made on a particular horse/foal
- Referral hospital information (address, telephone number, directions)
- Insurance company information (company name, telephone number, policy information)
- Pertinent medical history
- Breeding and foaling dates and other specific information for broodmares

Referral can also occur on an elective basis. While referral on an elective basis is generally less expensive, it should be reserved for patients with chronic intermittent or recurrent colic.

Veterinarians should be familiar with the referral procedures at a particular hospital. Admission information including client name, address, telephone number(s); horse name, age, breed, sex, and previous admission; and insurance information should be provided.

Pertinent information to be provided directly to the attending veterinarian at the referral hospital includes the following:

- History
  —Specific colic signs
  —Duration of colic
  —Previous colic history
  —Fecal production and consistency
  —Breeding status of mare
  —Concurrent disease (co-morbidities)
  —Current medication

- Physical examination
  —Severity of pain
  —Heart and respiratory rate
  —Rectal temperature
  —Oral mucous membrane color, moistness, capillary refill time
  —Borborygmi

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- Drugs administered
  —Flunixin meglumine: Time(s)? Dose? Route?
  —Sedation: Drug used? Time(s)? Dose? Route?
  —Response to analgesia

- Client expectations and financial constraints

Preparation involves having a patient as stable as possible upon arrival at the referral hospital and an owner/caregiver with appropriate expectations such that they can make decisions for their animal.

2. Patient

Patient preparation includes providing adequate analgesia for the trailer ride. If the horse is showing mild to moderate pain, xylazine with or without butorphanol is usually adequate. However, in the severely painful horse (e.g., large colon volvulus) detomidine may be necessary. Avoid using potent long-lasting analgesic drugs (e.g., detomidine) in horses that are only mild to moderately painful, especially if the trailer ride is short, because this makes evaluation upon admission to the referral hospital difficult. Analgesic drugs can be provided for the owner to administer to the horse during transportation, if necessary and if safe. Information pertaining to drug used, dose, route, and time of administration immediately before or during transportation should be provided to the attending veterinarian at the referral hospital.

If a horse has reflux following nasogastric intubation, or distended loops of small intestine on palpation per rectum or ultrasonographic evaluation, re-checking for reflux immediately prior to transportation is imperative. It is also recommended to transport the horse with the nasogastric tube secured in place. While gastric rupture can occur even with a nasogastric tube in place, it allows for decompression immediately upon arrival at the referral hospital and if the end of the tube is left unplugged then fluid under pressure can be expelled. Taping a gloved finger over the end of the tube and cutting a hole in the tip provides a one-way valve whereby reflux can be expelled if gastric pressure builds up while avoiding aspiration of air into the stomach. The tip of the nasogastric tube should be nowhere near the patient's eye because it can cause mechanical trauma or chemical injury can result from any expelled reflux. Rarely, horses can aspirate with the nasogastric tube in place and while there is nothing specific to prevent this, awareness is important for early identification of horses developing aspiration pneumonia.

Trocharization is generally not recommended prior to referral. While the procedure is safe when the appropriate technique is used, there is still the risk of developing peritonitis or intestinal injury. The only indication for trocharization prior to referral is when the severity of abdominal distention is such that the horse is unable to adequately ventilate and likely to go into respiratory arrest during transportation.

Intravenous fluid therapy is generally not necessary prior to referral. The exception to this would be a horse with a suspected small intestinal strangulating obstruction showing signs of shock and requiring a long trailer ride to the referral hospital. In most cases, the time taken to administer sufficient fluids to stabilize the horse does not warrant the delay in referral. It is not recommended to administer fluids during transportation particularly during winter when the fluid in the bags can freeze.

If it is anticipated that the horse may become recumbent during transportation, the dividers should be taken out of the trailer and the horse's head either not tied or tied loosely to facilitate getting the horse off the trailer upon arrival. Horses with large colon volvulus, gastrointestinal rupture, and severe colitis typically become recumbent during transportation. If possible, it can be useful to have the owner/caregiver or transporter give the referral hospital a call when they are 15–30 minutes from arrival in instances where travel exceeds an hour.

3. Client Preparation

The owner should be given an overview of expectations upon arrival at a referral hospital. Procedures and policies vary between hospitals and practitioners should be at least somewhat familiar with such information. Emergency clinicians have preferences based on clinical experience and geographical region regarding procedures and diagnostic tests. Many hospitals have referral packets that can be obtained to have on hand for clients when emergency referral of their horse is necessary.

In most hospitals, the client will need to register at the reception desk. The personnel will vary between hospitals and may include interns/residents, emergency clinician or surgeon, nursing or technical staff, and veterinary students.

Typically, a history will be taken by a veterinarian, student, or nurse. A physical examination may be performed by multiple veterinarians (and students). Blood may be drawn from the jugular vein for laboratory data, a nasogastric tube passed, a jugular vein catheter placed and the horse administered a bolus of intravenous fluids. Abdominocentesis may be performed using a needle or teat cannula and it is important to recognize that in some cases peritoneal fluid is not obtained. Abdominal palpation per rectum and often transabdominal ultrasonographic evaluation are performed. The client may or may not be able to be present during these procedures. The findings will be discussed with the owner and a treatment plan, which will involve the decision to manage the horse medically or surgically, with associated expenses and prognosis explained. An estimated 40% to 50% of horses referred for colic require surgery and it is important to recognize that certain medical diseases (e.g., colitis, enteritis) require intensive management with the associated expense.

Clients should be aware of the approximate expense associated with emergency (or elective) admission, medical treatment, surgical treatment as well as required deposits and payment requirements or options. There are considerable regional variations in expenses but some ranges of costs at US hospitals in 2020 are below:

- Emergency admission including emergency fee, assessment, intravenous catheterization and fluid bolus, palpation per rectum, laboratory work, and abdominocentesis/peritoneal fluid analysis: US $1,500 to $2,000
- Medical management including emergency admission plus intravenous fluids and analgesia with or without nasogastric intubation for 24–72 hours: US $2,000 to $4,000
- Surgical management including emergency admission plus basic postoperative care: US $6,000 to $10,000
- A deposit of 50% of the upper or lower end of the estimate is generally required.

While it is important that clients have reasonable expectations regarding the expense associated with referral of horses with colic, they should not be deterred because often the components that make up the "standard of care" can be modified. For example, a horse with a pelvic flexure impaction that did not respond to initial treatment in the field may not necessarily require laboratory data or intravenous catheterization. Enteral fluids are less expensive and likely more beneficial for resolving a pelvic flexure impaction than intravenous fluids.[1,2] These considerations can substantially lower the expense associated with treatment. Client budgetary restrictions and expectations should be communicated with the attending clinician at the referral hospital so that every attempt can be made to provide the best possible care for the patient within the client's financial means.

4. When to Refer the Horse with Colic

Colic requires emergency veterinary care and horses/foals that do not respond to initial treatment on the farm should be referred on an emergency basis. Early referral and surgical intervention has probably been the single most important factor contributing to the improvement in survival of horses requiring colic surgery.[3] When horses/foals requiring surgery or intensive medical care are treated early, there is improved survival and fewer complications such as shock, ischemia-reperfusion injury, postoperative reflux, adhesion formation, and laminitis. Fewer complications mean lower cost associated with treatment. Often, very early exploratory surgery of a horse with a small intestinal strangulating obstruction will mean that the lesion can be corrected without resection and anastomosis being necessary and the horse will have an excellent prognosis.[4] Survival rates for colic surgery in the late 1980s and early 1990s for small intestinal strangulating lesions were as low as 30% to 50%[5,6] whereas current survival rates of horses recovered from general anesthesia (i.e., not euthanized during surgery) are reported to be 80% to 95%.[7,8] Similarly, survival of horses with a large colon volvulus improved from approximately 25% to 60% to 70% from the late 1980s to the late 1990s[9] and was reported to be as high as 85% at one hospital.[3,10] While surgical technique and simply recovering the horse from surgery is likely to have played a role in some of these reports,[9] early referral has been shown to be important.[3,11]

Early referral is particularly important for horses with strangulating intestinal lesions. Complete ischemia for a period beyond 3 to 4 hours can lead to irreversible cell damage and tissue injury. Large colon volvulus is often a peracute disease that can result in irreversible colonic injury within a few hours and death within several hours. While in many cases of small intestinal strangulating obstruction, resection of injured tissue is possible; there are some cases where resection is not possible because of the location or extent of injury. Moreover, prolonged distention of the intestine proximal to the strangulating obstruction causes serosal injury and low-flow ischemia with reperfusion injury predisposing the patient to postoperative complications such as ileus and adhesion formation.[12,13]

Early lesion correction also minimizes signs of shock. Shock can be associated with endotoxemia (systemic inflammatory response syndrome), hypovolemia, and pain. Signs of shock worsen with a prolonged time between lesion occurrence and correction. Clinical and laboratory indices of shock including tachycardia, high packed cell volume (PCV), and hyperlactatemia are associated with prognosis for survival.[9,14–17]

Education of horse owners with regard to the implication of delayed referral is necessary for success. Owners need to understand the importance of having their veterinarian examine a horse with colic. Presentation of information to the owner with regard to the referral process and associated expense will influence their decision making. Information should be presented enthusiastically and positively yet realistic expectations provided.

While the vast majority of horses with colic can be managed in the field, approximately 10% to 20% will require referral to a hospital or surgical facility.[16,18] Referral does not necessarily mean that surgery is indicated but that closer monitoring, more thorough diagnostic tests, and/or intensive treatment with intravenous fluids and analgesia is recommended. There are several factors that go into the decision to refer a horse with colic:

- Persistent, severe, or recurrent abdominal pain
- Shock

- Tachycardia or increasing heart rate
- Nasogastric reflux, especially large volumes of reflux
- Evidence of complete intestinal obstruction or poor motility
- Palpation per rectum findings

Pain

The main indication for referral on an emergency basis is severe or persistent signs of abdominal pain despite treatment with analgesics. As a guideline, if the horse is treated with a dose of flunixin meglumine, then requires a dose of sedation (xylazine and butorphanol), and is persistently painful through this analgesic regimen, referral is indicated and should be discussed with the owner. Causes of persistent signs of pain despite medical management include strangulating intestinal obstruction, other causes of intestinal ischemia, gas distention associated with a complete mechanical obstruction, or an inflammatory process. Often a horse is not particularly painful or is temporarily responsive to analgesics, and other guidelines for referral are necessary. Examples of causes of colic that may have such a response include large colon and cecal impactions and colonic displacements. Individual variability in pain tolerance between horses exists. Geriatric horses and draft breeds tend to be less demonstrative of colic pain compared to other horses and this should always be considered. If referral is not an option, euthanasia is indicated in horses with severe pain that is unresponsive to analgesia (e.g., flunixin meglumine and multiple doses of detomidine).

Chronic or recurrent abdominal pain is also an indication for referral, although often these horses do not necessarily need to be referred on an emergency basis. The purpose of referring these horses is predominantly for further diagnostic evaluation including radiographic and ultrasonographic evaluation, abdominocentesis and peritoneal fluid analysis, clinical laboratory data, gastroscopy, and exploratory celiotomy in some instances. Owners should be aware, however, that often the evaluation of the horse with chronic colic is unrewarding. Examples of lesions that may cause such clinical signs include enterolithiasis, intermittent nephrosplenic entrapment of the large colon, gastric ulceration, inflammatory bowel disease, sand enteropathy, neoplasia, and adhesions.

Shock

Shock is defined as inadequate oxygen delivery to the cells leading to insufficient adenosine triphosphate (ATP) production and ultimately cell death. Hypovolemia, endotoxemia (systemic inflammatory response syndrome), sepsis, and hemorrhage can lead to shock in the horse showing signs of colic. Signs of shock include tachycardia (heart rate >70 beats/minute), injected or toxic mucous membranes, prolonged capillary refill time, poor jugular vein refill time, cool extremities, and dull demeanor. Referral of horses with shock is recommended because of the need of intravenous fluid therapy and the likelihood that they have serious disease. Shock, by definition, leads to anaerobic metabolism and lactate production. Point-of-care lactate meters may be useful for assessing and monitoring horses in the field. Horses with gastrointestinal perforation rapidly develop signs of shock including profuse sweating, muscle fasciculations, tachycardia, tachypnea with nostril flare, and injected or toxic mucous membranes. Horses with perforation often have a grimace and are reluctant to walk and develop a fever. Perforation can be confirmed with transabdominal ultrasonographic evaluation combined with abdominocentesis and peritoneal fluid analysis. Euthanasia is indicated in any horse with confirmed perforation.

Tachycardia or Increasing Heart Rate

When treated on the farm, horses should be monitored closely for tachycardia or increasing heart rate. A particularly high heart rate >60 beats/minute or a heart rate that is increasing despite medical management is an indication for referral because it suggests worsening of a condition and failure to respond to medical management. The main causes of tachycardia include shock and pain. Any horse with a heart rate >60 beats/minute is likely to have some signs of either severe pain or shock indicative of a referral.

Nasogastric Reflux

The horses with large volumes of nasogastric reflux should be referred because this is often an indication of either proximal enteritis or a small intestinal strangulating obstruction requiring surgery. Even if surgery is not necessary (i.e., proximal enteritis or ileus) intravenous fluids are recommended.

Evidence of Complete Intestinal Obstruction or Poor Motility

There are several clinical indications that the horse likely has a complete intestinal obstruction or is not responding to initial treatment with analgesia and/or enteral fluids and mineral oil: marked or increasing abdominal distention; absent, reduced or deteriorating borborygmi; and absent fecal output despite treatment. Of particular note is the association between lack of intestinal borborygmi and the need for colic surgery.[19]

Abdominal Palpation Per Rectum

While not necessarily an overriding clinical feature, findings on palpation per rectum that are indications for referral include the following:

- Cecal impaction: Horses with cecal impaction have a relatively high risk of cecal perforation that can be insidious. Signs of pain in horses with a cecal impaction often respond well albeit temporarily to treatment with flunixin meglumine.

- Small colon impaction: Impactions of the small colon require aggressive medical management including intravenous and enteral fluids because they can be challenging to resolve medically and often require a lot of analgesia, trocharization, and/or surgery. Horses with small colon impactions often develop marked colonic distention.
- Colonic displacement (either right dorsal displacement or nephrosplenic ligament entrapment): Similar to small colon impaction, these horses often require frequent analgesia, may benefit from intravenous fluids, and often require surgery. Horses with nephrosplenic entrapment may respond to intravenous phenylephrine administration and/or rolling under general anesthesia.[20–22] Of note is that horses with nephrosplenic ligament entrapment often have another lesion.[20,21]
- Severe colonic distention: Large colon volvulus or a complete large or small colon obstruction leads to severe colonic distention. Large colon volvulus requires immediate surgical treatment. Horses with a complete obstruction (e.g., enterolithiasis or sand impaction) also require surgery.
- Distended small intestine: Differentiating a small intestinal strangulating from a nonstrangulating obstruction often can be challenging and, therefore, referral is recommended for any horse with small intestinal distention.
- Abdominal mass(es) often require a thorough workup including ultrasonographic evaluation, peritoneal fluid analysis, biopsy, and laparoscopy or laparotomy.

Mild colonic or cecal distention and pelvic flexure/left ventral colon impaction alone are generally not indications for referral unless the referral hospital is several hours away and warrants careful patient monitoring for resolution or deterioration. Findings on palpation per rectum, however, were not necessarily associated with the need for surgery.[19]

Acknowledgments

Declaration of Ethics

The Author has adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Author has no conflicts of interest.

References

1. Lopes MA, Walker BL, White NA 2nd, et al. Treatments to promote colonic hydration: Enteral fluid therapy versus intravenous fluid therapy and magnesium sulphate. *Equine Vet J* 2002;34:505–509.
2. Hallowell GD. Retrospective study assessing efficacy of treatment of large colonic impactions. *Equine Vet J* 2008; 40:411–413.
3. Hackett ES, Embertson RM, Hopper SA, et al. Duration of disease influences survival to discharge of Thoroughbred mares with surgically treated large colon volvulus. *Equine Vet J* 2015;47:650–654.
4. Freeman DE, Schaeffer DJ, Cleary OB. Long-term survival in horses with strangulating obstruction of the small intestine managed without resection. *Equine Vet J* 2014;46:711–717.
5. Edwards GB, Proudman CJ. An analysis of 75 cases of intestinal obstruction caused by pedunculated lipomas. *Equine Vet J* 1994;26:18–21.
6. MacDonald MH, Pascoe JR, Stover SM, et al. Survival after small intestine resection and anastomosis in horses. *Vet Surg* 1989;18:415–423.
7. Freeman DE, Schaeffer DJ. Short-term survival after surgery for epiploic foramen entrapment compared with other strangulating diseases of the small intestine in horses. *Equine Vet J* 2005;37:292–295.
8. Morton AJ, Blikslager AT. Surgical and postoperative factors influencing short-term survival of horses following small intestinal resection: 92 cases (1994–2001). *Equine Vet J* 2002;34:450–454.
9. Southwood LL, Bergslien K, Jacobi A, et al. Large colon displacement and volvulus in horses: 495 cases (1987–1999), in Proceedings. *7th Int Equine Colic Res Symp* 2002;32–33.
10. Embertson RM, Cook G, Hance SR, et al. Large colon volvulus: Surgical treatment of 204 horses (1986–1995), in *Proceedings*. Am Assoc Equine Pract 1996;42:254–255.
11. Van der Linden MA, Laffont CM, Sloet van Oldruitenborgh-Oosterbaan MM. Prognosis in equine medical and surgical colic. *J Vet Intern Med* 2003;17:343–348.
12. Dabareiner RM, White NA, Donaldson LL. Effects of intraluminal distention and decompression on microvascular permeability and hemodynamics of the equine jejunum. *Am J Vet Res* 2001;62:225–236.
13. Dabareiner RM, Sullins KE, White NA, et al. Serosal injury in the equine jejunum and ascending colon after ischemia-reperfusion or intraluminal distention and decompression. *Vet Surg* 2001;30:114–125.
14. French NP, Smith J, Edwards GB, et al. Equine surgical colic: Risk factors for postoperative complications. *Equine Vet J* 2002;34:444–449.
15. Proudman CJ, Smith JE, Edwards GB, et al. Long-term survival of equine surgical colic cases. Part 2: modelling postoperative survival. *Equine Vet J* 2002;34:438–443.
16. Proudman CJ. A two-year, prospective survey of equine colic in general practice. *Equine Vet J* 1992;24:90–93.
17. Southwood LL, Gassert T, Lindborg S. Colic in geriatric compared to mature nongeriatric horses. Part 1: Retrospective review of clinical and laboratory data. *Equine Vet J* 2010;42:621–627.
18. Tinker MK, White NA, Lessard P, et al. Prospective study of equine colic incidence and mortality. *Equine Vet J* 1997;29: 448–453.
19. White NA, Elward A, Moga KS, et al. Use of web-based data collection to evaluate analgesic administration and the decision for surgery in horses with colic. *Equine Vet J* 2005;37: 347–350.
20. Gillen AM, Munsterman AS, Hanson R. Evaluation of phenylephrine and exercise with or without trocarization for treatment of suspected nephrosplenic entrapment in horses. *J Am Vet Med Assoc* 2019;254:1448–1453.
21. Hardy J, Minton M, Robertson JT, et al. Nephrosplenic entrapment in the horse: A retrospective study of 174 cases. *Equine Vet J Suppl* 2000;95–97.
22. Fultz LE, Peloso JG, Giguère S, et al. Comparison of phenylephrine administration and exercise versus phenylephrine administration and a rolling procedure for the correction of nephrosplenic entrapment of the large colon in horses: 88 cases (2004–2010). *J Am Vet Med Assoc* 2013;242:1146–1151.

How to Help Your Client with Their Horse Following Colic Surgery: Expectations, Potential Complications, and Ongoing Care

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1. Introduction

It is critical for the client to develop an understanding of the short-term and long-term complications that may affect a horse that has just been through colic surgery in order to optimize management. An understanding of the owner's expectation for return to performance is also crucial. For example, if the expectation is to save the horse's life, this makes some complications such as incisional hernias a less pressing concern, and even low-level chronic laminitis can be managed. However, these same complications are highly problematic and impede long-term success in horses intended to return to athletic performance. These factors can be discussed with the owner in the immediate post-operative period.

2. Referral Time

The greatest opportunity for maximizing success and reducing complications is at the time of referral, meaning that horses referred early in the disease process will likely have less intestinal injury, faster and less intricate surgeries, and a more rapid recovery in the post-operative period. The universal problem most colic surgeons have to deal with is duration of colic. Studies have shown that even the most fatal forms of colic, such as large colon volvulus, can have a remarkably positive long-term outcome if they are referred rapidly.[1] The aforementioned study is from a referral area that is unique in the Unites States (Lexington, KY), in that the value of the horses, the quality of the management, and the proximity to the referral hospital appears to reduce referral time down to a minimum. In other studies, the prognosis for large colon volvulus is notably lower, largely because of referral time.[2] Therefore, equine veterinarians have to continue to work on early referral with their clients to improve long-term results. Because the current state of colic surgical management is rapid, technically proficient, and highly successful, the short-term survival rate (discharge from the hospital) is progressively increasing into the range of 75% or above, even with severe conditions like small intestinal strangulating obstruction.[3] However, long-term survival continues to be more problematic, particularly in horses recovering from small intestinal surgery, because of complications such as adhesions.

3. Colic Surgery

To understand long-term management of horses following colic surgery, some understanding of what transpires within surgery is important. Once a

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horse has been referred, time is again of the essence to decide on whether or not a horse should go to surgery in order to improve long-term outcome. Once in surgery, the surgical team should be able to move swiftly through an exploratory and any surgical manipulations required within 2–3 hours. This should aim to maximally reduce time in the abdomen, which translates to trauma, systemic inflammation, and a poorer long-term outcome. Of all of the long-term complications hindering a good long-term outcome, adhesions are among the most problematic. These result both from the level of intestinal injury induced by the obstructive disease process and the level of manipulation at surgery. Another aspect of colic surgery that is critical to long-term outcome is closure of the incision. That is because in one study, one of the factors that limited long-term outcome to the greatest extent was abdominal hernias.[4] These likely relate to closure technique and whether or not the incision becomes infected. Infection rates tend to be up to ~20% at most surgical hospitals,[5] but should be monitored closely to make sure the prevalence is not increasing. An additional factor that likely has a role in incisional complications is trauma to the incision itself, which also relates to time and technical proficiency of the surgical team.

4. Post-Operative Complications

The initial objective following surgery is a satisfactory recovery from anesthesia. Although catastrophic injuries during anesthetic recovery, particularly fractures, have become more uncommon with advances in anesthetic techniques, nonetheless, colic patients that present with systemic compromise are at increased risk of complications, particularly following a long surgery for procedures such as a resection. Beyond anesthetic recovery, there are three major life-threatening complications of colic surgery that should be discussed with owners. First, assuming the horse recovers well from anesthesia, there is management of shock states (hypovolemia and endotoxemia [sepsis or systemic inflammatory response syndrome]). This includes optimal fluid and electrolyte administration, judicious use of non-steroidal anti-inflammatory drugs (NSAIDs), use of pain medications to optimize recovery,[6] and use of colloids or plasma as needed to maintain oncotic pressure. Medications to specifically target endotoxemia, such as polymyxin B (5,000 u/Kg, IV),[7] may be helpful, but remain largely unproven by clinical trials.[8] The next phase of post-operative management tends to be post-operative ileus (POI). There is reasonably good evidence that early return to feeding reduces POI.[9] Aside from this principal, for horses that do develop POI, current treatment includes continued use of anti-inflammatory drugs and intravenous (IV) lidocaine.[10] Studies have shown that COX-2 inhibitors may be more beneficial than non-selective NSAIDs because they are capable of managing pain without inhibiting intestinal repair.[11,12] Interestingly, concurrent use of IV lidocaine (1.3 mg/kg loading dose, 0.05 mg/mL controlled rate infusion [CRI]) also improves intestinal repair.[13] There has also been one clinical trial showing that IV lidocaine reduced the length of time of POI and amount of reflux,[14] but more rigorous clinical trials are needed to discern the utility of IV lidocaine. The latter phase of post-operative management in the hospital tends to relate to adhesion formation, particularly in patients treated for small intestinal obstruction. Development of adhesions are thought to be clinically evident based on recurrent episodes of colic in at-risk patients.[15] One intra-operative treatment that is believed to reduce onset of adhesions, based in a reduction in incidence of post-operative colic in patients following small intestinal surgery, is carboxymethylcellulose,[15] which can be used during surgery and following lavage of the abdomen with sterile saline in volumes of 500 mL to 1 L. In addition, post-operative peritoneal lavage and drainage has been found to mitigate adhesion formation in an experimental setting,[16] and can be used clinically by infusing ~10 L balanced polyionic fluids into an abdominal drain, and retrieving these fluids after allowing approximately 20 minutes of time within the abdomen.

There are also other post-operative complications that occur less frequently, including laminitis, which can be devastating. A relatively recent advance in treatment of laminitis has been the use of digital cryotherapy (continuous icing of the feet) in any horse at risk of laminitis,[17] and this may improve long-term results. Importantly, a great deal of attention should also be paid to the midline incision. Incisional infection remains a relatively common post-operative complication, and in some cases is associated with hernia formation. Incisional infections are resolved by early removal of skin staples or sutures to allow for drainage, and lavage of the incision. Horses may continue to have clinical evidence of an incisional infection at the time of discharge, which will need to be attended to by the referring veterinarian. The incision will need to be carefully probed to determine the extent of infection, including whether or not the sutures within the linea alba are prematurely breaking down. If there is a concern that a hernia may develop, commercial hernia belts are recommended to reduce tension on the linea alba. Once a hernia has formed, it can be monitored ultrasonographically and decisions can be made as to whether to ultimately perform herniorrhaphy. Unfortunately, the best time to take these horses back to surgery is after the incision has healed to the greatest extent possible, forming a sufficient thickness of fibrous tissue to optimize the repair, at approximately 6 months following surgery. This can be very difficult for owners to understand, and can require a lot of additional communication between the veterinarian, surgeon, and owner.

5. What is the Expectation for Long-Term Outcome?

An understanding of the owner's expectations can make a big difference in how to define long-term outcome. For example, if the expectation is solely to save the horse's life, then considerations over incisional hernias or other long-term management problems such as laminitis can be more readily reconciled within the owner's expectations. Long-term analyses based on the type of lesion a horse has had can also be discussed to make sure expectations are realistic. For example, once a horse has been discharged from the hospital, the long-term prognosis is lower for horses with small intestinal strangulation obstruction as compared to other forms of obstruction.[18] The principal reason for this appears to be recurrent colic, most likely associated with adhesions.[19] When advising owners, it is helpful for them to know that if a horse is going to have problems with adhesions, it is typically within 3 months of surgery. Unfortunately, colic that requires a second surgery because of adhesions carries a fair-to-guarded prognosis.

If owners expect a return to athletic performance, management of long-term complications becomes that much more critical, and complications such as incisional hernia may require an additional surgery to enable athletic performance. Other surgical interventions that can potentially be performed to reduce repeat colic that might require surgery are ablation of the nephrosplenic space in horses with repeat episodes of left dorsal displacement, and colopexy in horses with repeat episodes of large colon volvulus. The latter tends to preclude athletic performance because of colic associated with adhesion of the colon to the ventral body wall, but is particularly useful in broodmares that are at greatest risk of large colon volvulus. Resection of the colon is an alternative consideration to colopexy, allowing return to athletic performance. Larger studies to improve understanding of long-term outcome are needed, and beginning to be performed.

6. Helping Owners Return Their Horse to Performance

Return to intended use and performance following colic surgery is of major concern to horse owners. The potential for return to performance in an equine athlete is typically weighed against the cost of surgery, intensive post-operative care, and prolonged convalescence. In one published study on return to performance following colic surgery, 76% of horses discharged from the hospital had at least reached their pre-operative level of performance within 1 year.[4] Another study on Thoroughbred racehorses showed that 69% of horses taken to surgery for colic returned to racing within 6 months.[20] This illustrates how long it can take to fully rehabilitate a horse following colic surgery. Current recommendations are to stall rest horses following discharge from the hospital for colic surgery for 1 month, followed by 1 month of small paddock turnout, and a gradual return to exercise in the third month following colic surgery. This time frame approximately parallels the healing of the midline incision, which will have reached original strength in 8 weeks in the absence of any complications such as infection or repeat laparotomy.[21] From this perspective owners can expect to be riding their horses at a reduced but escalating level after 2 months, with most sport horses attaining full athletic potential within 12 months, depending upon the discipline and extent of surgery.[4] However, more recent studies on rehabilitation of horses with midline incisions suggest that practitioners could be advising clients differently in order to return to performance more rapidly. In particular, a recent study showed that having clients work with their horses in a controlled fashion in the post-operative period to reduce loss of muscle strength reduced the time to return to full performance, and resulted in more horses attaining a higher level of performance following colic surgery.[22]

7. Conclusions

Preparing a client for the post-operative period following colic surgery includes an understanding of short- and long-term complications. Once a horse has been discharged, the veterinarian should have the client focus on any instances of recurrent colic and the appearance of the incision. A good working knowledge of post-operative complications that occurred during hospitalization is important to be able to guide the client following hospital discharge. Finally, the post-operative exercise program should be carefully controlled to allow time for the midline incision to heal, but can be modified to reduce loss of muscle tone in order to increase the chances of earlier return to performance. Attention to feeding for optimal retention and strengthening of muscle mass is also an important component of post-operative rehabilitation.

Acknowledgments

Declaration of Ethics

The Author has adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Author has no conflicts of interest.

References

1. Hackett ES, Embertson RM, Hopper SA, et al. Duration of disease influences survival to discharge of Thoroughbred mares with surgically treated large colon volvulus. *Equine Vet J* 2015;47:650–654.
2. Gonzalez LM, Fogle CA, Baker WT, et al. Operative factors associated with short-term outcome in horses with large colon volvulus: 47 cases from 2006 to 2013. *Equine Vet J* 2015;47: 279–284.
3. Freeman DE. Fifty years of colic surgery. *Equine Vet J* 2018;50:423–435.

4. Davis W, Fogle CA, Gerard MP, et al. Return to use and performance following exploratory celiotomy for colic in horses: 195 cases (2003–2010). *Equine Vet J* 2013;45:224–228.
5. Torfs S, Levet T, Delesalle C, et al. Risk factors for incisional complications after exploratory celiotomy in horses: do skin staples increase the risk? *Vet Surg* 2010;39:616–620.
6. Sellon DC, Roberts MC, Blikslager AT, et al. Effects of continuous rate intravenous infusion of butorphanol on physiologic and outcome variables in horses after celiotomy. *J Vet Intern Med* 2004;18:555–563.
7. Barton MH, Parviainen A, Norton N. Polymyxin B protects horses against induced endotoxaemia in vivo. *Equine Vet J* 2004;36:397–401.
8. Burke M, Blikslager A. Advances in diagnostics and treatments in horses with acute colic and postoperative ileus. *Vet Clin North Am Equine Pract* 2018;34:81–96.
9. Freeman DE, Hammock P, Baker GJ, et al. Short- and long-term survival and prevalence of postoperative ileus after small intestinal surgery in the horse. *Equine Vet J Suppl* 2000:42–51.
10. Lisowski ZM, Pirie RS, Blikslager AT, et al. An update on equine post-operative ileus: definitions, pathophysiology and management. *Equine Vet J* 2018;50:292–303.
11. Cook VL, Meyer CT, Campbell NB, et al. Effect of firocoxib or flunixin meglumine on recovery of ischemic-injured equine jejunum. *Am J Vet Res* 2009;70:992–1000.
12. Ziegler AL, Freeman CK, Fogle CA, et al. Multicentre, blinded, randomised clinical trial comparing the use of flunixin meglumine with firocoxib in horses with small intestinal strangulating obstruction. *Equine Vet J* 2019;51:329–335.
13. Cook VL, Jones Shults J, McDowell M, et al. Attenuation of ischaemic injury in the equine jejunum by administration of systemic lidocaine. *Equine Vet J* 2008;40:353–357.
14. Malone E, Ensink J, Turner T, et al. Intravenous continuous infusion of lidocaine for treatment of equine ileus. *Vet Surg* 2006;35:60–66.
15. Fogle CA, Gerard MP, Elce YA, et al. Analysis of sodium carboxymethylcellulose administration and related factors associated with postoperative colic and survival in horses with small intestinal disease. *Vet Surg* 2008;37:558–563.
16. Hague BA, Honnas CM, Berridge BR, et al. Evaluation of postoperative peritoneal lavage in standing horses for prevention of experimentally induced abdominal adhesions. *Vet Surg* 1998;27:122–126.
17. Dern K, van Eps A, Wittum T, et al. Effect of continuous digital hypothermia on lamellar inflammatory signaling when applied at a clinically-relevant timepoint in the oligofructose laminitis model. *J Vet Intern Med* 2018;32:450–458.
18. Proudman CJ, Smith JE, Edwards GB, et al. Long-term survival of equine surgical colic cases. Part 2: modelling postoperative survival. *Equine Vet J* 2002;34:438–443.
19. Mair TS, Smith LJ. Survival and complication rates in 300 horses undergoing surgical treatment of colic. Part 3: Long-term complications and survival. *Equine Vet J* 2005;37:310–314.
20. Tomlinson JE, Boston RC, Brauer T. Evaluation of racing performance after colic surgery in Thoroughbreds: 85 cases (1996–2010). *J Am Vet Med Assoc* 2013;243:532–537.
21. Chism PN, Latimer FG, Patton CS, et al. Tissue strength and wound morphology of the equine linea alba after ventral median celiotomy. *Vet Surg* 2000;29:145–151.
22. Holcombe SJ, Shearer TR, Valberg SJ. The effect of core abdominal muscle rehabilitation exercises on return to training and performance in horses after colic surgery. *J Equine Vet Sci* 2019;75:14–18.

Stallion Semen Cooling Using Native Phosphocaseinate-Based Extender and Sodium Caseinate Cholesterol-Loaded Cyclodextrin-Based Extender

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Sodium casein cholesterol-loaded cyclodextrin extender is a suitable alternative extender to the most widely used native caseinate-based extender. Authors' address: Department of Veterinary Clinical Medicine College of Veterinary Medicine, University of Illinois, Urbana IL, 61802; e-mail: gpodico@illinois.edu. *Corresponding and presenting.

1. Introduction

Transport of cooled stallion semen is commonly performed with one extender based on native phosphocaseinate (NP)[a]; although this is an excellent extender, some stallions still do not cool well with this extender. The objective of this study was to compare the most widely used semen extender based on NP[a] with a new extender based on sodium caseinate (SC) associated with cholesterol-loaded cyclodextrin[b] and also three semen cooling containers by assessing semen parameters and embryo recovery rates of cooled stallion semen. The authors hypothesized that the combination of cholesterol and sodium casein results in superior parameters for cooled stallion semen than NP.

2. Materials and Methods

In experiment 1, 45 ejaculates from 9 mature stallions were collected, assessed, and equally split between both extenders and then extended to 50 million sperm/mL. Then, the extended semen was stored in three passive cooling containers[c,d,e] for 48 h. In experiment 2, the same ejaculates extended in experiment 1 were centrifuged, the supernatant was discarded, and the pellets were resuspended at 100 million sperm/mL with their respective extenders. Semen was then cooled and stored as in experiment 1. In both experiments, sperm motility parameters were assessed at 0, 24, and 48 h post-cooling. Plasma membrane integrity and high mitochondrial membrane potential were assessed with spectral flow cytometry[f] using a fixable staining with Zombie Green[g] and Mitotracker Deep Red.[h] For experiment 3, 12 mares (n = 24 cycles) were randomly bred with 48-h cooled semen from 1 stallion used in the previous experiments and available to the investigators. Semen was processed as described in experiment 1. Mares had

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embryo flushing performed by 8 days post-ovulation. Data were analyzed with mixed models.

3. Results and Discussion

In experiment 1, SC displayed superior total and progressive motility relative to NP ($P < 0.05$). There were no significant differences between the type of containers in any experiment. In experiment 2, NP and SC extenders had similar total and progressive motility, but SC had superior sperm velocity parameters at all timepoints. Embryo recovery was identical for both extenders (50%). Finally, the results obtained herein suggest that SC is a suitable alternative to be included in semen cooling tests against NP in clinical practice.

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Declaration of Ethics

The Authors have adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

Botupharma USA donated one of the extenders (Botusemen Gold) used in the experiment and one of the semen cooling containers. INRA 96 was purchased with a research discount from the manufacturer.

Footnotes

[a]INRA96, IMV, Maple Grove, MN 55369.
[b]BotuSemen Gold, Botupharma USA, Phoenix, AZ 85027.
[c]Equitainer II; Hamilton Research, Inc., Ipswich, MA 01938.
[d]Equine Express II, Exodus Breeders Supply, York, PA 17406.
[e]BotuFlex, Botupharma USA, Phoenix, AZ, 85027.
[f]Cytek Aurora, Cytek Bioscience, Freemont, CA 94538.
[g]Zombie Green Fixable Viability Kit #423112, BioLegend, San Diego, CA 92121.
[h]MitoTracker™ Deep Red #M22426, Invitrogen™-Thermo Fisher Scientific Corporation, Waltham, MA 02451.

One-Hour Post-Breeding Lavage Does Not Affect Pregnancy Rates in Mares Bred with Frozen Semen

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One-hour post-breeding uterine lavage of mares bred by deep horn insemination has no negative effect on pregnancy rates of sub-fertile mares and could be an additional breeding management tool.
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1. Introduction

Uterine lavage as early as 4 hours post-uterine insemination removes inflammatory products. The authors hypothesize that by using deep horn insemination (DHAI), mares could be lavaged earlier than previously thought without affecting the pregnancy rates.

2. Materials and Methods

Mares were randomly allocated to two groups (group 1 lavaged 1 hour and group 2 lavaged 4 hours post-DHAI) and bred over 14 cycles with frozen semen in a cross-over design. A total of 1 mg deslorelin was given intramuscularly, and mares were bred within 6 hours post-ovulation. A Student t-test determined differences between groups. In a commercial setting, 192 normal or subfertile mares bred by DHAI within 4 hours post-ovulation were not lavaged or were lavaged at 1 or 4 hours post-DHAI. Chi-square was used to determine the significance of the treatments on pregnancy rates.

3. Results

Overall, the pregnancy rate in experiment 1 was 42.8% with no difference ($P < 0.28$) in pregnancy rates between groups. Subfertile mares in the commercial setting that were lavaged at 1 hour or 4 hours had a higher pregnancy rate (48.4% vs. 42.86%) than those not lavaged (33.3%) ($P < 0.05$).

4. Discussion

The results from the timed uterine lavage especially in problem mares indicate that early lavage can be beneficial when mares are bred by DHAI, perhaps by reducing the length of uterine-sperm contact and therefore reducing the time in which the mare can mount a full uterine inflammatory reaction.

Research Abstract—for more information, contact the corresponding author

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Acknowledgments

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Declaration of Ethics

The Authors have adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Authors have no conflicts of interest.

Reproductive Outcomes of 71 Thoroughbred Mares Following Unilateral Ovariectomy of Granulosa Cell Tumor/Granulosa-Theca Cell Tumor

Sheila G. Spacek, DVM, MS*; Maria R. Schnobrich, VMD, DACT; Shavahn C. Loux, PhD; and Tom Riddle, DVM

Following ovariectomy, mean time to first ovulation was 174.5 (± 47.7) days, and mean time to first live foal produced was 739.8 (± 67.0) days. There was no difference in foal production in the 5 years following ovariectomy for mares of different age groups. Authors' addresses: Rood & Riddle Equine Hospital, PO Box 12070, Lexington, KY 40580-2070 (Spacek, Schnobrich, Riddle); Maxwell H. Gluck Equine Research Center, Department of Veterinary Science, University of Kentucky, Lexington, KY 40503 (Loux); e-mail: sheila0765@yahoo.com. *Corresponding and presenting author.

1. Introduction

Granulosa cell tumors/granulosa theca cell tumors (GCTs/GTCTs) reportedly cause abnormalities in mare cyclicity and reproductive behavior. The aim of this study was to evaluate reproductive function and performance following unilateral ovariectomy of a confirmed GCT/GTCT.

2. Materials and Methods

Mares that had a unilateral ovariectomy performed and histopathologic confirmation of a GCT/GTCT were included in this study. Veterinary and Jockey Club records from 71 mares (1987–2020) were reviewed. Statistical analysis was performed using JMP 14 program. Post-hoc analysis was performed using non-parametric comparisons with the Wilcoxon/Kruskal-Wallis test; significance: $P < .05$.

3. Results

Mean age of mares was 9.03 (± 1.1) years. Mean days to first detected ovulation was 174.5 (± 47.7) days; time to first pregnancy diagnosis was 302 (± 64.3) days; time to first foal was 739 (± 67.0) days. Age did not affect the number of foals produced in the 5 years following ovariectomy (P = .255): 2–9 years: 2.7 (± 0.4); 10–15 years: 2.2 (± 0.4); 16–27 years: 2.4 (± 0.5).

4. Discussion

Following removal of a GCT/GTCT, the mean time to first ovulation occurs within 6 months. A limitation of the study is that only Thoroughbred mares were included and bred via live-cover.

Acknowledgments

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ies for inspiring retrospective research so that they may better serve their clientele.

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Use of Interleukin-6 as a Biomarker for Ascending Placentitis

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Maternal serum interleukin-6 (IL-6) concentration is predictive of experimentally-induced ascending placentitis, and IL-6 functions as an anti-inflammatory cytokine in this disease. Authors' address: Department of Veterinary Science, University of Kentucky, 1400 Nicholasville Road, Lexington, KY 40503; e-mail: carleighfedorka@gmail.com. *Corresponding and presenting author.

1. Introduction

Ascending placentitis is one of the leading causes of abortion in the horse. Interleukin-6 (IL-6) is the gold standard diagnostic for intra-amniotic infection (chorioamnionitis) in humans, but minimal is understood regarding this cytokine in equine placental disease.

2. Materials and Methods

Placentitis was induced via trans-cervical inoculation of *Streptococcus zooepidemicus* and fetal fluids/serum/tissues were collected 8 days later following euthanasia. Cytokine concentrations were detected using a multiplex immunoassay within fetal fluids (amniotic and allantoic) and serum (maternal and fetal) in inoculated ($n = 6$) and control ($n = 6$) mares. Additionally, RNASeq was performed on the placenta (endometrium and chorioallantois) to assess transcripts relating to IL-6 pathways.

3. Results and Discussion

IL-6 appears to play a crucial role in the placental response to induction of equine placentitis, and an increase in this cytokine was noted in amniotic fluid, allantoic fluid, and serum following inoculation. An increase in maternal serum IL-6 following inoculation had a specificity of 75%, sensitivity of 97%, a positive predictive value of 99%, and a negative predictive value of 42%. Additionally, by day 8 following inoculation, IL-6 activates the classical signaling pathway to act as anti-inflammatory, pro-survival, and pro-proliferation via the JAK/STAT pathway. Therefore, IL-6 may alter disease progression, impede abortion signals, and assist with the production of a viable neonate.

Acknowledgments

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Doppler Indices of the Equine Fetal Carotid Artery Throughout Gestation

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Doppler indices of the carotid artery provide a novel diagnostic tool to assess fetal viability. Authors' addresses: Equine Veterinary Medical Center, Qatar Foundation Doha, Qatar (Bucca, Cunanan, Vinardell); Al Shaqab, Qatar Foundation, Doha, Qatar (Sousa De Oliveira); College of Health & Life Science, Hamad Bin Khalifa University, Qatar Foundation Doha, Qatar (Vinardell); Maxwell H. Gluck Equine Research Center, University of Kentucky, Lexington, KY 40546 (Troedsson); e-mail: stefbucca@gmail.com. *Corresponding and presenting author.

1. Introduction

Assessment of pregnancy viability in the equine patient is currently based on gestational profiles of limited prognostic value. In recent years, Doppler technology has been applied to uterine and umbilical arteries of pregnant mares to monitor fetal responsive hemodynamics, suggestive of compromise. To date, uterine artery Doppler indices failed to provide sufficient evidence of pregnancy viability and the umbilical cord of the equine fetus is inconsistently visualized past 250 days gestation. The objectives of this study were to 1) evaluate intracranial blood flow impedance of the fetal carotid artery, and 2) establish reference values for healthy, uncomplicated pregnancies.

2. Materials and Methods

For the purpose of this study, 12 pregnant mares were examined at 2 to 3 weeks interval by B mode and Doppler ultrasonography and a novel technique was developed for Doppler evaluation of the carotid artery in the equine fetus. Additional biophysical and biochemical parameters were collected to demonstrate appropriate pregnancy development.

3. Results and Discussion

In this study, Doppler waveform analysis of fetal intracranial vasculature demonstrated an elevated blood flow impedance, showing a significant negative correlation of carotid Doppler indices with gestational age (resistive index: $R = -499$; $P < .001$; pulsatility index: $R = -306$; $P < .001$). Results were comparable to human fetal trends for the middle cerebral artery from mid gestation to term.

Acknowledgments

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Intrauterine Administration of Platelet-Rich or -Poor Plasma Mitigates Persistent Breeding-Induced Endometritis in Mares

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Michael F. Rosser, DVM, MS, DACVP; and Marco A. Alvarenga, DVM, MS, PhD**

Intrauterine infusion of plasma reduced post-breeding endometrial inflammatory response. None of the mares treated with high concentrations of platelets had positive bacterial cultures at embryo flushing. Authors' addresses: Department of Veterinary Clinical Medicine College of Veterinary Medicine, University of Illinois, Urbana IL 61802 (Canisso, Leal, Novello, Podico, Rosser, Segabinazzi); Sao Paulo State University, Botucatu, Sao Paulo, 18618-970 Brazil (Alvarenga, Segabinazzi); e-mail: canisso@illinois.edu. *Corresponding author; †presenting author.

1. Introduction

Endometritis is the most common cause of subfertility in mares. All mares display a physiological post-breeding endometrial inflammation; however, 15% to 20% of mares have persistent breeding-induced endometritis (PBIE). This study aimed to compare plasma-rich (PRP) or -poor (PPP) in platelets and lactated Ringer's solution (LRS) infusions in mares susceptible PBIE.

2. Materials and Methods

Mares (n = 12) susceptible to PBIE had 3 cycles randomly assigned in a crossover design to receive intrauterine infusions with 40 mL of LRS (control), or autologous PRP or (PPP) at 48 and 24 hours pre- and 6 and 24 hours post-breeding. Both PRP and PPP were prepared with double centrifugation off a blood transfusion bag[a]. Platelet numbers were counted with a hemocytometer. Platelet viability was assessed with spectral flow cytometry[b] (mouse monoclonal antibody anti-CD41/61, secondary antibody anti-mouse IgG PE-conjugated)[c]. Mares were bred with fresh semen from one stallion. Intrauterine fluid accumulation and endometrial polymorphonuclear cells were assessed daily. Embryo flushing was performed 8 days post-ovulation, and the recovered uterine fluid was aerobically cultured. Data were analyzed with ANOVA-RM and post-hoc with Tukey's, and multivariate regression.

3. Results and Discussion

Platelet concentrations were 622.9 $\pm$ $144\times10^3/\mu L$ (PRP) and 36.1 $\pm$ $25\times10^3/\mu L$ (PPP). There were no differences in platelet viability between groups (97 $\pm$ 0.7% vs 97.2 $\pm$ 0.6%). Both treatment groups significantly reduced endometrial polymorphonu-

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clear cells and intrauterine fluid accumulation post-breeding when compared to control cycles. Controls had a significantly higher percentage of positive bacterial cultures (42%) in comparison to PRP-assigned cycles (0%), whereas cycles treated with PPP were not significantly different from the other groups (17%). PRP cycles tended (P = .08) to have higher embryo recovery rates (83%) than the control (33%), though not significantly different than PPP (60%). In conclusion, plasma infusion modulated the inflammatory response in mares susceptible to PBIE, and PRP appears to have additional benefits in comparison to PPP.

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Conflict of Interest

The Authors have no conflicts of interest.

Footnotes

[a]Blood collection bag, single, prefilled with 63 mL of CPDA-1, 450 mL #J0520, Jorgensen Labs, Loveland, CO 80538.

[b]Cytek Aurora, Cytek Bioscience, Fremont, CA 94538.

[c]Anti-CD41 antibody [CO.35E4] ab23615, and Goat anti-mouse IgG-Fc(PE) ab5881, Abcam, Cambridge, UK.

Review of Foal-Heat Breeding Options

Patrick M. McCue, DVM, PhD, DACT

Careful post-partum mare selection and adherence to sound reproductive principles can lead to an acceptable pregnancy rate while minimizing pregnancy loss in mares bred on the foal heat. Author's address: Equine Reproduction Laboratory, Colorado State University, 3101 Rampart Road, Fort Collins, CO 80521; e-mail: pmccue@colostate.edu.

1. Introduction

The mare is unique among domestic animals in having a short interval from parturition to first ovulation.[1] The "foal heat" is defined as the estrus that occurs within the first 20 days after foaling.[2–4] Behavioral estrus usually begins 5 to 12 days after foaling, while the average day of ovulation is 10 to 13 days postpartum, with a range of 7 to 20 days.[1,3,5–9] It is estimated that 85% to 95% of mares ovulate within the first 20 days after foaling.[3,6,10]

The gestation length in the horse is approximately 340 days and the interval from foaling to pregnancy for mares initially bred on their foal heat is approximately 25 days.[1,3,11] Consequently, in order to maintain a 12-month foaling interval and produce on average a foal per year, mare owners need to consider foal-heat breeding options. The seasonal pregnancy rate for mares bred on the foal heat has been reported to be comparable to that of mares bred on later heat cycles, indicating that there is no disadvantage in considering a foal-heat breeding.[3] Breeding mares on the foal heat was noted to increase the odds of foaling mares conceiving by the end of the season by a factor of 2.04 compared to mares not bred at the foal heat.[12]

Routinely waiting until the second (30-day) heat to begin breeding will inevitably result in a longer foaling-to-conception interval and an annual gradual drift toward a foaling date later in the season. A retrospective study in Thoroughbreds revealed that 69% of mares foaling on consecutive years drifted an average of 13 ± 23 days later in the subsequent year.[13] Owners that choose not to breed mares on the foal heat must accept the fact that mares will have to be left open for a season every 3 to 6 years when the potential foaling date becomes too late in the season to be acceptable.

2. Pregnancy and Pregnancy Loss Rates

Pregnancy rates for mares bred at the foal heat have been noted to be lower and pregnancy loss rates higher than for mares bred on a subsequent heat in a majority of reports (Table 1 and Table 2).[3,4,14–23] In contrast, some studies did not note any difference in pregnancy between foal-heat breeding and subsequent cycles.[24–28]

Pregnancy rates have been reported to be higher for mares bred on the foal heat if ovulation occurred after day 10 than mares that ovulated on or before day 10 in some studies,[3,29] but not in others.[4] Blanchard and coworkers[22] noted an increased odds ratio for pregnancy loss in mares bred before day 13 postpartum. Meyers and col-

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Table 1. Reports of Pregnancy Rates for Mares Bred on the First Post-Partum Estrus (Foal Heat) Versus the Subsequent Estrous Cycle

	Foal Heat		Subsequent Heat	
Study	(n)	Pregnancy Rate (%)	(n)	Pregnancy Rate (%)
Loy[3]	252	50.0	219	58.9
Lieux[16]	304	39	490	55
Saltiel et al[24]	24	50.0	12	50.0
Lowis and Hyland[31]	96	47.9	58	55.2
Camillo et al[26]	253	71.9	26	84.6
Morris and Allen[20]	210	57.6	560	65.9
Malschitzky et al[45]	89	71.9	14	64.0
Blanchard et al[27]	399	72.2	158	75.9

leagues[30] reported that mares bred on the foal heat were 1.9 times more likely to experience pregnancy loss than mares bred on a later heat. Embryo loss after a foal-heat breeding was reported to be decreased in mares with lower stress than in mares exposed to higher levels of stress.[31] The degree of stress was modulated by either maintaining mare social groups or frequently modifying social groups.

A current recommendation in clinical practice is to not breed foal-heat mares before the tenth day post foaling; if a mare does ovulate prior to day 10, it is recommended to administer prostaglandins 5 to 6 days post ovulation to short cycle and breed on the subsequent heat.[32–34]

Mare age also has a significant effect on fertility in post-partum mares, with mares greater than 14 to 16 years of age having a lower foal-heat pregnancy rate than younger mares.[7,12,27]

In most breeding programs, foaling mares constitute more than 50% of the population.[1] Management plans for rebreeding the post-partum mare are based on owner goals, presence or absence of foaling or post-partum complications, ovarian function in the post-partum period, stallion availability, and other factors. The goal of this review is to discuss physiologic events and management options for rebreeding the post-partum mare.

3. Considerations for Foal-Heat Breeding

Dystocia

Dystocia occurs in approximately 4% to 11% of equine births.[11,35,36] The average duration of stage II of labor is approximately 17 minutes with most foals delivered within 20 to 30 minutes after rupture of the chorioallantoic membrane.[36,37] Prolonged labor, severe bruising, lacerations or hematomas of the reproductive tract during spontaneous delivery, trauma secondary to dystocia or obstetrical manipulation, and hemorrhagic episodes can all adversely affect uterine involution, fertility or breeding decisions in the early post-partum period.[38–40] It is important to perform a thorough reproductive examination on all foaling mares by 7 to 8 days postpartum, including examination of the external genitalia, vaginal speculum examination, manual digital examination of the vagina and cervix, as well as transrectal palpation and ultrasound.[33]

Retained Fetal Membranes

Expulsion of the fetal membranes (chorioallantois, amnion, and umbilical cord) usually occurs within 30 minutes to 2 hours after foaling. In the mare, a “placenta” is considered to be abnormally retained beyond 3 hours postfoaling.[38,41] Retention of the fetal membranes is more common after dystocia, abortion, prolonged gestation, induction of labor and obstetrical procedures, and the overall incidence rate is 2% to 10% in the general horse population.[38] Retained placenta may predispose mares to systemic diseases such as metritis and laminitis, as well as adversely affect fertility in the early postpartum period.[42] Retention of the fetal membranes longer than 3 hours may result in decreased pregnancy rates in mares bred at the foal heat. Ishii

Table 2. Reports of Pregnancy Loss Rates for Mares Bred on the First Post-Partum Estrus (Foal Heat) Versus the Subsequent Estrous Cycle

	Foal Heat		Subsequent Heat	
Study	(n)	Pregnancy Loss Rate (%)	(n)	Pregnancy Loss Rate (%)
Loy[3]	126	12.7	280	11.4
Lieux[16]	103	16.5	232	13.8
Chavalier-Clément[24]	670	7.5	629	4.4
Lowis and Hyland[31]	80	10.0	52	3.9
Morris and Allen[20]	210	9.5	560	7.1
Malschitzky et al[45]	89	10.9	14	11.1
Miyakoshi et al[4]	389	11.1	531	3.8
Lane et al[23]	n/a	15.0	n/a	14.3

and colleagues[42] reported foal-heat pregnancy rates of 50% and <20% for Thoroughbred mares that passed their placentas in less than 3 hours and greater than 3 hours, respectively. Consequently, it is recommended that early prompt treatment be initiated to remove retained fetal membranes both for the health of the mare and to optimize her reproductive potential.[43,44]

Excessive Lochia

The term, lochia, refers to placental fluid, inflammatory cells, and debris remaining in the uterus after foaling. Mares normally pass a small amount of turbid red-brown non-malodorous lochia fluid for several days after foaling. A small amount of fluid may be observed in the uterine lumen during ultrasound examination for the first 3 to 6 days after foaling, after which the fluid volume should reduce significantly.[9,38] The presence of a small volume uterine fluid during the first post-partum estrus was not associated with a reduction in pregnancy rate in two studies.[45,46]

There is no clinical need to treat a mare for the presence of a normal amount of lochia discharge early in the post-partum period. However, a prolonged duration of lochial discharge, an abnormal odor or character to the discharge, or an increased volume or echogenicity of lochia within the uterus visible on ultrasound examination beyond 5 to 7 days after foaling are all abnormal and may decrease fertility or increase embryonic loss in the early post-partum period.[6,27,47–49] In these circumstances, a therapeutic uterine lavage along with administration of oxytocin should be considered.[46] Exercise may also be helpful for uterine involution and evacuation of uterine fluid in post-partum mares.[33,50–52]

Uterine Involution

The term, "involution", has been used to describe the restoration of the uterus to a pre-gravid state, and includes expulsion of uterine fluid and debris, a reduction in uterine size, and regeneration of the endometrial lining of the uterus.[51,52] In a study evaluating uterine involution, biopsy of the uterus the day after foaling revealed distinct microcaruncles, distended endometrial glands and marked edema.[53] Re-evaluation 7 days after foaling showed that microcaruncles were no longer present, the luminal epithelium was intact, and the endometrial glands were no longer distended, indicating that uterine involution was complete.

The previously gravid horn remains larger than the contralateral horn for approximately 3 weeks after foaling.[9,47] Histologically, the endometrium returns to normal by 14 days postfoaling.[8,53] The endometrium of the mare sustains only limited damage as a consequence of pregnancy, foaling, and passage of the placenta. This has been attributed to the non-invasive diffuse epitheliochorial placentation of the horse.[54]

Culture and Cytology

Culture of the uterus of post-partum mares commonly results in growth of *Streptococcus equi* subsp. *zooepidemicus* and/or *Escherichia coli*.[5,6,53,55–57] In some reports, a decrease in foal-heat pregnancy rate was noted in mares with a positive uterine culture,[56,58] whereas other studies did not note a difference in pregnancy rates based on the presence or absence of bacterial growth.[5,6] Mares with a positive culture on their foal heat typically have a negative culture on the subsequent heat.[55,57] Ultimately, there is no clear relationship between results of culture and pregnancy rates in mares bred on the foal heat.

Post-partum mares also exhibit considerable variability in the amount of inflammation present in the uterus as determined by the number of inflammatory cells in cytologic samples.[5,6,24,59] The number of neutrophils in uterine cytology samples was reported to increase from day 2 postpartum to day 5, but pregnancy rates after foal-heat breeding were not different between mares with neutrophils and mares without neutrophils on uterine swabs.[5] A second study noted that the number of neutrophils and amount of cellular necrosis decreased from parturition to the onset of the foal heat.[24] A third study revealed that 58% of post-partum mares had a significant degree of inflammation present at day 7 and yet 73% of mares with significant inflammation became pregnant after a foal-heat breeding.[6] In summary, there is not a clear relationship between the presence or absence of inflammatory cells in a sample collected during the foal heat and the potential for generating a pregnancy at a foal-heat breeding.

The post-partum period is the only period in the life of a mare in which the presence of bacteria (i.e., *Streptococcus* sp. and *E. coli*) on culture and white blood cells on cytology may have limited clinical relevance. If a stallion owner requires a "clean culture" prior to a live cover, it is anticipated that many foal-heat mares will be disqualified. If present, the bacteria and inflammation will usually be eliminated during and/or after the foal heat and a subsequent culture should be negative and cytology clean on the 30-day heat.

The author's current recommendation is that decisions regarding foal-heat breeding should not be based solely on endometrial cytology or culture samples collected early in the post-partum period.

Cervical Function

Speculum examination of the vagina early in the post-partum period may reveal a reddened or hyperemic cervix, and a cloudy discharge. The cervix of a post-partum mare remains relaxed and open until after the first ovulation, whether that is on the foal heat or a subsequent heat.[9] Closure of the cervix is due to an elevation in serum progesterone levels that occurs after the first post-partum ovulation.[52] Lacerations or bruising of the vulva, vestibule, vagina, and/or cervix are relatively common in the post-partum mare and may be a reason to pass on a foal-heat breeding.[33]

Ovarian Function

Ovarian follicular development is usually present in mares during late pregnancy and mares may have small (10 to 15 mm) to medium-sized (20 to 25 mm) follicles the day of foaling. Reproductive function in the post-partum mare follows 1 of 3 general scenarios:

- Development of a large follicle, with associated behavioral estrus and uterine edema, and ovulation in the foal-heat period followed by ovulations at normal 21-day intervals;
- A foal-heat ovulation followed by a regression into anestrus before eventual resumption of follicular activity;
- Limited to no follicular development in the post-partum period, with eventual initiation of follicular activity and ovulation.

Post-partum anestrus is a term used to describe mares in the latter 2 scenarios. Affected mares may remain anestrus for weeks or months before cyclic ovarian activity is initiated. A majority of mares that experience post-partum anestrus will resume cycling in the late spring (i.e., April or May in the Northern Hemisphere). It has been reported that up to 27% of foaling mares exhibit a delay in reproductive function in the post-partum period, dependent on the time of year.[8] Fortunately, a majority of mares have a true foal-heat ovulation and continue to cycle if they are not bred or do not become pregnant at a foal-heat breeding. One advantage of breeding mares on their foal heat is that mares that do become pregnant are not at risk of post-partum anestrus.[51]

Potential causes for post-partum anestrus include ambient photoperiod/season, lactation, and nutrition/body condition. Ambient photoperiod is the primary culprit responsible for post-partum anestrus in mares.[1] A majority of mares that exhibit post-partum anestrus are mares that foal out early in the year, prior to the vernal equinox.[10] Post-partum anestrus is much less common for mares that foal out after the vernal equinox. Maintaining pregnant mares due to foal in the winter under a stimulatory artificial photoperiod for at least the last 2 months of gestation will decrease the probability of post-partum anestrus.[60–62] The duration of artificial photoperiod exposure prior to foaling was noted to be inversely proportional to the percentage of mares that experienced post-partum anestrus.[62]

Additional consequences of housing pregnant mares under lights include a decreased duration of pregnancy observed by some authors,[62,63] but not by others,[61,62] a shorter foaling-to-ovulation interval,[60,61] and a lower average duration of open days post foaling.[61]

Lactation and nursing have a suppressive effect on reproductive function in some domestic animal species, most notably cats, pigs, and beef cows. Once the offspring are weaned in those species, ovarian function resumes. Lactation is considered to have a less dramatic effect on reproductive function in mares. However, anecdotal reports have suggested that some mares that failed to develop follicles in the post-partum period or become anestrus following a foal-heat ovulation exhibit rapid follicular development and come into estrus as soon as the foal is weaned. Restrictive suckling was reported to be associated with an earlier first ovulation in the post-partum period than control mares without restrictive suckling.[64] However, short-term foal removal for 24 hours on day 3 to 4 postpartum did not affect the interval from foaling to first estrus or ovulation.[65]

Inadequate nutrition and poor body condition in late gestation and the early post-partum period may also contribute to poor reproductive performance.[10,62,66,67] The effects of inadequate nutrition and poor body condition may be manifested in delayed return to reproductive cyclicity postpartum, reduced pregnancy rates, and increased embryo loss rates.

In addition, failure to exhibit behavioral signs of estrus (i.e., “silent heat”) is more common in the foal-heat period than in mares that have not recently given birth.[10,68] Mares with a young foal at side are very protective and may not show behavioral estrus to a stallion. A combination of ultrasound examinations and “adjusted” teasing techniques may be needed to monitor reproductive function in breeding programs that utilize or require live cover mating. A safe and effective teasing technique for a mare with a young foal may need to include manual restraint of both the foal and mare.

4. Maximizing Foal-Heat Breeding Success

Qualifications

In the author’s opinion, post-partum mares “qualify” for consideration of a foal-heat breeding under the following conditions:

- Normal foaling (i.e., no dystocia)
- No trauma to the reproductive tract
- No prolonged retained placenta
- No prolonged discharge of uterine fluid (lochia)
- No increased volume or echogenicity of fluid visible within the uterine lumen on transrectal ultrasound by day 7 to 10
- Ovulation does not occur prior to day 10 post foaling
- Mare is not of an advanced age (i.e., not $\geq$ 15 years old)

Potential Therapeutic Options

Several therapeutic strategies have been used in an attempt to enhance fertility of mares in the early post-partum period. Administration of 150 to 300 mg of progesterone with or without addition of 10 to 20 mg of estradiol-17β to post-partum mares have been used in an attempt to delay the first ovulation, enhance uterine involution, synchronize estrus, and/or enhance pregnancy rates.[16,17,69–75] In one study, administration of progesterone plus estradiol therapy initiated within 12 hours after foaling and continued for 6 days delayed the first ovulation of the year (day 15.6 $\pm$ 2.6 days vs 10.3 $\pm$ 2.4 days) and increased pregnancy rates (58.5% vs 53.0%) over that of untreated mares.[72] The combination of progesterone and estradiol initiated immediately after foaling results in suppression of the normal peripar-turient surge of follicle stimulating hormone and luteinizing hormone, and subsequently delays the development of the first follicular wave postpartum.[76] Administration of altrenogest (0.044 mg/kg) orally once per day for 8 days beginning the day after foaling was reported to delay the first post-partum ovulation to 18.2 days and increased pregnancy rates over that of untreated mares.[48]

Ecbolic agents have been administered to post-foaling mares to promote uterine contractions, eliminate fluid and debris, and/or decrease the size of the uterus in an attempt to enhance foal-heat conception rates.[25,77–80] Most studies report that administration of oxytocin or prostaglandins had no effect on increasing the rate of uterine involution or increasing pregnancy rate. One study noted an increase in foal-heat pregnancy rate when a synthetic prostaglandin analogue was administered twice daily for approximately 10 days beginning on the day of foaling.[77]

Lavage of the uterus of the post-partum mare has also been used in an attempt to enhance the rate of uterine involution, remove placental debris, reduce the degree of inflammation, reduce bacterial numbers, and/or improve foal-heat pregnancy rate.[6,8,57,58,81,82] However, controlled clinical trials determined that there is no advantage in performing a routine uterine lavage on post-partum mares that had a normal foaling, no retained placenta, or no prolonged or abnormal lochial discharge.[6,57,81,83] A therapeutic uterine lavage may be beneficial in mares that experience a retained placenta, prolonged lochial discharge or presence of an abnormal volume or adverse character of uterine fluid in the post-partum period.[51]

Adherence to the principles of antibiotic stewardship dictate that use of antimicrobial agents should be justified.[84] The routine use of antibiotics in the post-partum mare is controversial and most often not indicated. As noted previously, many post-partum mares have a positive growth on microbial culture and white blood cells are present on uterine cytology, are not treated with antibiotics, and have normal fertility. Systemic antibiotics may be indicated in mares with retained placenta, metritis-septicemia, and/or severe trauma to the reproductive tract.[34] Intrauterine infusion of antibiotics, if used at all, should follow a uterine lavage to eliminate inflammatory debris which may otherwise bind and inactivate the antibiotics. However, there have been clinical studies that report an increase in post-partum pregnancy rate following intrauterine infusion of antibiotics along with either infusion of autologous plasma[85] or systemic administration of oxytocin.[86]

Management Strategy

One management plan to optimize post-partum conception rates in mares with an uncomplicated foaling is to perform an initial reproductive examination on the mare 6 to 8 days after foaling. The goal of this examination is to evaluate the reproductive tract for trauma associated with foaling, determine the degree of follicular development, note the amount of uterine edema and identify the presence or absence of fluid in the uterine lumen. A subsequent ultrasound examination is performed on day 9 or 10. Mares that ovulate before day 10 are not bred, but are administered a dose of prostaglandins 5 to 6 days after ovulation to lyse the corpus luteum and bring them back into heat early. Mares that still have a large follicle 10 days post foaling are bred using standard techniques (live cover or artificial insemination). The use of an ovulation-inducing agent such as human chorionic gonadotropin or a gonadotropin-releasing hormone agonist is discouraged until at least day 9 or 10, since ovulations early in the post-partum period are associated with a lower pregnancy rate and higher embryonic loss rate.

Alternative Breeding Options

If an owner does not want to breed a mare on the foal heat, but also does not want to wait until the 30-day heat, an alternative strategy is to administer a dose of prostaglandins 5 to 6 days after the foal-heat ovulation to short cycle the mare.[22,32,33] This strategy results in higher per cycle and per season conception rates, a lower pregnancy loss rate and ultimately a higher foaling rate than mares first bred on the foal heat. However, it does result in a slightly longer foaling-to-conception interval (34.9 days vs 25.6 days).[32]

In lieu of multiple ultrasound examinations to determine the day of the foal-heat ovulation, an alternative plan would be to administer a dose of prostaglandins 17 to 20 days after foaling in an attempt to short cycle the mare, assuming that most mares will have ovulated by 12 days post foaling. The obvious risk is not knowing if or when a mare actually ovulated in the early post-partum period.

5. Summary

Factors that lead to consideration of foal-heat breeding include the long equine gestation length, photoperiod-dependent physiologic breeding season, limited-duration imposed breeding season, designation of January 1 as the official birth date of foals

(North America), and the possibility of a prolonged post-partum anestrus period. However, not every mare is a suitable candidate for foal-heat breeding and each foaling mare should be considered as an individual. Evaluation of foaling ease and passage of the placenta, a thorough physical and reproductive examination performed approximately 6 to 8 days postpartum and monitoring the development of the dominant follicle prior to and after day 10 will provide critical information for a foal-heat breeding decision. Adherence to sound reproductive management guidelines can yield an acceptable pregnancy rate while minimizing pregnancy loss. Mares that do not qualify for a foal-heat breeding may be short cycled by administration of prostaglandins approximately 5 to 6 days after the foal-heat ovulation.

Acknowledgments

Declaration of Ethics

The Author has adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Author has no conflicts of interest.

References

1. Ginther OJ. *Reproductive biology of the mare: basic and applied aspects*. 2nd ed. Cross Plains, WI: Equiservices, 1992; 475–486.
2. Matthews RG, Ropiha RT, Butterfield RM. The phenomenon of foal heat in mares. *Aust Vet J* 1967;43:579–582.
3. Loy RG. Characteristics of postpartum reproduction in mares. *Vet Clin North Am Large Anim Pract* 1980;2:345–349.
4. Miyakoshi D, Shikichi M, Ito K, et al. Factors influencing the frequency of pregnancy loss among thoroughbred mares in Hidaka, Japan. *J Equine Vet Sci* 2012;32:552–557.
5. Koskinen E, Katila T. Uterine involution, ovarian activity, and fertility in the post-partum mare. *J Reprod Fertil* 1987; 35(Suppl):733–734.
6. McCue PM, Hughes JP. The effect of postpartum uterine lavage on foal heat pregnancy rate. *Theriogenology* 1990;33: 1121–1129.
7. Sharma S, Morel MD, Dhaliwal GS. Factors affecting the incidence of postpartum oestrus, ovarian activity and reproductive performance in Thoroughbred mares bred at foal heat under Indian subtropical conditions. *Theriogenology* 2010; 74:90–99.
8. Blanchard TL, Macpherson ML. Breeding mares on foal heat. In: McKinnon AO, Squires EL, Vaala WE, Varner DD, eds. *Equine reproduction*. 2nd ed. Ames, IA: Wiley-Blackwell, 2011; 2294–2301.
9. Lemes KM, Silva LA, Alonso MA, et al. Follicular dynamics, ovarian vascularity and luteal development in mares with early or late postpartum ovulation. *Theriogenology* 2017;96: 23–30.
10. Nagy P, Huszenicza G, Juhasz J, et al. Factors influencing ovarian activity and sexual behavior of postpartum mares under farm conditions. *Theriogenology* 1998;50:1109–1119.
11. Rossdale PD, Ricketts SW. *The practice of equine stud medicine.* Baltimore, MD: Williams and Wilkins, 1974; 98–146.
12. Hanlon DW, Stevenson M, Evans MJ, et al. Reproductive performance of Thoroughbred mares in the Waikato region of New Zealand: 2. Multivariable analyses and sources of variation at the mare, stallion and stud farm level. *NZ Vet J* 2012;60:335–343.
13. Bosh KA, Powell D, Neibergs JS, et al. Impact of reproductive efficiency over time and mare financial value on economic returns among Thoroughbred mares in central Kentucky. *Equine Vet J* 2009;41:889–894.
14. Sullivan JJ, Turner PC, Self LC, et al. Survey of reproductive efficiency in the Quarter-Horse and Thoroughbred. *J Reprod Fertil* 1975;23(Suppl):315–318.
15. Merkt H, Günzel AR. A survey of early pregnancy losses in West German Thoroughbred mares. *Equine Vet J* 1979;11: 256–258.
16. Lieux P. Comparative results of breeding on first and second post-foaling heat periods, in *Proceedings.* Am Assoc Equine Pract 1980;26:129–132.
17. Bell RJ, Bristol FM. Fertility and pregnancy loss after delay of foal oestrus with progesterone and oestradiol-17B. *J Reprod Fert* 1987;35(Suppl):667–668.
18. Chevalier-Clément F. Pregnancy loss in the mare. *Anim Reprod Sci* 1989;20:231–244.
19. Kurtz Filho M, Deprá NM, Brass KÉ, et al. Post-partum fertility in Thoroughbred mares. *Brazilian J Vet Res Anim Sci* 1998;35:75–79.
20. Morris LH, Allen WR. Reproductive efficiency of intensively managed Thoroughbred mares in Newmarket. *Equine Vet J* 2002;34:51–60.
21. Yang YJ, Cho GJ. Factors concerning early embryonic death in Thoroughbred mares in South Korea. *J Vet Med Sci* 2007;69:787–92.
22. Blanchard TL, Thompson JA, Love CC, et al. Influence of day of postpartum breeding on pregnancy rate, pregnancy loss rate, and foaling rate in Thoroughbred mares. *Theriogenology* 2012;77:1290–1296.
23. Lane EA, Bijnen ML, Osborne M, et al. Key factors affecting reproductive success of Thoroughbred mares and stallions on a commercial stud farm. *Reprod Dom Anim* 2016;51:181–187.
24. Saltiel A, Gutierrez A, Sosa C. Cervico-endometrial cytology and physiological aspects of the post-partum mare. *J Reprod Fert* 1987;35(Suppl.):305–309.
25. Mattos RC, de Araújo Rocha AL, Zimmer Jr O, et al. Use of methylergonovine maleate and cloprostenol during uterine involution to improve conception rates of foal heat. *Biol Reprod Mono* 1995;52:533–537.
26. Camillo F, Marmorini P, Romagnoli S, et al. Fertility at the first post partum estrous compared with fertility at the following estrous cycles in foaling mares and with fertility in nonfoaling mares. *J Equine Vet Sci* 1997;17:612–616.
27. Blanchard TL, Thompson JA, Brinsko SP, et al. Mating mares on foal heat: A five-year retrospective study, in *Proceedings.* Am Assoc Equine Pract 2004;50:525–530.
28. Camargo CE, Kozicki LE, Ruda PC, et al. Reproductive efficiency in lactating mares inseminated early in the puerperium (< 10 days post partum) versus non-lactating mares inseminated 180 days post partum. *Pferdeheilkunde* 2017; 33:458–464.
29. Ishii M, Shimamura T, Utsumi A, et al. Reproductive performance and factors that decrease pregnancy rate in heavy draft horses bred at foal heat. *J Equine Vet Sci* 2001;21: 131–136.
30. Meyers PJ, Bonnett BN, McKee SL. Quantifying the occurrence of early embryonic mortality on three equine breeding farms. *Canadian Vet J* 1991;32:665–672.
31. Malschitzky E, Pimentel AM, Garbade P, et al. Management strategies aiming to improve horse welfare reduce embryonic death rates in mares. *Reprod Dom Anim* 2015;50: 632–636.
32. Lowis TC, Hyland JH. Analysis of post-partum fertility in mares on a Thoroughbred stud in southern Victoria. *Aust Vet J* 1991;68:304–306.
33. Zent WW. The postpartum breeding mare. In: Samper JC, Pycock JF, McKinnon AO, eds. *Current therapy in equine reproduction.* St. Louis, MO: Saunders Elsevier, 2007; 455–457.

34. Stout TA. How to decide when to breed the postpartum mare, in Proceedings. *Am Assoc Equine Pract* 2012;58:375–378.
35. Ginther OJ, Williams D. On-the-farm incidence and nature of equine dystocias. *J Equine Vet Sci* 1996;6:159–164.
36. McCue PM, Ferris RA. Parturition, dystocia and foal survival—A retrospective study of 1,047 births. *Equine Vet J* 2012;44(Supplement 41):22–25.
37. Frazer G. Dystocia management. In: McKinnon AO, Squires EL, Vaala WE, Varner DD, eds. *Equine reproduction*. 2nd ed. Ames, IA: Wiley-Blackwell, 2011; 2479–2496.
38. Vandeplassche M, Spincemaille J, Bouters R. Aetiology, pathogenesis and treatment of retained placenta in the mare. *Equine Vet J* 1971;3:144–147.
39. Belz JP, Glatzel PS. Fertility in mares after a disturbed as well as an undisturbed puerperium. Significance of histological and cytological examinations of the uterus. *Tierarztl Prax* 1995;23:267–72.
40. Steiger K, Kersten F, Aupperle H, et al. Puerperal involution in the mare-a comparison of clinical signs and pathology. *Pferdeheilkunde* 2001;17:627–32.
41. Provencher R, Threlfall WR, Murdick PW, et al. Retained fetal membranes in the mare: A retrospective study. *Can Vet J* 1988;29:903–910.
42. Ishii M, Aoki T, Yamakawa K, et al. Relationship between the placental retention time and the reproductive performance at the foal heat in Thoroughbred and a comparison with heavy draft. *J Equine Sci* 2013;24:25–29.
43. Burns SJ, Judge NG, Martin JE, et al. Management of retained placenta in mares, in *Proceedings.* Am Assoc Equine Pract 1977;23:381–390.
44. Meijer M, Macpherson ML, Dijkman R. How to use umbilical vessel water infusion to treat retained fetal membranes in mares, in *Proceedings.* Am Assoc Equine Pract 2015;61: 478–484.
45. Schilela A, Malschitzky E, Mattos AG, et al. Effect of accumulation of intra-uterine fluid before and after the first postpartum ovulation on pregnancy rates in the mare. *Pferdeheilkunde* 2001;17:639–643.
46. Malschitzky E, Schilela A, Mattos AL, et al. Effect of intrauterine fluid accumulation during and after foal-heat and of different management techniques on the postpartum fertility of Thoroughbred mares. *Theriogenology* 2002;58:495–498.
47. McKinnon AO, Squires EL, Harrison LA, et al. Ultrasonographic studies on the reproductive tract of mares after parturition: Effect of involution and uterine fluid on pregnancy rates in mares with normal and delayed first postpartum ovulatory cycles. *J Amer Vet Med Assoc* 1988;192:350–353.
48. Pycock JF, Newcombe JR. The relationship between intraluminal uterine fluid, endometritis, and pregnancy rate in the mare. *Equine Pract* 1996;18:19–22.
49. Malschitzky E, Schilela A, Mattos AL, et al. Intrauterine fluid accumulation during foal heat increases embryonic death. *Pferdeheilkunde* 2003;19:646–649.
50. Hooper RN, Blanchard TL, Taylor TS, et al. Identifying and treating uterine prolapse and invagination of the uterine horn. *Vet Med* 1993;88:60–65.
51. Macpherson ML, Blanchard TL. Breeding mares on foal-heat. *Equine Vet Educ* 2005;17:44–52.
52. Stanton ME. Uterine involution. In: McKinnon AO, Squires EL, Vaala WE, Varner DD, eds. *Equine reproduction*. 2nd ed. Ames, IA: Wiley-Blackwell, 2011; 2291–2293.
53. Gygax AP, Ganjam VK, Kenney RM. Clinical, microbiological and histological changes associated with uterine involution in the mare. *J Reprod Fertil* 1979;27(Suppl):571–578.
54. Steven DH. Placentation in the mare. *J Reprod Fertil* 1982;31(Suppl):41–55.
55. Purswell BJ, Ley WB, Sriranganathan N, et al. Aerobic and anaerobic bacterial flora in the postpartum mare. *J Equine Vet Sci* 1989;9:141–144.
56. Baranski W, Janowski TO, Ras T, et al. Relationship between bacteriological and cytological examination of the mares' uterus during foal heat and fertility rate. *Bull Vet Inst Pulawy* 2003;47:427–434.
57. Mitchell AR, Scott CJ, Cheong SH, et al. The effect of routine postpartum uterine lavage on endometrial cytology, culture, and pregnancy rates in Thoroughbred broodmares. *J Equine Vet Sci* 2019;80:5–9.
58. Lenz TR. One practitioner's approach to foal heat breeding, in *Proceedings. Soc Theriogenol* 1986;111–119.
59. Krohn J, Eilenberg RD, Gajewski Z, et al. Lochial and endometrial cytological changes during the first 10 days postpartum with special reference to the nature of foaling and puerperium in equine. *Theriogenology* 2019;139:43–48.
60. Palmer E, Driancourt MA. Some interactions of season of foaling, photoperiod and ovarian activity in the equine. *Livestock Prod Sci* 1983;10:197–210.
61. Witkowski M, Tischner M. Effect of increased daylight during late pregnancy on the reproductive performance of mares after parturition. *J Reprod Fertil* 2000;56(Suppl):673–677.
62. Malschitzky E, Schilela A, Meirelles LS, et al. Artificial photoperiod in pregnant mares and its effect on pregnancy length and postpartum reproductive performance. *Pferdeheilkunde* 2001;17:565–569.
63. Hodge SL, Kreider JL, Potter GD, et al. Influence of photoperiod on the pregnant and postpartum mare. *Am J Vet Res* 1982;43:1752–1755.
64. Henneke DR, Kreider JL. Effects of restrictive suckling on postpartum reproductive performance in mares. *Am J Vet Res* 1979;40:1281–1284.
65. Sargent GF, Pope NS, Kesler DJ. Postpartum LH profile characteristics, estrus and ovulation: The influence of short-term foal removal. *J Eq Vet S*ci 1988;8:156–160.
66. Henneke DR, Potter GD, Kreider JL. Body condition during pregnancy and lactation and reproductive efficiency of mares. *Theriogenology* 1984;21:897–909.
67. Hines KK, Hodge SL, Kreider JL, et al. Relationship between body condition and levels of serum luteinizing hormone in postpartum mares. *Theriogenology* 1987;28:815–825.
68. Najjar A, Taamouli C, Khaldi S, et al. Post-partum period in Tunisian Arab mares: Which factors influence the foaling heat? *Internat J Innov Approach Agric Res* 2019;3:1–7.
69. Loy RG, Swan SM. Effects of exogenous progestogens on reproductive phenomena in mares. *J Anim Sci* 1966;25: 821–826.
70. Loy RG, Hughes JP, Richards WPC, et al. Effects of progesterone on reproductive function in mares after parturition. *J Reprod Fertil* 1975;23(Suppl):291–295.
71. Pope AM, Campbell DL, Davidson JP. Endometrial histology of post-partum mares treated with progesterone and synthetic GnRH (AY-24, 031). *J Reprod Fertil* 1979;27(Suppl): 587–591.
72. Loy RG, Evans MJ, Pemstein R, et al. Effects of injected ovarian steroids on reproductive patterns and performance in postpartum mares. *J Reprod Fertil* 1982;32:199–204.
73. Bristol F, Jacobs KA, Pawlyshyn V. Synchronization of estrus in post-partum mares with progesterone and estradiol 17β. *Theriogenology* 1983;19:779–785.
74. Sexton PE, Bristol FM. Uterine involution in mares treated with progesterone and estradiol-17B. *J Am Vet Med Assoc* 1985;186:252–256.
75. Bruemmer JE, Brady HA, Blanchard TL. Uterine involution, day and variance of first postpartum ovulation in mares treated with progesterone and estradiol-17β for 1 or 2 days postpartum. *Theriogenology* 2002;57:989–995.
76. Turner DD, Garcia MC, Miller KF, et al. FSH and LH concentrations in periparturient mares. *J Reprod Fert* 1979;27(Suppl):547–553.
77. Ley WB, Purswell BJ, Bowen JM. The effects of prostalene and alfaprostol as uterine myotonics, and the effect on postpartum pregnancy rate in the mare following daily treatment with prostalene. *Theriogenology* 1988;29:1113–1121.
78. Blanchard TL, Varner DD, Brinsko SP, et al. Effects of ecbolic agents on measurements of uterine involution in the mare. *Theriogenology* 1991;36:559–571.

79. Tolksdorff E, Jochle W, Lamond DR, et al. Induction of ovulation during the postpartum period in the Thoroughbred mare with a prostaglandin analogue, Synchrocept. *Theriogenology* 1976;6:403–412.
80. Gündüz MC, Kaşıkcı G, Ekiz B. Follicular and steroid hormone changes in Arabian mares in the postpartum period. *Anim Reprod Sci* 2008;109:200–205.
81. Webb GW. Fertility and uterine histology of postpartum mares treated with estradiol, antibiotics or uterine lavage. PhD Thesis, Texas A & M University, 1983; l-88.
82. Shideler AE, McChesney, EL Squires, et al. Effect of uterine lavage on clinical and laboratory parameters in postpartum mares. *Equine Pract* 1987;2:20–26.
83. Blanchard TL, Varner DD, Brinsko SP, et al. Effects of postparturient uterine lavage on uterine involution in the mare. *Theriogenology* 1989;32:527–535.
84. Bowen M. Antimicrobial stewardship: Time for change. *Equine Vet J* 2013;45:127–129.
85. Pascoe DR. Effect of adding autologous plasma to an intrauterine antibiotic therapy after breeding on pregnancy rates in mares. *Biology Reprod Mono* 1995;52:539–543.
86. Pycock JF. Assessment of oxytocin and intrauterine antibiotics on intrauterine fluid and pregnancy rates in the mare, in *Proceedings*. Am Assoc Equine Pract 1994;40: 19–20.

Recumbency as a Risk Factor for Mare and Foal Survival Following In-Hospital Dystocia Management

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The proportions of mares and foals that survived following dystocia resolution were significantly higher from ambulatory mares than mares who were recumbent at hospital admission. Author's addresses: Department of Large Animal Clinical Sciences, College of Veterinary Medicine, University of Florida, 2015 SW 16th Avenue, Gainesville, FL 32608 (Roe, Macpherson, Denagamage); Rood and Riddle Equine Hospital, PO Box 12070, Lexington, KY 40580-2070 (Embertson, Hopper, Woodie); e-mail: heather.roe@ufl.edu. *Corresponding and presenting author.

1. Introduction

The objective of this study was to evaluate recumbency at hospital admission as a risk factor for the survival of mares and foals following dystocia management.

2. Materials and Methods

Retrospective data were obtained from medical records of mares with dystocia between 1995–2018. Mare signalment, ambulation status, and survival data were collected. The proportions of mare and foal survival were analyzed using the chi-squared and Fisher's exact tests, respectively. Odds ratios were calculated using univariate logistic regression (Statistix10 Analytical Software).

3. Results

The overall proportion of mares that survived after dystocia resolution was 90.6% (979/1,079) and of foals was 37.2% (402/1,079). Ambulatory mares had an 8-times greater odds of survival (odds ratio [OR], 8.15; 95% confidence interval [CI]: 4.21–15.78; $P < 0.001$) than recumbent mares. Foals delivered from ambulatory mares had a 12 times greater odds of survival (OR, 12.22; 95% CI: 2.97–50.34; $P < 0.001$) than foals delivered from recumbent mares.

4. Discussion

Based on these results, mare and foal survival were significantly decreased when mares with dystocia were recumbent at admission. Although speculative, prolonged laboring and attempts to extract the foal likely contributed to mare exhaustion and neurologic and/or musculoskeletal trauma, resulting in recumbency. Nonsurvivors rarely stood after delivery. A prompt resolution and/or early referral of mares with dystocia may reduce the likelihood of prolonged recumbency and may improve the survival of mares and foals.

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Acknowledgments

Declaration of Ethics

The Authors have adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Authors have no conflicts of interest.

Prediction of Gestational Age Based on Fetal Ultrasonographic Biometric Measurements in Quarter Horses

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A table was generated, based on fetal ultrasonographic measurements in light-breed mares for each day of gestation beginning with day 90 to provide the predicted value of 4 biometric parameters: fetal aortic diameter, eye approximated volume, biparietal diameter, and femur length. Using this table, days of gestation were predicted in 23 Quarter Horses within 2 weeks between 100 and 200 days and within 3 weeks thereafter. Authors' addresses: 1206 Deodara Street, Davis, CA 95618 (Renaudin); 230 Mrak Hall, 1 Shields Avenue, Davis, CA 95616 (Kass); College of Veterinary Medicine, Route de Gachet, 44307 Nantes, France (Bruyas); e-mail: cdrenaudin@gmail.com. *Corresponding and presenting author.

1. Introduction

Fetal age/growth evaluation is routinely done in humans based on ultrasonographic measurements of fetal parts that are compared to established tables. In this study, a table was generated based on fetal measurements in Quarter Horses (QHs) mainly. Fetal age prediction accuracy was then assessed using 23 QH pregnant mares.

2. Materials and Methods

Fetal ultrasonographic measurements (aortic diameter, eye approximated volume [EyV], biparietal diameter, and femur length) were taken in 10 pregnant mares with known breeding dates every 2 weeks starting at 100 days of gestation to establish a table with each day of gestation and its predicted value for the 4 biometric variables. Twenty-three QH pregnant mares with known ovulation dates unknown to the ultrasonographer were used to assess age prediction accuracy for each variable.

3. Results

Fetal age was predicted within 2 weeks from 100 to 200 days' gestation using femur length, biparietal diameter, and EyV and within 3 weeks thereafter using EyV.

4. Conclusion

The results suggest that fetal age/growth can be assessed within 3 weeks in QH mares that are more than 90 days pregnant using the generated table from light breed horses.

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The Authors have no conflicts of interest.

Inflammatory Protein Biomarkers in the Low-Volume Lavage of Mares with Endometritis and Degenerative Endometrial Fibrosis

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Multiple inflammatory cytokines are significantly increased in the low-volume uterine lavage fluid of mares with endometritis representing potential targets for a novel, efficient diagnostic test. Authors' addresses: Department of Clinical Sciences (Lection, Cheong, Diel de Amorim), Department of Population Medicine and Diagnostic Sciences (Wagner), Department of Biomedical Sciences (Miller), College of Veterinary Medicine, Cornell University, Ithaca, NY 14853; Department of Population Medicine, Ontario Veterinary College, University of Guelph, Guelph, ON N1G 2W1, Canada (Chenier); e-mails: jml586@cornell.edu, md649@cornell.edu. *Co-corresponding authors; †presenting author.

1. Introduction

For the equine practitioner, endometritis is frustrating to diagnose. Endometrial biopsy, the gold standard, is invasive, not always a diagnostic option for some owners, and turnaround can be lengthy. The objective was to investigate equine inflammatory biomarkers, which the authors hypothesized would be increased for mares with evidence of endometritis, in uterine low-volume lavage (LVL) fluid.

2. Materials and Methods

Twenty-nine mares had LVL followed by endometrial biopsy. Endometrial cytology was performed from LVL pellets. Biopsies were graded by a Board-certified veterinary pathologist. Mares were assigned to acute endometritis (n = 3) (cytology >1% polymorphonuclear leukocytes (PMN)s, no fibrosis), degenerative endometrial fibrosis (DEF) (n = 9) (poor endometrial biopsy [IIB/III]), or healthy (n = 17). LVL fluid was utilized in a multiplex bead assay[a] to quantify levels of the following biomarkers: IFN-γ, IL-1β, IL-10, IL-17, sCD14, TNF-α, chemokine (C-C motif) ligand 2 (CCL2), CCL3, CCL5, and CCL11. A Kruskal–Wallis with post-hoc Dunn's test was performed to compare the levels of markers between the groups.

3. Results

The following markers were significantly increased in LVL from mares with acute endometritis and DEF as compared to healthy mares: IFN-γ (P = .0262), CCL2 (P = .0482), and CCL3 (P = .0299).

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4. Discussion

These three biomarkers are all pro-inflammatory cytokines, which orchestrate the response of leukocytes to endometrial changes. This study demonstrates that these pro-inflammatory markers may serve as potential diagnostic markers for equine endometritis.

Acknowledgments

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Declaration of Ethics

The Authors have adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Authors have no conflicts of interest.

Footnote

[a]Luminex Corp., Austin, TX 78727.

Iodine Levels in Extensively Managed Broodmares and Their Foals

Maria F. Lopez-Rodriguez, DVM†; Brandi Bakken, BSc; Ashlyn Ketterer, BSc; Mikayla Swirski, BSc; and Claire E. Card, DVM, PhD, DACT*

Trace mineral supplementation using only mineral blocks results in insufficient levels of iodine in broodmares. Authors' address: Department of Large Animal Clinical Sciences, University of Saskatchewan, Saskatoon, SK S7N 5B4 Canada; e-mail: cec062@mail.usask.ca. *Corresponding author; †presenting author.

1. Introduction

Iodine deficiency has been reported in broodmares and has been associated with congenital hypothyroidism dysmaturity syndrome in foals that presents as abortion, stillbirth, contracted tendons, tendon rupture, hypothermia, bony dysgenesis, and goiter.

2. Materials and Methods

Client mares and foals supplied only with mineral blocks for trace mineral supplementation were studied. Serum (10 mL) and milk (30 mL) (n = 35) were obtained from healthy post-foaling mares (n = 50) ages (3–25 years) and foals (n = 31) ages birth to 35 days, in 2018 to 2019. Iodine was measured by inductively coupled mass spectrometry and thyroid hormones using immunoassays.[a]

3. Results and Discussion

Serum iodine level was low in 79% of mares and correlated with age (n = 48) (R = −0.41, $P < .003$), TT4 (n = 50) (R = 0.06, $P < .001$), TT3 (n = 50) (R = 0.45, $P < .001$) and milk iodine (n = 35) (R = 0.42, $P = .0124$). Some mares had low basal TT4 12.0% (6/50), and TT3 6.0% (3/50). Median milk (n = 35) iodine was 28 μg/L ± 2.3 (14.5, 70.5) and classified as high, 34% (12/35); adequate, 51% (18/35); and inadequate, 14% (5/35). Foal serum iodine was higher than mare levels ($P < .001$), week was correlated with iodine (R = −0.37, $P = .043$), TT4 (R = −0.69, $P < .001$), and TT3 (R = −0.69, $P < .001$). Mineral supplementation with blocks provided insufficient iodine.

Acknowledgments

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Declaration of Ethics

The Authors have adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Authors have no conflicts of interest.

Footnote

[a]Immulite kits, Siemens, Munich, Germany.

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Moving Equine Anesthesia from an Art Toward a Science

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1. Introduction

October 16 is celebrated as "Ether Day" in recognition of the first public demonstration of painless surgery by William Morton on October 16, 1846. Morton, a dentist, utilized sulfuric ether vapor at the Massachusetts General Hospital to provide anesthesia for the removal of a tumor. The development was an international sensation, allowing previously unbearable surgical procedures to be performed.[1] This event heralded a new era where those performing surgery (generally pathologists) went from being "barbarians" to "surgeons," raising their status in society. Interestingly, this advance preceded the introduction of the concept of antiseptic surgery by Lister and then aseptic surgery by Halstead, by more than 20 years. The following year, the use of ether for anesthesia of a horse at the Royal Veterinary College was reported in the newspaper, *The Times of London*, but widespread use was limited by its lack of potency.[2] Chloroform, another inhalant anesthetic administered using a mask, was used widely for brief procedures in the early 1900s but was never considered "safe."[2] At the time, the practice of anesthesia consisted primarily of local anesthesia, sedation and physical restraint. As the science behind the practice of anesthesia grew, attempts to define the goals of anesthesia led Woodbridge in 1957 to establish four specific components: sensory blockade, motor blockade, sleep or mental blockade, and blockade of undesirable reflex activity.[3]

The modern era of equine anesthesia and analgesia traces from the 1960s when nonsteroidal anti-inflammatories, alpha$_2$ adrenoceptor agonists, and inhalant anesthetics became available and were adopted into equine practice.[4-6] In the 60 years since, over 2400 citations concerning equine anesthesia have appeared at PubMed, attesting to the considerable interest in defining and advancing the science of equine anesthesia. This interest has been largely driven by the development of complex surgical procedures and advanced imaging modalities, many of which require both anesthetic periods of general anesthesia greater than 60 to 90 minutes and positioning in recumbencies for which the anatomy of the horse was not designed or to which it has not evolved. It is important to recognize that such advances in equine surgery and imaging would not have been possible without the ability of veterinarians to provide an anesthetized state with sufficient homeostasis to allow for a successful return to a standing posture in a relatively short time. There have been numerous notable successes in advancing equine anesthesia, yet safely anesthetizing system-

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ically healthy horses remains the most challenging of the common domestic species, with reported mortality rates of approximately 0.1 to 1%.[7–9]

Horses are physiologically stressed by anesthesia to a greater degree than other species.[10] Typically, a horse is anesthetized in an unaccustomed place where it is administered drugs that cause it to lose consciousness and fall to the ground or floor. Once recumbent, its mouth may be pried open and a large bore tube is inserted into the airway for a period of minutes to hours. In hospital situations, the horse is often lifted with hobbles by a hoist and positioned on a table in an unnatural position. Then, the horse is connected to a machine that delivers anesthetic and controls its breathing. Once an intended procedure is completed, the horse is again lifted by its limbs and placed in another room (recovery stall) or space where it is expected to attain a standing position in a relatively short period of time (less than 90 minutes) while recovering from the effects of the drugs that caused it to fall down in the first place!

2. The Developing Science of Equine Anesthesia

The current practices of equine anesthesia have evolved by necessity and because of the work of a large number of dedicated individuals and groups who have provided veterinary colleagues with information. The author has chosen to highlight publications that have had significant impact on the development of the practice of equine anesthesia to its current state. The publications are grouped in six subject areas and within groups are presented chronologically in an attempt to provide context. The publications were selected based on the author's experience and his perusal of the veterinary literature including works on the history of equine anesthesia.[2,11–13] Scientific articles published after the highlighted publications are discussed as a method to transition to today.

Veterinary medicine gained initial prominence in society in large part because of the importance of the horse in transportation and for work in agriculture. Prior to the development of the profession, much of medical care for horses was left to untrained individuals. Books such as *The Illustrated Horse Doctor*,[14] published in 1880 by Mayhew were written to "instruct the novice in such a manner as would afford a reasonable prospect of success." Such texts covered all of the known maladies of the day including simple ophthalmia (iridocyclitis?), staggers (mycotoxin-induced incoordination?), gutta serena (blindness of unknown origin?), nasal gleet (thick nasal discharge?), and scald mouth (slobbering or frothing?). Surgeries were performed with physical restraint of the horse usually in the absence of adjuvant drugs. Directions for casting the horse included: "Let it be hobbled and never, during the operation, hear any sound but soothing accents. Animals do not understand words, creatures may not be able to literally interpret; but they comprehend all that the manner conveys."[14] Veterinary care improved as colleges of veterinary medicine were established and their influence spread.

3. Early Anesthesia Texts

Sir Frederick Hobday (of the Hobday procedure on the equine throat), published an important text, *Anaesthesia and Narcosis of Animals and Birds* in 1915.[15] Hobday was a voice for humane care of animals and promoted augmenting physical restraint with chemical restraint, believing that surgical procedures should be performed as painlessly as possible. Available "narcotics" included chloral hydrate given orally or rectally. Intravenous administration was discouraged because of "violent irritation if the fluid finds its way under the skin" and the potential for air embolus. The use of morphine was discouraged because it produced excitement. Practical inhalant anesthesia was limited to chloroform by inhaler with surgical durations limited to 15 minutes. Unmedicated horses were hobbled and cast to the ground prior to application of the inhaler with the proviso that the hobbles should not be removed until the animal could rise properly.

Professor John G. Wright of the University of Liverpool published an early book, *Veterinary Anaesthesia*, in 1941, a text that has been revised and expanded through 11 editions, the last of which was presented in 2014.[16] The first edition of this book facilitated the transition from physical restraint to chemical restraint. The authors noted that adequate restraint was necessary even for quite simple procedures and stated that casting prior to the application of anesthetics may be necessary to ensure safety. The use of succinylcholine for painful surgery was discouraged but the authors noted that its use in casting may be no more distressing than hobbles and might be less risky. Chlorpromazine, promazine, meperidine, and chloral hydrate were available for use as premedicants and basal narcotics. Early editions of the book addressed endotracheal intubation and inhalant anesthesia with chloroform, cyclopropane, and halothane using both open and closed (circle) systems. Intravenous anesthetic techniques included the use of chloral hydrate, chloral hydrate with magnesium sulfate, chloral hydrate with magnesium sulfate and pentobarbital (Equithesin or "Army Anesthesia"), and thiopental. Recoveries from anesthesia were expected to be from 90 minutes to 2 hours in duration.

4. Sedatives and Analgesics

Xylazine was introduced as a new sedative for horses and cattle by Clarke and Hall in 1969.[4] Heart rate and cardiac output decreased and arterial blood pressure increased transiently after drug administration. The authors noted that xylazine was a "safe, reliable, short acting sedative" that was "better than any other compound in current use." Interestingly it was stated that "heavier doses seemed to produce no more profound sedation, but the effects became apparent after a shorter time interval and persisted longer." Detomidine and romifidine followed in the 1980's and 1990's, respectively.[17,18] Equipotent IV doses for the drugs are reported to be xylazine 1 mg/kg; detomidine 10 microg/kg; and romifidine 80 microg/kg.[18] Romifidine produces less lowering of the head and less ataxia than xylazine or detomidine at clinically recommended doses, which may make the degree of sedation produced more difficult to judge.[18]

Butorphanol was approved for use in the horse in the 1980s and remains the only opioid agonist with such a designation.[19] Approved as an analgesic drug for the treatment of abdominal pain, butorphanol's primary current use is in combination with alpha$_2$ agonists as an adjunct for standing chemical restraint. Robertson documented the cardiopulmonary, sedative, and analgesic effects of butorphanol given 5 minutes after xylazine by making a skin incision 5 minutes later.[19] The combination produced 15 to 30 minutes of analgesia with minimal and transient hemodynamic effects and insignificant respiratory depression. The authors stated, "The analgesic effects of each drug are additive and provided good chemical restraint." Butorphanol was not a controlled substance when first marketed for use in the horse. That fact, and papers like this documenting its efficacy led to its widespread adoption.

The analgesic and other effects of butorphanol, flunixin, levorphanol, morphine, and xylazine were examined in ponies by Kalpravidh in 1984.[20] This paper used the pony's response to repeatable stimuli to examine and quantify the analgesic effects of drugs. A heat lamp model was used to produce acute superficial pain and a cecal balloon model was used to assess acute visceral pain. Analgesia was assessed by measuring how long it took for the pony to react to the stimulus. Xylazine produced the highest pain threshold for 60 minutes with significant effects lasting 180 minutes and 240 minutes for superficial pain and visceral pain, respectively. Morphine was the next best drug for superficial pain but produced only slight effects for visceral pain. Butorphanol was the best drug after xylazine for visceral pain. Interestingly, flunixin was not shown to be effective for acute pain in this model, but it is widely used as an initial treatment in many instances. Modifications of this methodology continue to be used widely to assess analgesic effects of drugs. A number of drugs and drug combinations have been reported including alpha$_2$ adrenergic agonists combined with acepromazine,[21] morphine,[22,23] ketamine,[24] buprenorphine,[25] lidocaine,[26] meperidine,[27] and methadone.[27]

5. Intravenous Anesthetics and Adjuncts

The skeletal muscle relaxant guaifenesin (then known as glyceryl guaiacolate ether) was introduced into equine anesthesia in 1968 by Gertsen and Tillotson.[28] Guaifenesin was administered rapidly in 5% solutions alone or in combination with thiamylal or pentobarbital after sedation with acepromazine and meperidine. Apnea did not occur at induction and at least three times the calculated dose was required to produce death. The authors reported that guaifenesin produced "excellent results when used as the sole anesthetic agent in short procedures" and the technique had a "wide margin of safety and consistently excellent results." Although guaifenesin remains a component of many intravenous anesthetic combinations, its use as a sole agent is discouraged because of its minimal analgesic effects.

Likely among the most significant reports in the history of equine anesthesia was published in 1977 by Muir describing the use of xylazine and ketamine for short-term anesthesia.[29] This study investigated the anesthetic and cardiopulmonary effects of xylazine and ketamine with xylazine given intravenously 5 minutes prior to intravenous ketamine. Recumbency occurred within 30 to 60 seconds of ketamine administration and anesthesia lasted approximately 16 minutes with a mean time to standing of 26 minutes. The quality of recovery was excellent with most horses standing on their first attempt. Hemodynamic variables including cardiac output and ventilation were well maintained while arterial oxygenation was decreased. Analgesia and muscle relaxation were described as good. The authors stated, "Xylazine and ketamine appears to be a safe and practicable anesthetic regimen in the horse." This paper provided a safe, humane alternative to just physical restraint or the administration of succinylcholine for short-term "recumbent restraint" for procedures like castration. There have been a number of modifications of this technique since its introduction but xylazine or another alpha$_2$ agonist and ketamine still form the basis of the majority of equine anesthetic protocols whether the procedures are conducted in the hospital setting or in the field. Substitution of detomidine for xylazine produces similar quality induction of anesthesia but is associated with poorer recoveries with ataxia.[30,31] Replacing xylazine with romifidine is not recommended unless muscle relaxants, such as guaifenesin or midazolam, are co-administered.[32] The addition of butorphanol to xylazine does not increase the duration of anesthesia but the quality of anesthesia is improved.[31]

Equine veterinarians needed a method to extend xylazine and ketamine anesthesia when the surgical task could not be completed in a 15- to 20-minute period. The question of how to safely extend the anesthetic period was answered with the publication of a paper by Greene in 1986 describing the use of guaifenesin in combination with ketamine and xylazine (Triple Drip or G-K-X) for total intravenous anesthesia (TIVA) of 2 hours' duration.[33] Anesthetic conditions were good and the ponies stood without help in 15 to 30 minutes after the infusion was stopped. This paper provided important information about an anesthetic technique that continues to be widely used, particularly in out-of-hospital settings. The addition of a muscle relaxant like guaifenesin to xylazine-ketamine anesthesia extended the anesthetic period and provided improved anesthetic conditions. While guaifenesin is useful in this setting, its use is cumbersome because dilute solutions (5% to 10%) are required to avoid hemolysis and vasculitis after IV administration, resulting in the need to administer a volume of 0.5 to 1 L of solution to have a significant effect. An alternative method of providing muscle relaxation was addressed in a 1990 report from Brock that compared diazepam to guaifenesin as the anesthetic adjunct.[34] This paper described the use of diazepam as a replacement for guaifenesin as part of an induction technique prior to maintenance with halothane. It followed an earlier paper suggesting that the addition of diazepam improved xylazine/ketamine anesthesia in the field.[35] The authors found that a 0.1 mg/kg dose of diazepam was useful and "produces a quality of anesthetic induction, transition, and recovery comparable to guaifenesin."[34] The required volume of diazepam was smaller (approximately 10 mL or less) but was a controlled substance, requiring strict documentation of use. Subsequent papers have investigated the use of midazolam, another benzodiazepine, and have found it to be similarly convenient and useful.[36,37]

The proprietary combination of tiletamine and zolazepam administered after alpha$_2$ adrenergic agonists produces qualitatively similar anesthesia to xylazine-diazepam-ketamine and is of longer duration but the quality of recovery is reduced.[38] Propofol, a widely used drug in other species, is not widely used in horses. Initial reports suggested that propofol, after xylazine, was a satisfactory technique but subsequent investigations raised concerns with excitement on induction, significant respiratory depression, and hypoxemia.[39–41] More recently, the combination of propofol and ketamine after xylazine sedation has been investigated and may have some applicability, particularly in-hospital settings where ventilation can be easily assisted.[42]

6. Inhalant Anesthetics and the Pathophysiology of Anesthesia and Recumbency

Important information concerning the cardiac and respiratory effects of recumbency in anesthetized horses were addressed by Gillespie and co-workers in 1969.[43] This paper was accompanied by a paper by the same authors in the British literature and documented that anesthetized horses have large differences between their alveolar and arterial oxygen tensions.[44] Cardiac output was consistently reduced and calculated pulmonary shunt averaged 14% of pulmonary blood flow. Potential causes of the dysfunction were postulated to be maldistribution of perfusion due to gravity; hypoventilation of the down lung; development of atelectasis; and decreases in cardiac output. The dysfunction occurred relatively rapidly with the assumption of recumbency and was not corrected by the delivery of large tidal volumes. These papers revealed that recumbency associated with anesthesia produced significant depression of both cardiovascular and respiratory function that needed to be counteracted. These papers introduced a subject and line of investigation that have dominated the equine anesthesia literature since their publication.

The recognition that anesthesia, particularly inhalant anesthesia, causes ventilatory compromise led to the development of equipment to provide assisted or controlled ventilation. No commercial company produced equipment capable of delivering an adequate tidal volume in an appropriate time frame so investigators developed equipment from available parts used in human medicine. An early paper (1975) by Thurmon utilized a Bird Mark IX respirator powered by an air compressor to compress a multivolume bellows in order to ventilate anesthetized horses.[45] A rebreathing bag was hermetically sealed in a 12-gallon steel drum (bag in a barrel). The opening of the rebreathing bag was connected to a large animal circle anesthesia machine. This paper provided a blueprint for veterinarians to construct ventilators of sufficient capacity to ventilate an adult horse. The advent of mechanized assisted ventilation allowed for increased complexity and duration of surgery because manual compression of a large animal rebreathing bag to assist ventilation for more than a few minutes is exhausting and thus impractical.

The equipment required to anesthetize large animals had to be developed de novo because the tidal volumes and respiratory velocities inherent in the respiration of the horse could not be accommodated by the available equipment.

The dynamics of establishing sufficient percentages of the anesthetic gases to provide anesthesia were considerably different than those seen in human patients or small animals. Steffey addressed these differences with his paper of 1977 titled, "Rate of Change of Halothane Concentration in a Large Animal Circle Anesthetic System."[46] This paper demonstrated how to rapidly develop sufficient concentrations of inhalant anesthetics to maintain anesthesia. Specifically, large-animal anesthetic systems at maintenance flow rates (3 L/min) require 30 minutes to reach concentrations sufficient to maintain anesthesia. Most intravenous induction techniques provide only 20 minutes of anesthesia thus strategies to more rapidly increase the concentration of inhalant are required. A suggested strategy was "to initiate anesthesia with high delivered fresh gas flow rates (i.e., 8 to 12 l/min) then after 10 to 15 minutes reduce them to low maintenance flows (about 3 to 6 l/min)." This paper gave veterinarians a way to safely and rapidly develop concentrations of inhalant anesthetics that produce anesthetic states. Largely because of this paper, flowmeters on large-animal anesthetic machines have 10 L/min flow capacity.

The development of specialized anesthetic machines and ventilators and the increased clinical availability of arterial blood gas analysis to adjust ventilatory variables facilitated the completion of longer, more complex surgical procedures. Although, it was suspected from laboratory studies, the increased use of arterial blood gas analysis confirmed that a small, but significant number of anesthetized horses breathing oxygen concentrations in excess of 90%, particularly those placed in dorsal recumbency, did not maintain expected levels of arterial oxygenation even when they were ventilated to produce arterial partial pressure of carbon dioxide ($PaCO_2$) levels in the normal range. Ideally, horses breathing oxygen concentrations in excess of 90% should have arterial partial pressures of oxygen (PaO_2) in excess of 400 mm Hg, but this is infrequent. The PaO_2 in some cases falls below those levels seen in standing healthy horses breathing room air (approximately 90 to 100 mmHg). This "relative hypoxemia" has been the subject of over 90 scientific publications since the advent of convenient arterial blood gas analysis in the 1970s. Current thought is that the majority of the impairment of oxygenation occurs because of physiologic shunts or blood flow through the lung that does not pass by alveoli that are being appropriately ventilated.[47] The alveoli that are not being appropriately ventilated appear shrunken or atelectic, due to a combination of compression and absorption of the gases contained in the alveolar space. One of the early, more interesting papers on the subject appeared in 1987. Nyman placed small-bore, extended-length endotracheal tubes into the bronchi leading to the diaphragmatic lung lobes of adult horses.[48] This allowed for selective ventilation of the diaphragmatic lobes with the application of positive end expiratory pressure (PEEP). Arterial partial pressures of oxygen increased 3 to 3.5 times with the application of selective mechanical ventilation with PEEP to the diaphragmatic lobes alone. These results suggested that the diaphragmatic lung lobes had collapsed or were occluded prior to selective ventilation. While the technique is impractical for clinical use, it established that reduced ventilation of the diaphragmatic lung lobes is a major contributor to differences between alveolar and arterial oxygen tension differences.

7. Monitoring and Complications of Anesthesia

Post-operative myopathy, rhabdomyolysis, or tying-up syndrome is a significant complication of equine anesthesia but its incidence has been greatly reduced based on the evidence found and the recommendations made in a series of papers. The topic was the subject of a session at the 1978 annual meeting of the American Association of Equine Practitioners. As part of the session, Klein[49] presented a review of 50 cases of post-operative myopathy in the horse and discussed intrinsic and management factors affecting risk. Between 3% and 4% of horses anesthetized over a 2-year period in the study had neurologic or muscular deficits (localized and generalized) following anesthesia. No direct causes were established although 46% of myopathic horses had mean arterial blood pressures below 55 mm Hg for 30 minutes or longer and duration of anesthesia (2.9 hours) was longer than in a comparison group. Cited potential contributors to myopathy included difficulties in maintaining anesthesia including movement, pronounced cardiopulmonary depression, and increases in body temperature. This paper supported the growing recognition of post-anesthetic complications and suggested that hypotension was a potential contributor.

The significance of arterial hypotension as a factor in postoperative myopathy was established by a paper from Grandy et al in 1987.[50] Six horses were anesthetized for 3 hours on 2 occasions, once with mean arterial blood pressures maintained in the range of 85 to 95 mm Hg (normotensive) and once with mean arterial blood pressures maintained in the range of 55 to 65 mm Hg (hypotensive). There were no significant complications after the normotensive anesthesia but every horse in the hypotensive group had muscle dysfunction with increases in serum enzymes indicative of muscle damage. Three of six animals were euthanized due to their condition. This study provided dramatic evidence of the association between arterial hypotension and post-anesthetic myopathy. Its conclusions have been confirmed by a number of subsequent retrospective studies and led to a number of additional investigations looking at methods of monitoring and manipulating arterial blood pressure under anesthesia.

Monitoring arterial blood pressure in anesthetized horses and striving to maintain the mean arterial blood pressure in excess of 60 to 70 mm Hg are arguably the most important components of safe anesthetic practice, particularly when inhalant anesthetics are employed. A number of methods have been and are being employed in support of blood pressure including the administration of large volumes of isotonic fluids, calcium solutions, inhalant-sparing anesthetic adjuncts, vasopressors and drugs used to increase myocardial contractility. The most consistently useful drug for increasing arterial blood pressure in the anesthetized horse is dobutamine. Dobutamine was compared to a similar agent, dopamine, in a paper by Swanson et al in 1985.[51] Horses were anesthetized in two experimental groups and received dopamine (3, 5, 10 ug/kg/min, IV) on one occasion and dobutamine (3, 5, 10 ug/kg/min,IV) on another. Both drugs produced positive inotropic effects at doses that increased contractility without causing tachycardia. This study demonstrated that dobutamine was more predictable than dopamine for support of arterial blood pressure in horses anesthetized with halothane.

8. The Recovery Period

A recent publication suggests that the portion of morbidity and mortality once associated with the maintenance of anesthesia has been shifted to the recovery phase, presumably due to better anesthetic agents and improved monitoring.[9] Recovery remains the most problematic part of the anesthetic period, primarily driven by the horse's apparent desire to stand soon after regaining consciousness. A number of strategies have been devised to facilitate the safe return to a standing posture, but none is without complication. The most comprehensive study of recovery was published by Whitehair et al in 1993.[52] The paper reported an extensive laboratory study of horses recovering from inhalant anesthesia without other drugs. Horses were anesthetized on 3 occasions: twice with halothane (1- and 3-hour duration) and once with isoflurane (3-hour duration). Horses were placed in a recovery stall and allowed to recover undisturbed other than for sample collection. Rate of elimination of the inhalants was measured and the time to recovery events (eyelid, ear, head, and limb movement, and others) were recorded. The importance of this paper is that it provided a context for evaluating the events that occur during the transitions between the anesthetized and awake states. Useful signs for gauging the progress of the recovery included increasing eyelid and eyeball movement, ear movement, swallowing, lifting of the head, and limb movement. This information allows personnel assisting recovery from anesthesia to better determine when a horse is ready to stand. Further, the study provided basic information for the development of subsequent research on methods to modify the recovery period.[53]

9. Morbidity and Mortality

Equine anesthesia is more perilous than anesthesia of the other domestic species as previously noted. A landmark series of papers on morbidity and mortality was published by Johnston, beginning in 1995 with a preliminary report.[54] This paper established mortality rates for anesthesia in the horse. The authors collected and analyzed data on 41,824 anesthetic episodes from 129 surgical centers. The overall death rate within 7 days of anesthesia was 1.9%. Death rate of non-colic patients was 0.9%. Cardiovascular arrest or collapse during anesthesia and fractures or myopathies in recovery accounted for 33% and 32% of deaths, respectively, with the remainder due to various causes. Horses anesthetized for fracture repair, horses anesthetized outside of normal working hours, and foals less than 1 month of age were at increased risk. Risk increased with age with horses older than 14 years. Lack of any preanesthetic sedation increased risk and acepromazine administered as a single drug (not in combination) reduced risk. Inhalant anesthesia without premedication was at higher risk and TIVA of shorter duration was at less risk. By comparison, the mortality rate in humans was cited as 1 in 10,000. Others have examined the issue and reported rates between 0.08 and 1.8% depending on the design of the study.[7,9] As previously noted, a recent paper from 2015, reported on mortality rates, suggesting that the incidence has not changed in 20 years.[7,9]

10. The Stress of Anesthesia

Stress is a significant component of equine anesthesia. The most comprehensive examination of this phenomena was conducted by Taylor[10] and published in a series of articles highlighted by the 1989 publication, "The Equine Stress Response to Anaesthesia." In a series of accompanying papers, 6 ponies were anesthetized at least 12 times using a variety of anesthetic drugs, techniques, and interventions (ventilation, cardiovascular support). Indices of stress (serum cortisol, catecholamines, insulin, glucose) were measured prior to and for 24 hours after each anesthetic episode. Ponies anesthetized with sodium thiopental alone and with TIVA showed little to no evidence of stress. All other anesthetic techniques were stressful. Normalization of ventilation and arterial blood pressures did not reduce stress. This series of papers established that anesthesia (without surgery) is a stress for equines. Subsequent papers have largely confirmed these findings with the suggestion that TIVA is less stressful than inhalant anesthesia or suppresses the stress response.[55] The validity of this suggestion is unproven, largely because most procedures completed using TIVA are of shorter duration, making parallel comparisons difficult.

11. The Things We Know We Know: The Current Practice of Equine Anesthesia

The advances that have been made in the period of "modern" anesthesia have dramatically improved the ability of veterinarians to provide care to equine patients. Many of these advances are the result of the development of molecular biology and molecular pharmacology which fostered the discovery of the mechanism of action of many anesthetic drugs and paved the way for the formulation of new drugs. The use of drugs in the horse has generally followed their use in humans and other animals but occasionally developed simultaneously (ketamine) or predated use in humans (alpha$_2$ agonists).[11] For example, when xylazine was first marketed for sedation of the horse, the fact that the majority of the drug's effects were produced via stimulation of alpha$_2$ receptors was not known because the existence of alpha$_2$ receptors was unknown until Langer discovered them in 1974. This knowledge facilitated the development of detomidine, romifidine, and dexmedetomidine, and the antagonist, atipamezole. In addition, the development and commercialization of anesthetic equipment specifically designed for large animals, cost-effective catheters for IV and intra-arterial use, and clinically useful monitoring equipment including electrocardiograms and blood gas analyzers have brought dramatic improvements to current practices.

The current practice of equine anesthesia is further shaped by a number of factors including the collective experiences of equine veterinarians, the scientific literature addressing issues pertinent to anesthesia of the horse, legal considerations, the availability or lack thereof of some anesthetic medications, and the economics of equine practice and the horse industry. Most equine veterinarians utilize standing chemical restraint daily with alpha$_2$ adrenergic agonists, alone or in combination, being the predominant first choice.[56] Most equine veterinarians performing short- or long-term anesthesia administer an alpha$_2$ adrenergic agonist, utilize ketamine alone or in combination with a muscle relaxant for induction of anesthesia and maintain anesthesia with a guaifenesin recipe (52%) or an inhalant (47%).[56] Despite these apparent commonalities with regard to the methods used, anesthesia of the horse remains perilous. So what do we do? Do we accept that somewhere between 1 in 100 and 1 in 1000 normal horses will die when anesthetized? Do we avoid anesthetizing horses in favor of standing procedures? Or, do we provide support for investigators to employ focused research to examine and improve our current "best" practices or perhaps, discover other pathways to make equine anesthesia safer?

We know we know these things about anesthesia for elective procedures in healthy horses:

1. Anesthesia is stressful for horses.
2. Horses will attempt to rise to a standing procedure as soon as they are conscious.
3. Horses that cannot stand 2 hours after anesthesia are unlikely to survive.
4. Shorter anesthetics ($<$ 60 minutes) are safer, longer anesthetics ($>$ 3 hours) have greater risk.
5. The very young and the old (sedentary) are at greater risk.
6. Horses should be sedated before they are anesthetized.
7. Mean arterial blood pressures less than 60 mm Hg for significant durations in anesthetized horses are associated with increased complications, primarily rhabdomyolysis and neuropraxia.
8. Some level of cardiovascular function, ventilation, and oxygenation is necessary.
9. Standing chemical restraint is safer than general anesthesia.
10. Lateral recumbency is "more physiologic" than dorsal recumbency.

Based on these "knowns" and other factors, groups including the American College of Veterinary Anesthesia and Analgesia formulated guidelines to provide direction on appropriate techniques.[57,58] The guidelines recommend a thorough preoperative assessment, limiting TIVA to 60 minutes, and monitoring arterial blood pressure if inhalants are used. Injectable adjuncts such as opioids or ketamine and local anesthetics may be indicated to improve the quality of anesthesia. Recommendations for recovery include continuous observation and the use of sedatives to aid in the transition to standing. It is not known how widely the American College of Veterinary Anesthesia and Analgesia guidelines are used, or if it would make a difference if they were universally employed.[59]

12. Standing Chemical Restraint in the 21st Century

Some 30 years ago, the author penned an editorial titled, "The Search for the Ultimate Equine Sedative: Are We 'Waiting for Godot."[60] We are still waiting. In the place of the ultimate equine sedative, veterinarians prefer to use drugs in combination. Satisfactory standing chemical restraint can be produced in most adult horses for extended periods of time with alpha$_2$ agonists in combination with opioids or opioid-like drugs being the primary method used.[61] Longer duration standing chemical restraint in combination with appropriate local and regional anesthesia allows more extensive procedures to be performed. Local and regional anesthetic techniques with longer acting local anesthetic drugs will allow more complex procedures such as dental extractions, sinus exploratory procedures, laryngeal tie-backs, and fracture fixation to be performed in the standing horse, if desired. Additional progress will include the development of additional alpha$_2$ adrenergic antagonists to the currently available tolazoline, yohimbine, and atipamezole. The current drugs enjoy some popularity but have significant side effects and durations of action that may be shorter than the sedatives themselves.[62,63] The new agents should have a longer duration of action and fewer deleterious side effects.[64]

13. TIVA in the 21st Century

The combination of guaifenesin, ketamine, and xylazine remains a mainstay of TIVA in the horse.[33] This popularity continues despite the lack of a commercial pharmaceutical source for guaifenesin solution, the volume of solution required, and the difficulties keeping guaifenesin in solution.[65] The combination is used in field conditions because it produces minimal cardiovascular depression and moderate hypoventilation but in the absence of a frank overdose, rarely apnea.[33,66] Perhaps, a pharmaceutical firm will decide to market guaifenesin. More likely, guaifenesin will be replaced by one of the benzodiazepines (likely midazolam). Midazolam has been investigated as a replacement for guaifenesin and appears to be a useful alternative.[37,67,68] Other reported techniques include repeated boluses of a variety of induction drugs and propofol-ketamine combinations.[69,70,71] Recommendations for TIVA with any drug combination include limiting duration of anesthesia to 1 hour unless oxygen can be supplemented and ventilation can be provided, if necessary. If propofol is more widely adopted, a method for the support of ventilation will be required, particularly in out-of-hospital environments.

14. Inhalant Anesthesia in the 21st Century

Significant changes have occurred in the 50 years since the introduction of halothane and closed inhalant anesthetic systems.[6,11–13] Halothane has been replaced by the halogenated ethers isoflurane, sevoflurane, and desflurane.[72,73,74] The development of more sophisticated surgical procedures requiring longer durations of anesthesia have resulted in the consistent use of mechanical ventilation, an increased level of monitoring, a variety of strategies to support cardiovascular function, and modifications in the methods used in recovery.

Mechanical ventilation is used to restore normocapnea and provide consistent delivery of the inhalants but standard mechanical ventilation strategies may not restore "normal" arterial oxygen tensions in horses with suboptimal tensions.[43,44,47] This has led to the development of a number of strategies for increasing arterial oxygen tensions that are not consistently effective or only effective for short time periods.[47] A continuing question is, what should the target level of PaO_2 be?[47] The question is posed because most techniques of mechanical ventilation used to increase PaO_2 do so at the expense of blood flow and arterial blood pressure. Further, studies assessing the effects of less than ideal PaO_2 tensions in anesthetized horses have not shown increased morbidity/mortality.[75] A recent paper by Hopster et al[76] suggests that intestinal oxygenation and perfusion may not be significantly compromised until arterial oxygen saturations fall below 80% and mean arterial blood pressures fall below 51 mm Hg, respectively. If a PaO_2 greater than 60 mm Hg is associated with 80% saturation of hemoglobin, how hard should we work to increase PaO_2 above 60 mmHg? The author would argue that the maintenance of sufficient arterial blood pressure and cardiac output to deliver oxygen to the tissues is of greater importance than employing methods to increase PaO_2 greater than 70 mm Hg.

Monitoring recommendations include the use of direct monitoring of arterial blood pressures in all horses anesthetized with inhalants.[58] Strategies to counteract hypotension include the use of inotropes such as dobutamine and the co-administration of anesthetic adjuncts (partial intravenous anesthesia) to allow a reduction in inhalant concentrations.[77–79] The currently used halogenated ethers are less soluble in blood than halothane so recovery from anesthesia occurs more rapidly.[52,72–74] This has led to the development of equipment, methods, and protocols designed to produce safe recovery from anesthesia.

15. Recovery from Anesthesia in the 21st Century

Reports on morbidity and mortality rates indicate considerable variation with some reports suggesting that mortality rates remain at 1% and others pointing to lower rates.[7–9] A recent publication reported no intraoperative deaths (approximately 30% of deaths in previous reports) and a shift to fractures in recovery as the primary source of mortality.[9] A number of recovery strategies have been developed including the use of head and tail ropes, inflatable pads, swimming pools, slings and drugs, both sedatives and anesthetics.[80–85] Clearly improvements are still required. Potential solutions are complicated by the difficulty in determining which horses will have problems in recovery. Many of the investigated strategies are labor, time, and equipment/facility intensive and none eliminate the potential for complications. To which cases can they or should they be applied? The author's best guess is that some combination of sedation followed by pharmacologic reversal and physical assistance will provide the most practical method of enhancing safety until some, yet-unknown method or technique, is manifest.

16. Anesthesia of the Neonate and the Young Horse in the 21st Century

Horses are more mature at birth than are most of the domestic species and come in varying sizes and temperaments. Approaches to handling foals are frequently influenced by the husbandry practices of the caretakers, the breed, degree of prior human interaction, and other learned behaviors.[86–88] The age, attitude, and behavior of the foal should be assessed prior to the administration of any sedative or analgesic medication with sick foals requiring minimal sedation to accomplish tasks such as catheter placement. Foals requiring sedation and/or anesthesia because of temperament or the need for more extensive procedures should receive a complete physical examination prior to drug administration.

The cardiovascular system of the neonatal horse has less reserve than that of the adult, making the foal more dependent on heart rate to maintain cardiac output.[89] Foals have a larger surface-to-body weight ratio than adult horses and higher total body water, higher extracellular fluid volume, lower body fat, lower total protein, and a larger volume of distribution for some drugs.[90,91] Foals breathe at higher rates than adult horses and have a higher minute ventilatory volumes based on weight.[92] In addition, foals are insensitive to changes in oxygen and carbon dioxide tension, thus they hypoventilate under anesthesia. Hepatic oxidative capacity for drugs is lower in 4-day-old foals than in older animals but it appears to increase rapidly, reaching adult levels at 3 to 4 weeks of age. Protein binding appears to be less in the foal than in the adult horse which could mean that drugs that are highly protein bound would be more active. Withholding of food in the foal is not necessary and may be detrimental due to lower glycogen stores.

Neonates are generally easy to restrain. Typically, foals can be placed into lateral recumbency using physical restraint or by using the "squeezing" method.[93] Young foals requiring sedation for procedures, such as catheter placement, respond well to the administration of butorphanol in combination with a benzodiazepine (diazepam or midazolam).[94] The sedative response to benzodiazepines seems to be significantly greater in foals compared to adult horses and the combination produces less cardiopulmonary depression than $alpha_2$ agonists. If this is not sufficient, small doses of xylazine or detomidine are administered IM. Intramuscular administration reduces the negative cardiopulmonary side effects (bradycardia, respiratory depression) associated with $alpha_2$ administration and increases the duration of action. Sedation combined with restraint and local anesthesia (as necessary) is usually sufficient for repair of simple lacerations or application of splints.

Short-term anesthesia in the field is performed with the IV administration of ketamine in combination with diazepam or midazolam. The combination (given after sedation) provides approximately 15 to 20 minutes of anesthesia. Longer durations can be accomplished with a combination of guaifenesin, ketamine, and xylazine. If more extensive surgical procedures are planned, inhalation anesthesia should be employed. Foals less than 100 to 150 kg can be anesthetized with machines typically used for small animals. Retrospective studies suggest that the incidence of mortality is reduced in foals when adjuvant drugs such as xylazine and ketamine are used in combination with inhalants.[8] Serum glucose concentrations should be monitored and glucose containing fluids used in the very young foal under general anesthesia. Thermoregulation is impaired so it is important to monitor body temperature and warm the foal, if necessary, postoperatively. The differences between foals and adult horses that affect anesthesia are, for the most part, resolved by 3 to 4 months of age.

17. Pain Management in the 21st Century

A recent review of pain control in horses begins with the sentence, "Currently, approaches to pain control in horses lack a robust evidence base" and notes that pain control is both an art and a science.[95] With the increasing life expectancy of the horse, it is fortunate that nonsteroidal anti-inflammatory drugs provide relatively consistent, low-cost pain relief for many arthritic conditions, allowing many aging horses to live apparently comfortable lives. Where efforts are inadequate is in the control of pain not alleviated by nonsteroidal anti-inflammatory drug administration that persists beyond a 24-to-48-hour period. This inadequacy is particularly apparent in horses with severe laminitis.[96] A variety of strategies are currently employed including the administration of $alpha_2$ adrenergic agonists, opioids, lidocaine, and ketamine, alone or in combination.[86] Two oral drugs, gabapentin and tramadol, show some evidence of efficacy in largely anecdotal reports.[97–99] Soluble epoxide hydrolase inhibitors currently being investigated may provide a novel method of anti-inflammatory activity through their inhibition of cytochrome P450 pathways.[100]

Pain management in the horse as in other species requires at least 3 components: recognition that the pain exists; a desire to provide relief from the pain; and the ability to provide relief. Deficiencies or controversies exist in each area. The development of pain scoring systems has provided methods for systematic assessment of pain and has served to raise consciousness, but their principles are not used widely.[101] The author knows of no veterinarian who would not want to relieve a horse's pain, but recent surveys indicate that there is considerable variability within the profession with regard to what procedures or conditions are thought to produce a level of pain that requires treatment or the level of treatment that should be provided.[102] Finally, new methods and medications must be developed or adapted to optimize comfort for our equine patients.

18. Managing Equine Stress in the 21st Century

The role that stress plays in the complications associated with equine anesthesia deserves increased attention as we try to improve outcomes. Anesthesia stresses horses more than it does other domestic animals and the consequences of stress go beyond just behavioral issues extending to decreases in immune function and other effects.[103] Known potential stressors that may be associated with surgery and anesthesia might include transportation to a new facility, separation from a pasture mate, or withholding of food. Stressors associated with anesthesia itself might include restraint, hypercarbia, hypoxemia, hypotension, and pain. Transportation, fasting, and anesthesia all significantly altered intestinal microflora in horses.[104] Withholding of food prior to anesthesia for periods of up to 24 hours was once widely recommended but the practice is seemingly less prevalent. Recent work suggests that the incidence of post-operative colic may be increased when food is withheld, potentially due to better maintenance of gastrointestinal motility in fed horses.[105]

Individual horses have variable responses to a variety of stimuli. Current anesthetic practices and techniques do not consistently reduce the stress related to anesthesia. There is an interesting, relatively new, body of work in the area of horse personalities including information about differences due to breed, use, husbandry, genetic variation, and receptor populations. Many equine veterinarians have developed different dosing regimens for different breeds or types of horses based on their experiences and anecdotal reports. For example, the author believes that draft horse breeds and American Saddlebreds require smaller doses of alpha$_2$ agonists (mg/kg basis) to produce useful sedation compared to mustangs, Arabian horses, and Appaloosas. Minimal hard data are available to directly support such beliefs. Lloyd et al[106] looked at the personalities of 8 different breeds in the United Kingdom, finding that Thoroughbreds, Arabian horses, cobs, and Welsh ponies were significantly more anxious and excitable than the other breeds assessed. More recently, Sackman and Houpt[107] assessed 16 behavioral traits in over 850 American horses via a survey of their owners. They determined that Arabians, Thoroughbreds, and Walking Horses were the most nervous and American Quarter Horses, Paints, Appaloosas, and drafts were the least nervous breeds. Another interesting paper from Sweden analyzing the genome of Swedish warmblood horses identified long areas of homozygosity shared by 85% of the warmbloods, suggesting that such "signatures" could be responsible for behavior, physical abilities, and fertility.[108] With regard to specific drug classes, Wetmore found differences in locomotor responses to fentanyl between horses with and without polymorphism of the mu opioid receptor, which may help explain the previously reported differences in response to similar drugs.[109,110] Others have compared the opioid and alpha$_2$ receptor populations of horse brains to other species and found differences in the distribution of receptors, perhaps accounting for the variability in efficacy and side effects of opioids across the horse, dog, guinea pig, and rat.[111,112] As work on the analysis of the horse genome continues, perhaps scientists will discover additional information to help development of new receptor-specific agents or specific techniques to modify behavior and reduce perianesthetic stress in equine patients.

A better method of assessing the stress level of patients prior to anesthesia with the goal of minimizing stress throughout the perioperative period is needed. Historically, physiologic measures such as heart rate, heart rate variability, and blood or salivary cortisol levels have been used to measure stress.[113,114] Other potential indices include height of head carriage, orientation of the ears, frequency of vocal behavior, and mouth movements.[115] Each of these methods have limitations. Recently, an interesting paper suggested that assessing eye blink rates and eyelid twitches may be useful as a noninvasive way to predict a horse's response to stress. The investigators utilized feed restriction, separation from paddock mates, and a startle test to induce stress while recording eye movements, noting that eyelid blinks decreased and eyelid twitches increased as stress levels increased.[116] Perhaps moving forward, there will be better methods to assess stress and when possible, adjust anesthetic times and methods to minimize its effects on outcomes.

19. Moving Forward: Aspirational Goals for Equine Anesthesia

The author has attempted to describe and provide evidence for the "known knowns" of equine anesthesia.[117] As previously stated, the current practices of equine anesthesia have evolved by necessity and because of the work of a large number of dedicated individuals and groups who have provided veterinary colleagues with information. Many, but not all of these individuals are included in the references cited in this report. Much gratitude for the information that has fostered clinical progress is owed to them. What are left are the "known unknowns" and "unknown unknowns" (things we don't know we don't know).[117] Today, if we effectively manage the list of "known knowns" of equine anesthesia, we position a horse in a recovery stall with sufficient faculties to regain consciousness and attain a standing position in a reasonable amount of time. Currently, that results in a mortality rate of somewhere between 0.1% and 1% for "physiologically normal" horses. We need to do better.

"Known unknowns" include lack of knowledge on how best to facilitate the patients' smooth, uncomplicated return to a conscious standing posture in a repeatable, practical, and widely applicable manner. As referenced above, a number of methodologies have been proposed and reported but few are universally and practically applicable. Most of the evidence currently available is from clinical studies, both retrospective and prospective, that compare currently available methods to determine which method should be "preferred." The problem is that "preferred" is not good enough. What is needed is an organized, focused, scientific approach to examining equine behavior in the recovery stall with the goal of modifying the transition from the induced recumbent "sleep" of anesthesia to an awake, standing horse. Such an approach will require a core group of individuals from a variety of disciplines (anesthesiologists, surgeons, behaviorists, etc.) with the interest, resources, and time not only to investigate the "known unknowns" but also to discover and solve the "unknown unknowns." Success in this regard requires financial support to both facilitate the work of creating new knowledge in equine anesthesia and to inspire both present and succeeding generations of veterinarians to take on the present challenges. Both actions, in turn, will meaningfully improve health care delivery to equine patients.

Acknowledgments

Declaration of Ethics

The Author has adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Author has no conflicts of interest.

References

1. Robinson DH, Toledo AH. Historical development of modern anesthesia. *J Invest Surg* 2012;25:141–149.
2. Weaver BMQ. The history of veterinary anaesthesia. *Vet Hist* 1988;5:43–57.
3. Woodbridge PD. Changing concepts concerning depth of anaesthesia. *Anaesthesiology* 1957;18:536–550.
4. Gabriel KL, Martin JE. Phenylbutazone: Short-term versus long-term administration to Thoroughbred and Standardbred horses. *J Am Vet Med Assoc* 1962;140:337–341.
5. Clarke KW, Hall LW. "Xylazine"—A new sedative for horses and cattle. *Vet Rec* 1969;85:512–517.
6. Fisher EW. Observations on the disturbance of respiration of cattle, horses, sheep, and dogs caused by halothane anesthesia and the changes taking place in plasma pH and plasma CO_2 content. *Am J Vet Res* 1961;22:279–286.
7. Bidwell LA, Bramlage LR, Rood WA. Equine perioperative fatalities associated with general anaesthesia at a private practice—A retrospective case series. *Vet Anaesth Analg* 2007;34:23–30.
8. Johnston GM, Eastment JK, Wood JLN, et al. The confidential enquiry into perioperative equine fatalities (CEPEF): Mortality results of phases 1 and 2. *Vet Anaesth Analg* 2002;29:159–170.
9. Dugdale AH, Obhrai J, Cripps PJ. Twenty years later: A single-centre repeat retrospective analysis of equine perioperative mortality and investigation of recovery quality. *Vet Anaesth Analg* 2016;43:171–178.
10. Taylor PM. Equine stress response to anaesthesia. *Br J Anaesth* 1989;63:702–709.
11. Muir WW. A commentary on the history of equine anesthesia. In: Rossdale PD, Greet TRC, Harris PA, et al, eds. *Guardians of the horse: Past Present and Future. 1st ed*. Suffolk, UK: British Equine Veterinary Association and Romney Publications. 1999;257–263.
12. Hall LW. Equine anesthesia: Discovery and rediscovery. *Equine Vet J* 1983;15:190–195.
13. Taylor P. Veterinary anaesthesia and analgesia: From chloroform to designer drugs. *Vet Rec* 2014;174:318–321.
14. Mayhew E. *The illustrated horse doctor.* Philadelphia, PA: Lippincott; 1880.
15. Hobday F. *Anaesthesia and narcosis of animals and birds.* London, UK: Bailliere, Tindall and Cox; 1915.
16. Clarke KW, Trim CM, Hall LW. *Veterinary Anaesthesia. 11th ed.* London, UK: Saunders Ltd; 2014.
17. Clarke KW, Taylor PM. Detomidine: a new sedative for horses. *Equine Vet J* 1986;18:366–370.
18. England GC, Clarke KW, Goossens L. A comparison of the sedative effects of three alpha 2-adrenoceptor agonists (romifidine, detomidine and xylazine) in the horse. *J Vet Pharmacol Ther* 1992;15:194–201.
19. Robertson JT, Muir WW. A new analgesic drug combination in the horse (butorphanol). *Am J Vet Res* 1983;44: 1667–1669.
20. Kalpravidh M, Lumb WV, Wright M, et al. Effects of butorphanol, flunixin, levorphanol, morphine, and xylazine in ponies. *Am J Vet Res* 1984;45:217–223.
21. Muir WW, Skarda RT, Sheehan W. Hemodynamic and respiratory effects of a xylazine-acetylpromazine drug combination in horses. *Am J Vet Res* 1979;40:1518–1522.
22. Klein LV, Baetjer C. Preliminary report: Xylazine and morphine sedation in horses. *Vet Anaesth* 1974;1:2–6.
23. Muir WW, Skarda RT, Sheehan WC. Hemodynamic and respiratory effects of xylazine-morphine sulfate in horses. *Am J Vet Res* 1979;40:1417–1420.
24. Wagner AE, Mama KR, Contino EK, et al. Evaluation of sedation and analgesia in standing horses after administration of xylazine, butorphanol, and subanesthetic doses of ketamine. *J Am Vet Med Assoc* 2011;238:1629–1633.
25. Taylor P, Coumbe K, Henson F, et al. Evaluation of sedation for standing clinical procedures in horses using detomidine combined with buprenorphine. *Vet Anaesth Analg* 2014;41:14–24.
26. Risberg A, Spadavecchia C, Ranheim B, et al. Antinociceptive effects of three escalating dexmedetomidine and lignocaine constant rate infusions in conscious horses. *Vet J* 2014;202: 489–497.
27. Clarke KW, Paton BS. Combined use of detomidine with opiates in the horse. *Equine Vet J* 1988;20:331–334.
28. Gertsen KE, Tillotson PJ. Clinical use of glyceryl guaiacolate in the horse. *Vet Med Small Anim Clin* 1968;63:1062–1066.
29. Muir WW, Skarda RT, Milne DW. Evaluation of xylazine and ketamine hydrochloride for anesthesia in horses. *Am J Vet Res* 1977;38:195–201.
30. Clarke KW, Taylor PM, Watkins SB. Detomidine/ketamine anaesthesia in the horse. *Acta Vet Scand Suppl* 1986;82:167–179.
31. Matthews NS, Hartsfield SM, Cornick JL, et al. A comparison of injectable anesthetic combinations in horses. *Vet Surg* 1991;20:268–273.
32. Kerr CL, McDonell WN, Young SS. A comparison of romifidine and xylazine when used with diazepam/ketamine for short duration anesthesia in the horse. *Can Vet J* 1996;37: 601–609.
33. Greene SA, Thurmon JC, Tranquilli WJ, et al. Cardiopulmonary effects of continuous intravenous infusion of guaifenesin, ketamine, and xylazine in ponies. *Am J Vet Res* 1986;47:2364–2367.
34. Brock N, Hildebrand SV. A comparison of xylazine-diazepam and xylazine-guaifenesin-ketamine in equine anesthesia. *Vet Surg* 1990;19:468–474.
35. Butera TS, Moore JN, Garner HE, et al. Diazepam/xylazine/ketamine combination for short-term anesthesia in the horse. *Vet Med Small Anim Clin* 1978;73:495–496.
36. Hubbell JAE, Kelly E, Aarnes TK, et al. Pharmacokinetics of midazolam following intravenous administration to horses. *Equine Vet J* 2013;45:721–725.
37. Hubbell JAE, Aarnes TK, Lerche P, et al. Evaluation of a midazolam-ketamine-xylazine infusion for total intravenous anesthesia in horses. *Am J Vet Res* 2012;73:470–475.
38. Hubbell JAE, Muir WW. Xylazine and tiletamine-zolazepam anesthesia in horses. *Am J Vet Res* 1989;50:737–742.
39. Nolan AM, Hall LW. Total intravenous anesthesia in the horse with propofol. *Equine Vet J* 1985;17:394–398.
40. Mama KR, Steffey EP, Pascoe PJ. Evaluation of propofol for general anesthesia in premedicated horses. *Am J Vet Res* 1996;57:512–516.
41. Muir WW, Lerche P, Erichson D. Anaesthetic and cardiorespiratory effects of propofol at 10% for induction and 1% for maintenance of anesthesia in horses. *Equine Vet J* 2009;41:578–585.
42. Posner LP, Kasten JL, Kata C. Propofol with ketamine following sedation with xylazine for routine induction of general anaesthesia in horses. *Vet Rec* 2013;173:550.
43. Gillespie JR, Tyler WS, Hall LW. Cardiopulmonary dysfunction in anesthetized laterally recumbent horses. *Am J Vet Res* 1969;30:61–72.
44. Hall LW, Gillespie JR, Tyler WS. Alveolar-arterial oxygen tension differences in anaesthetized horses. *Br J Anaesth* 1968;40:560–568.
45. Thurmon JC, Menhusen MJ, Hartsfield SM. A multivolume ventilator-bellows and air compressor for use with a Bird Mark IX respirator in large animal inhalation anesthesia. *Vet Anesthesiol* 1975;2:34–39.
46. Steffey EP, Howland D. Rate of change of halothane concentration in a large animal circle anesthetic system. *Am J Vet Res* 1977;38:1993–1996.
47. Hubbell JAE, Muir WW. Oxygenation, oxygen delivery and anesthesia in the horse: A review. *Equine Vet J* 2015; 47:25–35.
48. Nyman G, Frostell C, Hedenstierna G, et al. Selective mechanical ventilation of dependent lung regions in the anaesthetized horse in dorsal recumbency. *Br J Anaesth* 1987; 59:1027–1034.

49. Klein L. A review of 50 cases of postoperative myopathy in the horse—Intrinsic and management factors affecting risk, in *Proceedings*. Am Assoc Equine Pract 1978;24:89–94.
50. Grandy JL, Steffey EP, Hodgson DS, et al. Arterial hypotention and the development of postanesthetic myopathy in halothane-anesthetized horses. *Am J Vet Res* 1987;48: 192–197.
51. Swanson CR, Muir WW, Bednarski RM, et al. Hemodynamic responses in halothane-anesthetized horses given infusions of dopamine or dobutamine. *Am J Vet Res* 1985;46: 365–370.
52. Whitehair KJ, Steffey EP, Willits NH, et al. Recovery of horses from inhalation anesthesia. *Am J Vet Res* 1993;54: 1693–1702.
53. Matthews NS, Hartsfield SM, Mercer D, et al. Recovery from sevoflurane anesthesia in horses: Comparison to isoflurane and effect of postmedication with xylazine. *Vet Surg* 1998;27:480–5.
54. Johnston GM, Taylor PM, Holmes MA, et al. Confidential enquiry of perioperative equine fatalities (CEPEF-1): Preliminary results. *Equine Vet J* 1995;27:193–200.
55. Luna SP, Taylor PM, Wheeler MJ. Cardiorespiratory, endocrine and metabolic changes in ponies undergoing intravenous or inhalation anesthesia. *J Vet Pharmacol Ther* 1996;19:251–258.
56. Hubbell JAE, Saville WJA, Bednarski RM. The use of sedatives, analgesic and anaesthetic drugs in the horse: An electronic survey of members of the American Association of Equine Practitioners (AAEP). *Equine Vet J* 2010;42:487–493.
57. Brouwer GJ. Practical guidelines for the conduct of field anaesthesia in the horse. *Equine Vet J* 1985;17:151–154.
58. Martinez EA, Wagner AE, Driessen B, et al. American College of Veterinary Anesthesiologists Guidelines for Anesthesia in Horses. Available from: http://www.acvaa.org/doc/equine. Accessed November 5, 2015.
59. Senior JM. Barking up the wrong tree: would international guidelines improve safety in equine anaesthesia? *Equine Vet J* 2015;47:14–5.
60. Hubbell JAE. The search for the ultimate equine sedative: Are we 'Waiting for Godot'? *Equine Vet J* 1988;20:314–315.
61. Muir WW. New perspectives on the drugs used to produce sedation, analgesia, and anesthesia in horses, in *Proceedings*. Am Assoc Equine Pract 2004;50:287–290.
62. Scofield DB, Alexander DL, Franklin RP, et al. Review of fatalities and adverse reactions after administration of alpha-2 adrenergic agonist reversal agents in the horse, in *Proceedings*. Am Assoc Equine Pract 2010;56:44–49.
63. Hubbell JA, Muir WW. Antagonism of detomidine sedation in the horse using intravenous tolazoline or atipamezole. *Equine Vet J* 2006;38:238–241.
64. Zeiler GE. A review of clinical approaches to antagonism of alpha-2-adrenoreceptor agonists in the horse. *Equine Vet Educ* 2014;27:48–54.
65. Grandy JL, McDonell WN. Evaluation of concentrated solutions of guaifenesin for equine anesthesia. *J Am Vet Med Assoc* 1980;176:619–622.
66. Young LE, Bartram DH, Diamond MJ, et al. Clinical evaluation of an infusion of xylazine, guaifenesin and ketamine for maintenance of anaesthesia in horses. *Equine Vet J* 1993;25:115–119.
67. Hopster K, Muller C, Hopster-Inversen C, et al. Effects of dexmedetomidine and xylazine on cardiovascular function during total intravenous anaesthesia with midazolam and ketamine and recovery quality and duration in horses. *Vet Anaesth Analg* 2014;41:25–35.
68. Bettschart-Wolfensberger R, Taylor PM, Sear JW, et al. Physiologic effects of anesthesia induced and maintained by intravenous administration of a climazolam-ketamine combination in ponies premedicated with acepromazine and xylazine. *Am J Vet Res* 1996;57:1472–1477.
69. Muir WW, Lerche P, Robertson JT, et al. Comparison of four drug combinations for total intravenous anesthesia of horses undergoing surgical removal of an abdominal testis. *J Am Med Assoc* 2000;15:869–873.
70. Umar MA, Fukui S, Kawase K, et al. Cardiovascular effects of total intravenous anesthesia using ketamine-medetomidine-propofol (KMP-TIVA) in horses undergoing surgery. *J Vet Med Sci* 2015;77:1–8.
71. Flaherty D, Reid J, Welsh E, et al. A pharmacodynamic study of propofol or propofol and ketamine infusions in ponies undergoing surgery. *Res Vet Sci* 1997;62:179–184.
72. Grosenbaugh DA, Muir WW. Cardiorespiratory effects of sevoflurane, isoflurane, and halothane anesthesia in horses. *Am J Vet Res* 1998;59:101–106.
73. Steffey EP, Woliner MJ, Puschner B, et al. Effects of desflurane and mode of ventilation on cardiovascular and respiratory functions and clinicopathologic variables in horses. *Am J Vet Res* 2005;66:669–677.
74. Steffey EP. Inhalation anesthetics and gases. In: Muir WW, Hubbell JAE, eds. *Equine anesthesia monitoring and emergency therapy. 2nd ed.* St. Louis, MO: Saunders Elsevier; 2009:288–314.
75. Auckburally A, Nyman G. Review of hypoxaemia in anaesthetized horses: Predisposing factors, consequences and management. *Vet Anaesth Analg* 2017;44:397–408.
76. Hopster K, Wittenberg-Voges L, Geburek F, et al. Effects of controlled hypoxemia or hypovolemia on global and intestinal oxygenation and perfusion in isoflurane anesthetized horses receiving an alpha-2-agonist infusion. *BMC Vet Res* 2017;13:361.
77. Yamashita K, Muir WW. Intravenous anesthetic and analgesic adjuncts to inhalation anesthesia. In: Muir WW, Hubbell JAE, eds. *Equine anesthesia monitoring and emergency therapy. 2nd ed.* St. Louis, MO: Saunders Elsevier; 2009;260–276.
78. Gozalo-Marcilla M, Gasthuys F, Schauvliege S. Partial intravenous anaesthesia in the horse: A review of intravenous agents used to supplement equine inhalation anaesthesia. Part 1: Lidocaine and ketamine. *Vet Anaesth Analg* 2014; 41:335–345.
79. Gozalo-Marcilla M, Gasthuys F, Schauvliege S. Partial intravenous anaesthesia in the horse: A review of intravenous agents used to supplement equine inhalation anaesthesia. Part 2: Opioids and alpha-2 adrenoceptor agonists. *Vet Anaesth Analg* 2015;42:1–16.
80. Hubbell JAE. Recovery from anesthesia in horses. *Equine Vet Educ* 1999;11:160–167.
81. Wagner AE, Mama KR, Steffey EP, et al. Evaluation of infusions of xylazine with ketamine or propofol to modulate recovery following sevoflurane anesthesia in horses. *Am J Vet Res* 2012;73:346–352.
82. Ray-Miller WM, Hodgson DS, McMurphy RM, et al. Comparison of recoveries from anesthesia of horses placed on a rapidly inflating-deflating air pillow or the floor of a padded stall. *J Am Vet Med Assoc* 2006;229:711–716.
83. Wiese AJ, Brosnan RJ, Barter LS. Effects of acetylcholinesterase inhibition on quality of recovery from isoflurane-induced anesthesia in horses. *Am J Vet Res* 2014;75:223–230.
84. Francois I, Lalèyê FX, Micat M, et al. Arterial oxygen tension and pulmonary ventilation in horses placed in the Anderson Sling suspension system after a period of lateral recumbency and anaesthetised with constant rate infusions of romifidine and ketamine. *Equine Vet J* 2014;46:596–600.
85. Clark-Price SC. Recovery of horses from anesthesia. *Vet Clin North Am Equine Pract* 2013;29:223–242.
86. Spier SJ, Berger Pusterla J, Villarroel A, et al. Outcome of tactile conditioning of neonates, or "imprint training" on selected handling measures in foals. *Vet J* 2004;168:252–258.
87. Henry S, Richard-Yris MA, Hausberger M. Influence of various early human-foal interferences on subsequent human foal relationship. *Dev Psychobiol* 2006;48:712–718.

88. Robinson T. Managing a resistant horse: the right mixture of sweetness and strength, in *Proceedings*. Am Assoc Equine Pract 2014;60:543–547.
89. Ohmura H, Jones JH. Changes in heart rate and heart rate variability as a function of age in Thoroughbred horses. *J Equine Sci* 2017;28:99–103.
90. Baggot JD, Short CR. Drug disposition in the neonatal animal, with particular reference to the foal. *Equine Vet J* 1984;16:364–367.
91. Norman WM, Court MH, Greenblatt DJ. Age-related changes in the pharmacokinetics disposition of diazepam in foals. *Am J Vet Res* 1997;58:878–890.
92. Koterba AM, Kosch PC. Respiratory mechanics and breathing pattern in the neonatal foal. *J Reprod Fert Suppl* 1987; 35:575–586.
93. Toth B, Aleman M, Brosnan RJ, et al. Evaluation of squeeze-induced somnolence in neonatal foals. *Am J Vet Res* 2012;73:1881–1889.
94. Bidwell LA. How to anesthetize foals on the farm for minor surgical procedures, in *Proceedings*. Am Assoc Equine Pract 2009;55:48–49.
95. Sanchez LC, Robertson SA. Pain control in horses: What do we really know? *Equine Vet J* 2014;46:517–523.
96. Hopster K, van Eps AW. Pain management for laminitis in the horse. *Equine Vet Educ* 2018;31:384–392.
97. Davis JL, Posner LP, Elce Y. Gabapentin for the treatment of neuropathic pain in a pregnant horse. *J Am Vet Med Assoc* 2007;231:755–758.
98. Guedes AG, Matthews NS, Hood DM. Effect of ketamine hydrochloride on the analgesic effects of tramadol hydrochloride in horses with signs of chronic laminitis-associated pain. *Am J Vet Res* 2012;73:610–619.
99. Guedes A, Knych H, Hood D. Plasma concentrations, analgesic and physiologic assessments in horses with chronic laminitis treated with two doses of oral tramadol. *Equine Vet J* 2016;48:528–531.
100. Guedes AG, Morisseau C, Sole A, et al. Use of a soluble epoxide hydrolase inhibitor as an adjunctive analgesia in a horse with laminitis. *Vet Anaesth Analg* 2013;40:440–448.
101. Van Loon JP, Van Dierendonck MC. Monitoring acute equine visceral pain with the Equine Utrecht University Scale for Composite Pain Assessment (EQUUS-COMPASS) and the Equine Utrecht University Scale for Facial Assessment of Pain (EQUUS-FAP): A scale-construction study. *Vet J* 2016;216:175–177.
102. Waran N, Williams VM, Clarke N, et al. Recognition of pain and use of analgesia in horses by veterinarians in New Zealand. *N Z Vet J* 2010;58:274–280.
103. Kambayashi Y, Tsuzuki N, Tokushige H, et al. Comparison of oxidative stress under different propofol administration protocols in Thoroughbred racehorses by bOS and bAP assessment. *J Equine Sci* 2018;29:75–78.
104. Schoster A, Mosing M, Jalali M, et al. Effects of transport, fasting and anaesthesia on the faecal microbiota of healthy adult horses. *Equine Vet J* 2016;48:595–602.
105. Bailey PA, Hague BA, Davis M, et al. Incidence of post-anesthetic colic in non-fasted adult equine patients. *Can Vet J* 2016;57:1263–1266.
106. Lloyd AS, Martin JE, Bornett-Gauci HLI, et al. Horse personality: variation between breeds. *Appl Anim Behav Sci* 2008;112:369–383.
107. Sackman JE, Houpt KA. Equine personality: Association with breed, use, and husbandry factors. *J Equine Vet Sci* 2019;72:47–55.
108. Ablondi M, Viklund A, Lindgren G, et al. Signatures of selection in the genome of Swedish warmblood horses selected for sport performance. *BMC Genomics* 2019;20:717.
109. Wetmore LA, Pascoe PJ, Shilo-Benjamini Y, et al. Effect of fentanyl administration on locomotor response in horses with the G57C mu opioid receptor polymorphism. *Am J Vet Res* 2016;77:828–832.
110. Tranquilli W, Thurmon JC, Turner TA, et al. Butorphanol tartrate as an adjunct to xylazine-ketamine anesthesia in the horse. *Equine Pract* 1983;5:26–29.
111. Hellyer PW, Bai L, Supon J, et al. Comparison of opioid and alpha-2 adrenergic receptor binding in horse and dog brain using radioligand autoradiography. *Vet Anaesth Analg* 2003;30:172–182.
112. Thomasy SM, Moeller BC, Stanley SD. Comparison of opioid receptor binding in horse, guinea pig, and rat cerebral cortex and cerebellum. *Vet Anaesth Analg* 2017;34:351–358.
113. Ohmura H, Hobo S, Hiraga A, et al. Changes in heart rate and heart rate variability during transportation of horses by road and air. *Am J Vet Res* 2012;73:515–521.
114. Janczarek I, Wilk I, Stachurska A, et al. Cardiac activity and salivary cortisol concentration of leisure horses in response to the presence of an audience in an arena. *J Vet Behav* 2019;29:31–39.
115. Young T, Creighton E, Smith T, et al. A novel scale of behavioural indicators of stress for use with domestic horses. *Appl Anim Behav Sci* 2012;140:33–43.
116. Merkies K, Ready C, Farkas L, et al. Eyeblink rates and eyelid twitches as a non-invasive measure of stress in the domestic horse. *Animals* 2019;9:562–562.
117. Rumsfeld D. Brainyquote.com. Accessed December 13, 2019.

Loan Repayment—Programs and Strategies for Equine Vets

Martha Mallicote, DVM, MBA, DACVIM

The impact of the current DVM student loan burden on the veterinary profession, and most particularly the equine veterinary profession, cannot be overstated. An important part of the solution to this challenge is a clear understanding of loan repayment strategies that are realistic solutions for recent graduates. This presentation will review the programs and strategies for student loans to assist graduates in planning their approach to this financial challenge. Author's address: College of Veterinary Medicine, University of Florida, Gainesville, FL 32610; e-mail: mfmallicote@gmail.com.

1. Terminology

Principal—The total sum of money borrowed plus any interest that has been capitalized.

Interest—A loan expense charged for the use of borrowed money. Interest is paid by a borrower to a lender. The expense is calculated as a percentage of the unpaid principal amount of the loan.

Interest rate—The numerical percentage at which interest is calculated on a loan(s).

Unsubsidized loan—Interest on unsubsidized loans accrues from the date of disbursement and continues throughout the life of the loan. These loans are available to graduate students with no financial need required and the school determines the amount available to borrow based on cost of attendance (subsidized loans are only for undergrads—the Department of Education pays interest on direct subsidized loans while in school).

Capitalization—The addition of unpaid interest to the principal balance of a loan. This increases the outstanding principal amount due on the loan. Interest is then charged on that higher principal balance, increasing the overall cost of the loan and the monthly payment amount.

2. Introduction—The Basics of Getting Organized

In order to identify the best plan for student loan repayment, one must first assess the details of what they will be managing—from both a debt and income perspective.

First, get the details about the loans: what type of loans were issued and how much money is owed? Who is the loan servicer? Will there be a grace period following graduation?

For federal loans, this information can be found through nslds.ed.gov. For any private loans (these are much less common), check the borrower's credit report to confirm all private loans and identify the lender. Grace periods of 6 months (9 months on Perkins loans and 12 months on Health Professions loans) will be in effect after graduation—ensure that the borrower is still eligible on all loans and did not use up this grace period after the completion of undergraduate training. A grace period is only

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available ONCE to any given borrower, even for new loans that are issued in a graduate program.

Then, regarding income: what kind of payment will be affordable after graduation? What is the Adjusted Gross Income for the first 6 months of repayment and then likely Adjusted Gross Income for the next year? Can automatic electronic debit be set up?

Finally, regarding repayment strategy: Is consolidation or refinancing right? What repayment strategy will combine realistic amounts and least total amount paid out for the loan?

Use a repayment calculator to assess WHICH plan will be best for each individual situation! Data used in the Free Application for Federal Student Aid required of all borrowers can be plugged right into the calculators. Start this analysis right after graduation and ensure alternate payment plan applications are filed no later than 2 months before the end of the grace period to allow time for acceptance. It is incredibly important to consider each individual scenario in determining the ideal repayment strategy—factors such as individual and spouse income, children, career goals (pursuit of specialty training versus entering practice), household expenses and personal feelings about carrying debt all influence the selection of debt repayment strategy.

After getting the repayment plan in place, set up automatic direct debit for payments in advance and get an interest rate discount of 0.25%. Be ready to start paying the loan back on time—a quarter to a third of borrowers are LATE on the very first payment.

3. Solution—Details and Repayment Strategies

DVM Student Loans

Federal student loans that are currently being issued are Direct Loans—the US Department of Education is the lender. Loans issued prior to July 1, 2010 are likely Federal Family Education (FFEL) Loans, which were either federally issued/held or commercially held loans with federal guarantees.

Primary vet student loan types are listed below:

- Unsubsidized Stafford Loan (currently at 6.08% interest prior to July 2020 reset).
- Plus Loan (unsubsidized, currently at 7.08% interest prior to July 2020 reset).
- Health Professions Loan—subsidized, 5% interest.
- Perkins Loan—subsidized, 5% interest.

Loan Consolidation

It may be necessary to consolidate for eligibility for some repayment programs. For example, FFEL loans (prior type of loans) aren't eligible for the Pay as You Earn (PAYE) program, but a consolidation loan IS eligible. Borrowers are eligible to consolidate at graduation, departure from school, or below half-time enrollment. It is important to discuss the advantages/disadvantages of consolidation with the loan servicer—some benefits may be lost with consolidation. There is no interest rate benefit, but the borrower may be able to secure lower cost payments with an income-driven repayment scheme by consolidating and waiving the grace period to immediately enter repayment. Consolidation will also likely give the borrower less to keep up with in terms of loans and paperwork.

Loans MUST be in repayment or grace period to start the consolidation process. There is no application fee for consolidation, so avoid and beware of private companies that offer to do that at a cost to the borrower.

Most federal student loans, including the following, are eligible for consolidation: Direct Subsidized Loans, Direct Unsubsidized Loans, Subsidized Federal Stafford Loans, Unsubsidized Federal Stafford Loans, Direct PLUS Loans, PLUS loans from the FFEL Program, Supplemental Loans for Students, Federal Perkins Loans, Federal Nursing Loans, Health Education Assistance Loans and some existing consolidation loans. Private education loans are not eligible for consolidation. If in *default*, certain requirements must be met before consolidating loans.

Loan Refinancing

Refinancing is different from consolidation of loans—some private lenders will offer refinancing at interest rates that seem appealing (lower than rates paid for student loans). Be aware that the rules protecting student loan borrowers (allowing changes in payments tied to borrower income and access to repayment schemes based on type of employment) will not apply to these private loans. This is best used if the borrower intends to pay off the loan before it is due and is comfortable with the maximum potential monthly payment (more commonly with smaller loans and aggressive repayment plans).

Repayment Plans

The most common repayment plans are as follows:

Standard/Fixed Plans

Standard Repayment. Under this plan the borrower pays a fixed monthly amount for a loan term of up to 10 years. Depending on the amount of the loan, the loan term may be shorter than 10 years.

Extended Repayment. This plan is like standard repayment, but allows a loan term of 12 to 30 years, depending on the total amount borrowed. Stretching out the payments over a longer term reduces the size of each payment, but increases the total amount repaid over the lifetime of the loan.

Graduated Repayment. Unlike the standard and extended repayment plans, this plan starts off with lower payments, which gradually increase every 2 years. The loan term is 12 to 30 years, depending on the total amount borrowed. The monthly payment can be no less than 50% and no more than 150% of the monthly payment under the standard repayment plan. The monthly payment must be at least the interest that accrues.

Income-Driven Repayment Plans

PAYE. Payments under the PAYE plan are based on the borrower's income and the total amount of debt. Monthly payments are adjusted each year as the borrower's income changes and monthly payments will be 10% of discretionary income, but never more than would be paid under the 10-year Standard Repayment Plan. PAYE is for a loan term of 20 years. Initial loans can be issued no earlier than 2007 and disbursements must have been received after October 2011.

Revised Pay as You Earn (REPAYE) is similar to PAYE. If married, both the borrower and their spouse's income or loan debt will be considered when calculating the payment amount, whether taxes are filed jointly or separately (with limited exceptions)—in PAYE this does not occur. Repayment will likely continue into 25 years, due to graduate loans being included.

Income-Based Repayment is similar to PAYE and REPAYE, but caps the monthly payments at 10% to 15% of discretionary income. Repayment is over a term of 20 to 25 years, depending on the types of loans held.

Income-Contingent Repayment is also similar to those above but monthly payment will be the lesser of 20% of discretionary income, or the amount one would pay on a repayment plan with a fixed payment over 12 years. The loan term is up to 25 years. Income-Contingent Repayment is available only for Direct-Loan borrowers.

****It is important to note that income tax is due on any amount that is forgiven for the standard income-driven repayment schemes.** This tax is based on the fact that the forgiven amount is reported as income in the year it is forgiven—the entire tax bill will be due THAT year.

An excellent chart comparing these options and their terms can be found at https://studentaid.ed.gov/sa/repay-loans/understand/plans. Ultimately, the choice of which repayment strategy to take depends on factors including individual and household income, children, career trajectory, and household expenses. Personal feelings about carrying debt also cannot be ignored—for some individuals, the concept of carrying a large loan that will not be paid off by the borrower (as with income-based repayment schemes) is not acceptable. The use of repayment calculators can help determine which is the best overall financial approach, while also taking into account the individual factors above.

For standard borrowers who are recent or current DVM graduates, PAYE is typically the best income-driven repayment choice—but everyone's variables are different and individual assessment is important. For borrowers who determine that they will repay their entire loan (NOT use income-driven repayment with loan forgiveness), aggressive repayment to minimize interest charges will decrease the total financial burden. For borrowers who utilize income-driven repayment and forgiveness, paying the least amount of money into the loan will maximize the financial benefit.

Loan Forgiveness

Public Service Loan Forgiveness (PSLF) Program forgives the remaining balance on Direct Loans after 120 qualifying monthly payments under a qualifying repayment plan while working full time for a qualifying employer. Private loans are not eligible for forgiveness with this program. Qualifying employers include government organizations at any level (federal, state, local, or tribal), Not-for-Profit organizations that are tax-exempt [501(c)(3)], and other types of not-for-profit organizations that provide certain types of qualifying public services. The PSLF has gotten substantial bad press over the last 2 years as some borrowers have reached their point of loan forgiveness. Unfortunately, many of the first borrowers to enter PSLF were misinformed about qualifying loans and payments—many 2007 loans did not qualify as is and needed to be consolidated to qualify under the program terms.

Veterinary Medicine Loan Repayment Program will pay up to $25,000 each year toward qualified educational loans of eligible veterinarians who agree to serve in a National Institute of Food and Agriculture (NIFA)-designated veterinarian shortage situations for a period of 3 years. Program details and a map of eligible areas can be found here: www.nifa.usda.gov/program/veterinary-medicine-loan-repayment-program. For mixed large-animal veterinarians, this may be a useful adjunct to loan repayment when working in relatively underserved areas.

Armed Forces F. Edward Hébert Armed Forces Health Professions Scholarship Program—students receive full tuition at any accredited veterinary, medical, dental, psychology, or optometry program, plus a generous monthly stipend of more than $2,000. There is an active-duty service obligation to the US Army is 1 year of service for every year of scholarship received. *Army Active Duty Health Professions Loan Repayment Program* pays up to $120,000 over 3 years to repay veterinary school loans for active duty; participants receive $40,000 per year for 3 years. *For reserve duty*, veterinarians are eligible for loan repayment of up to $50,000 over 3 years through the Healthcare Professionals Loan Repayment Program; participants receive $20,000 per year for the first 2 years and $10,000 the third year.

State-Funded Loan Repayment Programs—some states have passed legislation establishing their own loan repayment or loan forgiveness programs for veterinarians.

Advanced Training/Graduate Students

The common "old sage" advice for DVMs in graduate or specialty training programs was to enter loan deferment during the training program due to low income. Deferment allows the borrower to completely avoid making payments and borrowers can indeed qualify under the economic hardship clause to do so, but there are consequences to this choice. Unsubsidized and private loans will continue to accumulate interest in the deferment period and this accrued interest will be capitalized when the borrower reenters repayment. With the availability of income-driven repayment schemes, the lower-income trainee DVM can continue making very minimal payments tied to their income status. This allows the borrower to accumulate time paying on the loan but with very small payments. If the borrower is utilizing an income-driven scheme with loan forgiveness over the long term, this is financially advantageous—particularly for those in the PSLF program with its shorter timeline. With careful investigation and planning, time spent in advanced training programs may even be counted against the years of nonprofit work required for forgiveness under the PSLF.

4. Additional Resources

www.vinfoundation.org/loansim
www.studentaid.gov
www.avma.org/resources-tools/personal-finance
www.studentloanplanner.com

Acknowledgments

Declaration of Ethics

The Author has adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Author has no conflicts of interest.

Why Veterinarians Are Leaving Equine Practice

Amy L. Grice, VMD, MBA

Data show that over the last 20 years, fewer new graduates are entering equine practice and nearly half have left the equine field by the fifth year after graduation. With a significant number of AAEP members over the age of 50 years, there may be a shortfall in veterinarians to care for our nation's horses in the near future. Author's address: PO Box 192, Virginia City, MT 59755; e-mail: amyvmdmba@gmail.com.

1. Introduction

American Association of Equine Practitioners (AAEP) membership records show that more than 50% of recent graduates have failed to renew their membership within 5 years following their graduation, a figure that has been trending upward (Fig. 1).[1] For example, of those AAEP members graduating in 2014, by 5 years later in 2019, 52% were no longer members. In addition, the number of new graduates that chose careers in equine practice dropped from 5.7% in 2003 to 1.1 in 2017, and then increased slightly to 1.5% in 2018, according to American Veterinary Medical Association (AVMA) data (Fig. 2).[1]

Over 200 job opportunities have been consistently available on the AAEP Job Board over the past several years, and many practices report receiving few to no applications. In veterinary medicine as a whole, the unemployment rate was 0.8% in 2019, and according to the AVMA Career Center, applicant to job ratios varied between states, with the majority having a ratio from 0.0 to 0.5.[2] Currently, about two thirds of AAEP members are less than 50 years of age, with 17.4% aged 51 to 60 years, and 26.6% over the age of 60 years.[a] Over the next decade, it is likely that many of these practitioners, which represent 44% of the AAEP membership, will retire. If the attrition of new equine practitioners continues and the retirements of aging equine veterinarians occur as expected, horse owners could experience difficulty finding equine-focused doctors to care for their mounts, especially in some more rural regions.

Against this backdrop, an effort was made to determine possible reasons for the trend of decreasing attraction and retention of veterinarians in equine practice.

2. Methods and Materials

An eight-question survey link utilizing Survey Monkey was distributed on several Facebook sites in May 2019. The sites utilized were the closed groups Women in Equine Practice, Equine Vet-2-Vet, Moms with a DVM, and AAEP Member Vet Talk. The survey was open for about 10 days, and 647 veterinarians responded.

The survey instructions asked the doctors to answer based on the equine practice where they were currently working or where they had previously worked before leaving the career. Survey questions to assess the profiles of the respondents included the percentage of equine work done by the practitioner, the year of graduation from veterinary

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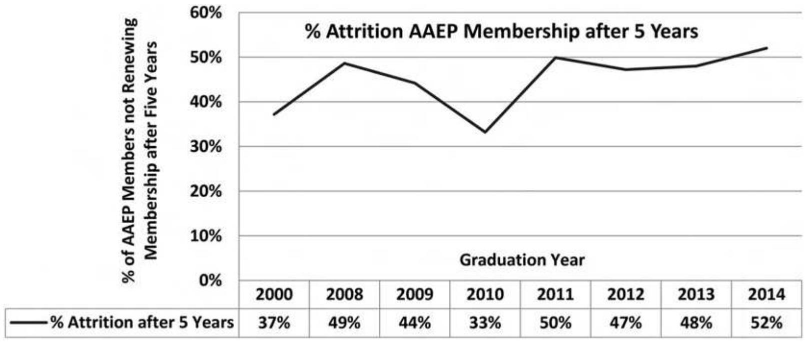


Fig. 1. Percentage attrition in AAEP membership in 5 years since graduation.

school, whether the respondent was an associate or an owner, and the size of the practice. The most important questions in the survey were those that focused on leaving the profession. All of the questions allowed the veterinarians to write comments.

3. Results

When asked, “How much of your practice is or was equine?”, the majority of the respondents (63.8%) reported that they were currently or had formerly been at a 100% equine practice, followed by 24.6% that reported their practice was 75% to 99% equine. Few respondents reported less than 75% equine work (Fig. 3).

Because the noted trend of attrition of equine graduates from AAEP membership showed an increase from 2000 onward, the survey broke the respondent cohort into fairly small groups in order to see if there were differences among different sets of graduation years. Those graduating 10 years or more ago were grouped together, while the most recent decade was grouped in 3-year increments. As might be expected, the majority (50.8%) of respondents graduated in 2009 or prior. The most recent decade was well represented in each of the three segments of graduation years (Fig. 4).

Another survey question asked, “Are or were you an associate or owner in equine practice?” Most likely due to about half of respondents graduating in the last decade, associates (64.6%) outnumbered owners (35.4%) overall. When looking at just those who graduated in the last decade, 80.6% identified themselves as associates and 19.4% identified as owners. This is in contrast to those graduating in 2009 or before, of whom 49% reported they were associates and 51% reported they were practice owners.

Respondents were fairly equally distributed among different sized practices, providing a view of equine veterinarians across a variety of work settings. The equine veterinary industry is largely made up of small practices. While only 20.9% reported being solo practitioners, well below the approximately 35% of AAEP members that consistently report being solo, over 58% reported working in practices of 1 to 3 veterinarians. This is consistent with the findings of the 2016 AVMA AAEP Economic Survey, which found that 52.5% of equine practices have 2 or fewer full-time equivalent (FTE) veterinarians.[1] Almost 20% of respondents reported working at large practices with more than 6 doctors. Again, this result showed consistency with

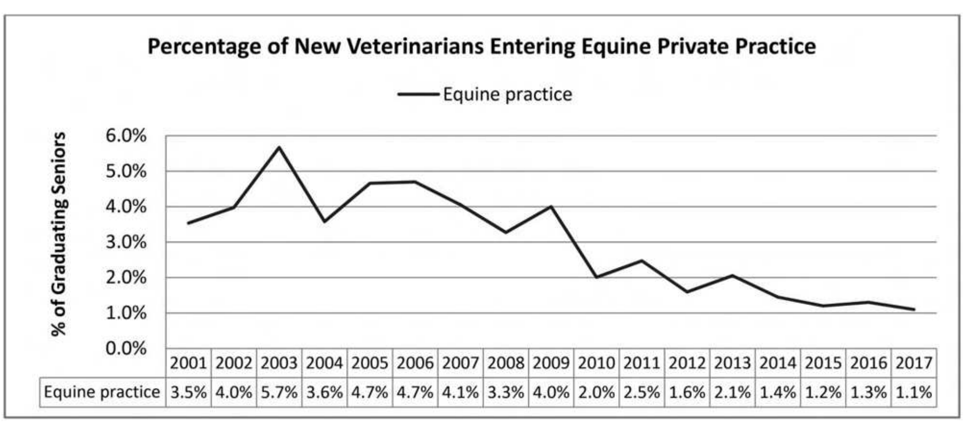
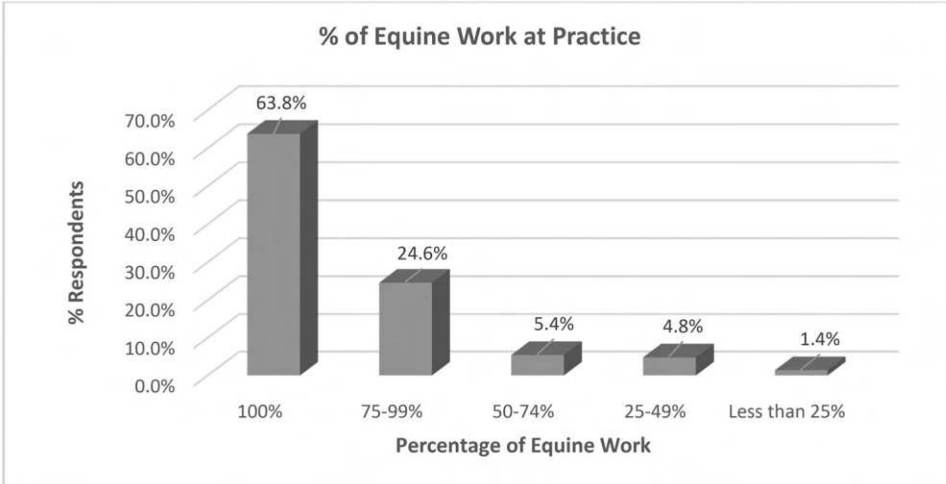
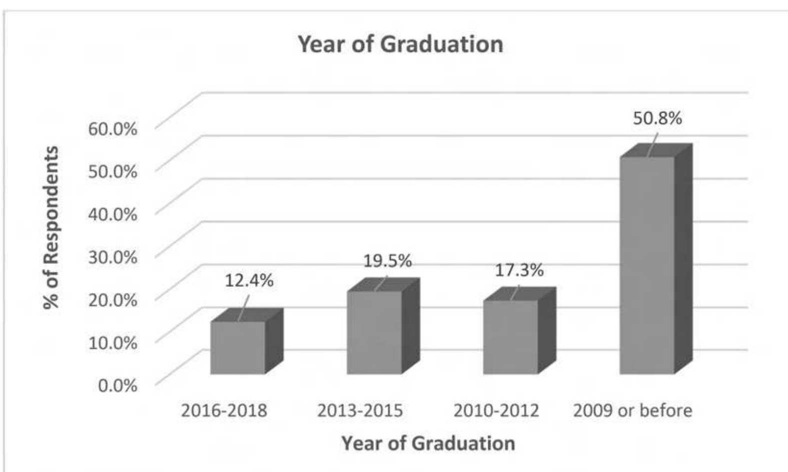


Fig. 2. Percentage of new graduates entering equine private practice.



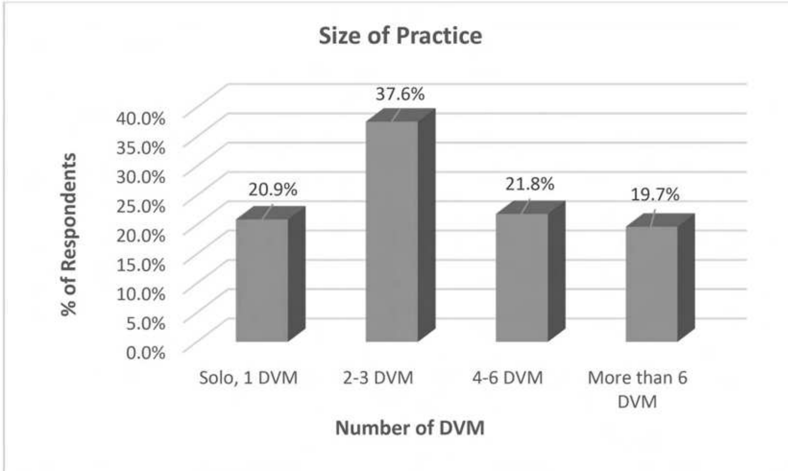
Answer Choices			
100%	63.8%	412	
75-99%	24.6%	159	
50-74%	5.4%	35	
25-49%	4.8%	31	
Less than 25%	1.4%	9	
		646	**TOTAL**

Fig. 3. Survey question: "How much of your practice is or was equine?"



Answer Choices			
2016-2018	12.4%	80	
2013-2015	19.5%	126	
2010-2012	17.3%	112	
2009 or before	50.8%	328	
		646	**TOTAL**

Fig. 4. Survey question: "When did you graduate?"



Answer Choices			
Solo, 1 DVM	20.9%	134	
2-3 DVM	37.6%	241	
4-6 DVM	21.8%	140	
More than 6 DVM	19.7%	126	
		641	**TOTAL**

Fig. 5. Survey question: "What is or was the size of the practice where you did equine work?"

the 2016 AVMA AAEP Economic Survey, which found that 20.5% reported working at equine practices with 6 or more FTE veterinarians (Fig. 5).[1]

The next questions in the survey were those that focused on leaving the profession. The first question in the survey asked, "Which statement is true for you?" and the answers included, "I have never considered leaving equine practice," "I considered leaving equine practice but decided to stay," "I am currently considering leaving equine practice but have not decided," and "I have left equine practice or have definitely decided to leave equine practice" (Fig. 6).

Somewhat shockingly, only 181 (28%) of the 645 respondents have never considered leaving the profession of equine veterinary medicine, of whom 107 graduated in 2009 or before. Of the 80 respondents who graduated in 2016 to 2018, 22 (27.5%) had never considered leaving and 30 (37.5%) had considered leaving and decided to stay. Similarly, 20.6% of the 126 respondent graduates of 2013 to 2015 had never considered leaving and 35.7% had considered leaving and decided to stay. Of those 110 respondents graduating in 2010 to 2012, 22.7% had never considered leaving equine practice and 37.3% had considered leaving and decided to stay. Because the recession of 2009 to 2011 affected equine practice substantially, one might have expected there to be higher attrition in those graduation years, but the data do not support this.

Sadly, 127 (19.7%) of the total 645 respondents have already left or have definitely decided to leave equine practice, and another 113 (17.5%) are currently considering leaving the profession. When considered by graduation year, 19.5% of those graduating in 2009 or prior have left or have definitely decided to leave,

Answer Choices	Responses	
I have never considered leaving equine practice	28.1%	181
I considered leaving equine practice but decided to stay	34.7%	224
I am currently considering leaving equine practice but have not decided	17.5%	113
I have left equine practice or definitely decided to leave equine practice	19.7%	127
TOTAL	**100.0%**	**645**

Fig. 6. Survey question: "Which statement is true for you?"

Answer Choices	Year of Graduation							
	Before 2009		2010-2012		2013-2015		2016-2018	
I have never considered leaving equine practice	32.62%	107	22.73%	25	20.63%	26	27.50%	22
I considered leaving equine practice but decided to stay	32.93%	108	37.27%	41	35.71%	45	37.50%	30
I am currently considering leaving equine practice but have not decided	14.94%	49	21.82%	24	16.67%	21	23.75%	19
I have left equine practice or definitely decided to leave equine practice	19.51%	64	18.18%	20	26.98%	34	11.25%	9
TOTAL	**100.00%**	**328**	**100.00%**	**110**	**100.00%**	**126**	**100.00%**	**80**

Fig. 7. Survey question: "Which statement is true for you?" By Graduation Year.

compared with 18.2% of those who graduated in 2010 to 2012, 27.0% of those who graduated in 2013 to 2015, and 11.3% of those who graduated in 2016 to 2018. Currently considering leaving the equine veterinary career path are 14.9% of 2009 or prior graduates, 21.8% of 2010 to 2012 graduates, 16.7% of 2013 to 2015 graduates, and 23.8% of 2016 to 2018 graduates. The data suggest that the reality of life as an equine practitioner may become untenable to some after several years in the career (Fig. 7).

When this question was analyzed by size of practice, interesting results emerged. Those respondents working for themselves as solo practitioners were the least likely to have considered leaving equine practice, and the least likely to have left equine practice. They were similar in percentage to respondents from large practices with more than 6 veterinarians in considering leaving but deciding to stay. However, they were more likely than those working at larger practices to be currently considering leaving equine veterinary medicine. Surprisingly, those in larger practices of 4 or more doctors were the most likely to have left or be definitely leaving the career (Fig. 8). When considered additively, those respondents in practices of 2 to 3 doctors (39.58%) and 4 to 6 doctors (40.29%) were those most likely to be currently considering leaving equine practice but not yet decided, or to have already left equine practice or definitely decided to leave equine practice (Fig. 9). However, those in practices with more than 6 doctors were close behind with 37.30%. Solo practitioners were lower at 29.85%.

Understanding why talented equine veterinarians are leaving the profession was the main objective of this survey, and to that end, questions were asked to identify both the contributing as well as the primary reasons for the exodus. The top 5 contributing factors when respondents could select all factors that influenced their decisions were lifestyle and number of work hours required (57.7%), emergency on-call duty (53.0%), low salaries and compensation (51.8%), mental health and stress (44.5%), and culture of equine veterinary industry (36.6%). Mentioned less frequently as contributors to leaving equine practice were culture of my practice (28.4%), having children (26.4%), physical injuries (24.4%), and high educational debt (22.8%). The least chosen factor was

Answer Choices	Size of Practice							
	1 DVM		2-3 DVM		4-6 DVM		> 6 DVM	
I have never considered leaving equine practice	38.81%	52	23.75%	57	24.46%	34	30.16%	38
I considered leaving equine practice but decided to stay	31.34%	42	36.67%	88	35.25%	49	32.54%	41
I am currently considering leaving equine practice but have not decided	19.40%	26	19.58%	47	15.83%	22	13.49%	17
I have left equine practice or definitely decided to leave equine practice	10.45%	14	20.00%	48	24.46%	34	23.81%	30
TOTAL	**100.00%**	**134**	**100.00%**	**240**	**100.00%**	**139**	**100.00%**	**126**

Fig. 8. Survey question: "Which statement is true for you?" By size of practice.

Answer Choices	Size of Practice 1 DVM		2-3 DVM		4-6 DVM		> 6 DVM	
I am currently considering leaving equine practice but have not decided	19.40%	26	19.58%	47	15.83%	22	13.49%	17
I have left equine practice or definitely decided to leave equine practice	10.45%	14	20.00%	48	24.46%	34	23.81%	30
ADDITIVE considering, have left or definitely decided to leave	**29.85%**	**40**	**39.58%**	**95**	**40.29%**	**56**	**37.30%**	**47**

Fig. 9. Survey question: "Which statement is true for you?" By size of practice with only, "I am currently considering leaving equine practice but have not decided," and "I have left equine practice or definitely decided to leave equine practice." Answers considered additively.

needs of elderly or ailing parents or family members (2.9%) (Fig. 10).

Forty-one respondents chose "Other" as one of the reasons for considering leaving equine practice. Those respondents choosing "Other" were asked to comment. A total of 81 comments were made on this question. Included was the following: "I think for me, the main reason I could not make equine practice work was because of the culture and demanding hours. It was a challenge before kids, but afterwards it became impossible. Being on call 50% of the time with a newborn that didn't sleep was an enormous strain on our family, and if I'm being completely honest it put my marriage in jeopardy. Then taking time off to take my sick daughter to the doctor was a strain on the practice. Planning to leave early one day to pick up my kid on a day my husband had a late meeting was a lot to ask my employer. Trying and failing to make it home in time for dinner was the norm. The list goes on. I did look for other equine jobs, but never found one in our area that seemed to be enough of an improvement to make it worth it. For now, I am doing SA [small animal], and hope to get back to equine after my kids are a bit older—maybe solo. I hate to be another female vet that couldn't make it in equine practice. It's all I ever wanted to do, since I was 7; I completed an internship and almost accepted a residency; I thought I was well prepared and fully informed on what to expect out of this career path. I love equine medicine, but could not find a way to do it and also feel like I was being a good mother/wife—or even daughter/sister/friend/etc."

Answer Choices - 647 Respondents	Responses	
Lifestyle & number of work hours required	57.7%	373
Emergency on-call duty	53.0%	343
Low salaries and compensation	51.8%	335
Mental health & stress	44.5%	288
Culture of equine veterinary industry	36.6%	237
Culture of my practice	28.4%	184
Having children	26.4%	171
Physical injuries or wear & tear	24.4%	158
High educational debt	22.9%	148
I never considered leaving equine practice	21.8%	141
Desire to work part-time	10.2%	66
Other financial stress	10.1%	65
Other (please comment)	6.3%	41
Needs of elderly or ailing parents or family members	2.9%	19

Fig. 10. Survey question: "What factors contributed to you leaving or considering leaving equine practice?" Choose all that apply.

Another comment was, "Equine practice is still very much a lifestyle, not a job. The lines between clients & friends is blurred. Not only must you be available 24/7 and are made to feel guilty if you are not, forget about going to the barn to play with your horses uninterrupted. I go, only when I know others won't be there, and it causes me more anxiety than calm. As much as these clients act like friends, I am a monkey that serves them. And if I died, they'd find another monkey. That's a tough reality when you dedicate your life to something. The people make it suck, the stupidly low pay and constant on-call make it sick [sic]. The horses make it worth it." Other comments referenced unethical behavior, a "good old boys club", inability to compete with online options that can sell below a small practice's cost of goods, misogyny, inadequate support staff, and a lack of opportunity to buy shares.

The most prevalent reasons chosen for leaving equine practice did not differ considerably between graduate year cohorts, but there were interesting trends in the percentage of respondents choosing each option. Lifestyle and number of work hours required was the most frequently named contributor to respondents' decisions to leave or consider leaving equine practice across all graduation years, cited by 52.7% of those graduating in 2009 or before, 58.9% of those graduating in 2010 to 2012, 67.5% of 2013 to 2015 graduates, and 61.3% of respondents from 2016 to 2018. Those from more recent graduating years were more likely to attribute low salaries and compensation to influencing their departure, with

Answer Choices	2009 or before	2010-2012	2013-2015	2016-2018
Lifestyle and work hours	52.70%	58.90%	67.50%	61.30%
Low compensation	43.00%	58.00%	64.30%	60.00%
Emergency on-call duty	47.60%	58.00%	60.30%	57.50%
Mental health & stress	40.20%	47.30%	52.40%	46.30%
Culture of equine industry	30.50%	40.20%	44.40%	45.00%
Educational debt	12.50%	29.50%	32.50%	41.30%
Culture of my practice	23.50%	31.30%	37.30%	31.30%
Physical injury	26.50%	25.00%	21.40%	20.00%
Children	26.20%	34.80%	27.00%	15.00%
Respondents = 647	**328**	**112**	**126**	**80**

Fig. 11. Survey question: "What factors contributed to you leaving or considering leaving equine practice?" Top factors by graduation years.

Answer Choices - 459 Respondents	Responses	
Lifestyle & number of work hours required	27.5%	126
Emergency on-call duty	17.9%	82
Mental health & stress	11.5%	53
Low salaries and compensation	10.0%	46
Culture of my practice	9.8%	45
Culture of equine veterinary industry	6.5%	30
Having children	6.3%	29
Physical injuries or wear & tear	3.7%	17
Other (please comment)	2.8%	13
High educational debt	2.6%	12
Desire to work part-time	1.1%	5
Needs of elderly or ailing parents or family members	0.2%	1
I never considered leaving equine practice	0.0%	0
Other financial stress	0.0%	0
TOTAL	**100.0%**	**459**

Fig. 12. Survey question: "What is the primary or most important factor that contributed to you leaving or considering leaving equine practice?"

43.0% of 2009 and before, 58.0% from 2010 to 2013, 64.3% from 2013 to 2015, and 60.0% from 2016 to 2018 citing this factor. One respondent commented, "I could literally not afford to eat meat. I love the job, but it wasn't sustainable." Emergency on-call duty, and mental health and stress were less frequently reported by those graduating in 2009 or prior compared to the most recent decade's graduates. A sharply rising trend in the importance of educational debt and a smaller rise in influence of the culture of the equine veterinary industry was seen across graduation years (Fig. 11).

Respondents to the survey were asked to choose the <u>most important</u> factor in their decision to leave or consider leaving equine practice. Not surprisingly, those factors that were the most prevalent when multiple reasons could be chosen, again rose to the top in the responses. Lifestyle and number of work hours required was the most frequently chosen response (27.5%), followed by emergency on-call duty (17.9%) and mental health and stress (11.6%). Low salaries and compensation (10.0%) garnered a fourth place in importance, followed by culture of my practice (9.8%) (Fig. 12).

When responses were sorted by graduation year, clear differences in the most important factors became evident. While lifestyle and number of hours worked was the primary factor across almost all graduation years, after that a divergence was apparent. Low salaries and compensation was chosen as most important by more of those respondents who graduated in 2016 to 2018 and decreased in importance as a factor the more years the respondent had been in practice. Mental health and stress were chosen by more 2016 to 2018 graduates as the primary reason for leaving or considering leaving compared to all other graduation years, but those who graduated in 2009 or before showed an increasing trend compared to those who graduated in 2010 to 2012. Emergency on-call duty was lower in importance as a factor among graduation years 2016 to 2018, and showed an ascending trend from the most recent graduation years to later years, peaking for years 2010 to 2012 as the most important factor for those respondents at 19.64% and then decreasing somewhat (14.24%) for those who graduated in 2009 or before. The culture of the equine industry was higher in importance as a factor for the most recent graduates, while the culture of the practice in which the respondent worked became more significant as years in practice accumulated, then waned in those more than 10 years out of school. Having children increased in significance to those who were in graduation years 2010 to 2012 and 2013 to 2015 before declining somewhat, most likely reflecting childbearing years. The same trend was seen with educational debt, which could be influenced by the increasing financial needs of those with families or the purchase of a house. Physical injuries or wear and tear increased with time since graduation, not surprisingly. The needs of elderly family members and other financial stresses were of little consequence in choosing to leave equine practice for nearly all respondents (Fig. 13).

The final question of the survey asked what those who had left practice were doing now. About 47% of respondents reported that they are now in companion animal practice and another 10% have an academic position of some kind. Another 4% of respondents reported they are now working in industry and government positions.

4. Discussion

The culture of the equine veterinary industry and that of many individual practices has not changed as the demographics of the profession have changed.

Answer Choices - 641 Respondents	Year of Graduation Before 2009		2010-2012		2013-2015		2016-2018	
Lifestyle & number of work hours required	21.36%	69	16.96%	19	23.81%	30	25.00%	20
Low salaries and compensation	6.19%	20	8.93%	10	9.52%	12	13.75%	11
Mental health & stress	8.67%	28	5.36%	6	8.73%	11	11.25%	9
Emergency on-call duty	14.24%	46	19.64%	22	13.49%	17	8.75%	7
Culture of equine veterinary industry	5.26%	17	4.46%	5	3.17%	4	8.75%	7
Culture of my practice	6.19%	20	9.82%	11	8.73%	11	5.00%	4
Having children	4.64%	15	6.25%	7	5.56%	7	2.50%	2
High educational debt	0.62%	2	5.36%	6	3.97%	5	2.50%	2
Physical injuries or wear & tear	4.02%	13	1.79%	2	2.38%	3	1.25%	1
Other (please comment)	2.17%	7	4.46%	5	1.59%	2	1.25%	1
Desire to work part-time	0.62%	2	0.89%	1	1.59%	2	0.00%	0
Needs of elderly or ailing parents or family members	0.00%	0	0.00%	0	0.79%	1	0.00%	0
Other financial stress	0.31%	1	0.00%	0	0.00%	0	0.00%	0
I never considered leaving equine practice	25.70%	83	16.07%	18	16.67%	21	20.00%	16
TOTAL	**100.00%**	**323**	**100.00%**	**112**	**100.00%**	**126**	**100.00%**	**80**

Fig. 13. Survey question: "What is the primary or most important factor that contributed to you leaving or considering leaving equine practice?" By graduation year.

Traditionally, many equine practitioners worked 10–12-hour days, often 6 or 7 days a week in the busy season. Many practices operated (and some still do) with doctors as silos, holding the expectation that each will attend their "own" clients' emergencies whenever they arise. In some practices, the work ethic is that all doctors should work until all the calls of the day are completed, rather than having emergency service begin at some designated time. This lack of a "hard" stop to the scheduled day makes it very difficult for veterinarians to have other activities, responsibilities, or priorities after work. This culture is particularly hard for women veterinarians who have families. About 80% of new graduates are female now, and if they follow a traditional path through their undergraduate, doctoral, and internship studies, they enter the profession in their prime child-bearing years. This upends many budding equine veterinary careers.

Many respondents to the survey wrote comments that showed a deep love for the profession but a frustration with the constraints of the lifestyle and number of work hours required. The long hours required in the profession were the focus of one respondent's comment: "When people ask me what my hobbies are, I don't know what to say anymore. Sleeping? I used to have hobbies. My mom suggested the other day that we shop for summer shirts at TJ Maxx. I didn't know why she would say that, why would I need a summer shirt, I will be working. . . and wearing work shirts. I truly love my job and I love what I do. But it takes my whole life."

Changing the culture of equine practice with regard to the number of work hours and the expectations of clients for 24/7/365 access to their veterinarian is not an easy task, because it will require horse owners to be more flexible and accept boundaries. Historically, many equine practitioners have made themselves available for their clients' needs at all times, making their profession their first priority before family, health, or personal time. Many newer veterinarians are unwilling to make these sacrifices, wanting to live lives more balanced between work and other needs. This has created friction between practitioners accustomed to the old ways and newer veterinarians searching for a fresh approach. Recent developments suggest that finding a new paradigm will be necessary to retain veterinarians in equine practice.

In order to effect change, veterinarians will need to explore their priorities and set appropriate boundaries on their work lives. This may be having an automatic reply to non-urgent texts, phone calls, and e-mails that come in after hours or on weekends, saying that a response will be made when the office reopens. It could take the shape of having a "hard stop" on regular workdays when a veterinarian has no emergency duty, with the doctor on-call taking emergencies starting at 4 or 5 p.m. in the afternoon. Practices can experiment with 4-day work weeks or compensatory days off after working a weekend. Importantly, doctors can create space for time away from the practice by supporting their colleagues' competence in their communication with their clients. Horse owners may prefer a certain provider, but they need to learn to accept care with gratitude from whomever shows up.

Increasing efficiency in ambulatory practice can increase doctors' time away from the practice. Utilizing "area days" where certain geographical areas are assigned to certain days of the week for farm calls can cut down on driving time. If urgent calls are required to other regions, additional fees would apply. Clients often appreciate being able to plan in advance, knowing that the practice routinely is in the neighborhood on Tuesdays, for instance.

Emergency on-call shifts are a significant factor in the loss of veterinarians from equine practice, ranking second in this survey among all respondents. Said one, "As I'm sure many people will say, the on-call and the hours (working every weekend during breeding season whether on call or not, staying late frequently, etc.) are major contributors in considering leaving equine practice. When most of my friends were vets this seemed normal, but now that many of my friends have non-vet jobs I am insanely jealous of their ability to make definitive evening & weekend plans, have entire weekends off, and not be restricted to the on call radius and tethered to the phone. I enjoy emergencies but have come to hate being on call."

Many practices, especially those that are solo or small, have formed emergency cooperatives to share on-call duties. These loose confederations are more frequent in some regions than others, depending on local competitive pressures. Clients quickly become accustomed to understanding that in an emergency they may need to see a veterinarian that they don't know, and most seem to adjust readily. This is common in human medicine, as well as in emergency clinic settings for companion animals, and people seem to be increasingly understanding the need for change in veterinary medicine.

Emergency care is often needed less frequently for horses that have the benefit of regular primary care. In order to encourage routine wellness care, some practices offer a discount on robust emergency call fees for horses that receive vaccinations and other primary care through the firm. Others offer well-care programs for a menu of services to help ensure that horses get the care they need. Education can also decrease the need for emergency care by early recognition or through prevention. Client seminars about equine management and health can also help minimize urgent visits.

The 2012 AAEP Owner Trainer survey demonstrated that horse owners highly value emergency care delivered in the home setting. The 2017 AVMA Pet Owner Demographic Study revealed that 89% of horse owners consider their horses to be pets or family members, not livestock. Providing emergency care that addresses this emotional bond is a huge opportunity to create client loyalty, and most clients are willing to pay high fees to obtain such care. Some larger practices strategically hire associates to provide emergency care services for surrounding small practices in order to reap the revenue from this highly valued service.

Mental health issues and stress were shown by the 2016 AVMA AAEP Economic study to be increased in veterinarians from more recent graduation cohorts. This survey supports those findings, with stress and mental health the third most common reason for respondents to leave or consider leaving equine practice. Exhaustion, lack of personal time, and frequent on-call shifts can all contribute to lack of personal wellness. Seeking a life more conducive to wellness may be a healthy and appropriate choice for many veterinarians that are struggling personally. The challenge is to make equine practice sustainable for those entering the profession and all those currently serving the equine industry.

It is very important for equine veterinarians to avoid a victim mentality and take responsibility for shaping the life they wish to lead. Creation of a personal mission and personal vision statement can help in this regard. Joining a peer networking group (e.g., Decade One) can help doctors feel less isolated as they discuss shared challenges and solutions. Other strategies for wellness include regular exercise, adequate sleep, good nutrition, and time for family and friends.

The thread of the higher compensation, shorter hours, and minimal emergency duty found in companion animal practice was woven into many respondents' comments in this survey but was not the primary reason most equine veterinarians left or considered leaving the field. Over all the respondents, low compensation was the fourth most commonly cited as the primary factor. However, for more recent graduating classes, low salaries (often well below those found in companion animal jobs) were the second most commonly cited reason for leaving the equine sector. As educational debt has increased in recent graduating classes, financial concerns are more prevalent, but according to the results of this survey, they still remain less of a stumbling block than the lifestyle of equine practice.

Real mean debt of all 2018 graduates from US veterinary colleges, including those without debt, was $143,111, an increase from $133,086 in 2017 and $138,151 in 2016.[3] Results of the 2016 AVMA AAEP Equine Economic Survey indicated that equine practitioners must use much more of their annual compensation than (primarily companion animal) AVMA members, when considering all respondents (Fig. 14). The mean percentage of compensation used to service debt for 2006 to 2016 graduates in equine practice was found to be 20%.[1]

In 2018, about 30% of graduates who entered equine practice had no debt, compared with approximately 20% of graduates who entered companion animal practice. Perhaps, inadvertently, the equine profession is now becoming more accessible and attractive to those with more personal or familial financial resources. This could have a positive effect if these veterinarians feel less stressed by debt and will then remain in the profession. Conversely, will those with robust financial reserves be satisfied with life in equine practice as it currently exists, or will they carve out niches that require less time and effort?

A healthy debt-to-income ratio (DIR) for professionals is considered to be $\leq$1.4, and veterinarians in equine practice well exceed this measure. For

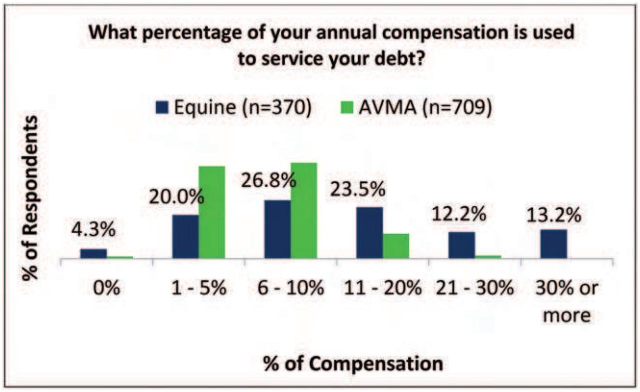


Fig. 14. Percentage of annual compensation used to service educational debt.

graduates of 2001 to 2016, the average DIR of veterinarians who worked full time in equine medicine was 2.48 (median, 2.04). The DIR for recent graduates entering full-time equine practice was 3.2 in 2017 and 4.7 in 2018. Clearly, this is not sustainable, and changes must occur that allow for higher compensation for veterinarians entering equine practice.

Veterinary business management experts recommend that payment for effort as a veterinarian, including all costs of employment, should not exceed 25% of the doctor's gross revenue production. Those costs of employment include benefits, payroll taxes, Workman's compensation, professional liability insurance, etc. Because compensation follows revenue production, higher salaries will necessarily need to follow higher revenue production in order for practices to stay financially healthy. One of the most effective ways to increase revenue is to increase the prices charged for services. If instead, practice owners utilize profit to increase salaries, they will decrease the value of their practices, and will receive less when they one day sell their shares.

Because practice owners receive practice profit in proportion to their percentage of share ownership, in addition to compensation for their effort as veterinarians, total compensation for those veterinarians that are practice owners can well exceed that of associates. Many young equine veterinarians have started their own (often solo) practices as a result. A well-managed small ambulatory practice can be quite profitable, allowing these new entrants to the equine veterinary field to be more financially successful. The positive aspect of greater financial success must be balanced by the added stresses of managing a practice, providing emergency service, and bearing the burden of needed equipment purchases alone. Some newer graduates choose to have niche practices that concentrate on areas of service that do not require general emergency service, such as dentistry or integrative therapy. These young practice owners also can set boundaries on their own terms and minimize accounts receivable by setting strict payment policies from the beginning.

Interestingly, only 6.3% chose having children as the primary reason for leaving or considering leaving the profession. This may reflect the fact that because having a family is a natural and expected part of many if not most adults' lives, those aspects of practice that do not allow for this normal life phase may have been called out as the reason, not the act of having children. Comments in the survey and on the Facebook pages where this survey was posted certainly highlighted the difficulties of veterinarians blending young families with equine practice as it exists today.

Said one doctor, "I never considered leaving until having my daughter. I was all-in, gung-ho equine. And then she came along and the time, financial, and quality of life sacrifices I was making for the privilege of working with horses were not just my sacrifices anymore… I miss horses, but I love my family more." Said another, "I'm one of the "dark side" converts… never thought I would be, but here I am. I was a solid equine ambulatory vet for 11 years, then worked a handful of small-animal days while on maternity leave with my second kid. Ended up making the switch. It has been good for me and my family, but I still struggle with my choice some days. The decision was primarily made to have better quality of life with two kids. I now work only 4 days a week, with no on-call, and earn considerably more. I struggle with the decision, partly from the sense that I gave up my passion, my dream career… I had to accept that doing what was best for myself and my family ended up being more important than my job. I still consider myself a 'horse vet doing small animal' even three years later."

Although opportunities in other areas of the veterinary field abound, those who have trained for and dreamed of a career in equine veterinary medicine often have sadness about their transition. Dr. J. J. Vautier-Brown planned to be an equine surgeon and was proud to be chosen for an internship at Rood and Riddle Equine Hospital several years ago. She described her training there as exceptional and perfect for her career trajectory. After a second surgical internship at the University of Georgia, she was poised to apply for a surgical residency when she became pregnant. "It is horribly crushing to invest eight years of your life to be a surgeon, loving every minute of two intense internships, but feeling like your dream has been crushed. But my son is the biggest blessing of my life, and I wouldn't ever trade him for a residency." Dr. Vautier-Brown worries that her educational loans are a burden to her family and says, "I don't know how to balance my love for my family, my career aspirations, and my financial obligations. We don't leave the equine profession because we want to—we leave because we have no other choice!"

Equine veterinarians often work very hard to continue to work in the traditional cultural mores even as they become pregnant and have a young family depending on them. They often feel diminished by their inability to be perfect in all their roles simultaneously. This is stressful and may lead to depression. The exhaustion of early motherhood is undoubtedly an additional factor in these veterinarians' struggle.

One young equine veterinarian described that "Being a horse doctor was always my dream since I was 7 years old." After her internship, which she described as an amazing experience, she began equine practice at a 6-doctor firm. Although the practice seemed progressive in its medicine, the culture was not family friendly. Neither the staff nor other associates had children, and there was little teamwork. "Every doctor was a silo, never sharing cases or treatments, or helping each other." When this veterinarian became pregnant, she felt she needed to prove that she could do the work without accommodations because of the culture. She worked until the day she delivered, including emergencies. As her first child grew, she felt torn by the demands of her job, saying, "I felt I had to choose between the two and couldn't have both. I felt like I wasn't doing a good job in either role." She recently began a full-time job at a companion animal practice working 36 hours a week with no emergency on-call hours. Her compensation is 50% more than her previous equine position for two thirds as many hours. This talented veterinarian stated, "I feel guilty, embarrassed, and like I don't belong in the equine vet tribe anymore. I took a spot at a prestigious practice for my internship, and now I'm not using that training. I used to judge people for leaving because they couldn't hack it. And now that's me."

Dr. Brittany Breidenbach describes the loss of veterinarians from the equine side as "a huge crisis." After her internship, she felt exceptionally qualified to start as an associate at a busy equine practice. She was 5 months' pregnant when she was hired for her first position post internship and found the practice owners to be very supportive and accommodating. As so many amazing women do, Dr. Breidenbach worked until her delivery, doing a full schedule of dentals the day before she gave birth to her son. The birth was physically traumatic, and she suffered femoral nerve paralysis which affected her ability to walk and balance for nearly 6 months. Overwhelmed by stress and anxiety, the doctor felt enormous pressure "to be exactly the same and not let everyone down." When she returned to work after 8 weeks, still not entirely healed, she went right back into the on-call schedule despite her exhaustion and physical deficits, as she felt the need to prove her worth. In time, life normalized and she began talking with the owners about partnership in the practice. But when she and her husband decided to have a second child, the physicality of the profession began to weigh on her when she was injured tubing a choked horse while pregnant. Several weeks ago, Dr. Breidenbach started work at a companion animal hospital where she earns the same compensation for half the hours, with no emergency duty, and a regular schedule of hours. She laments, "I must accept being the stereotype, but I'm dying inside from the loss of my identity. I dreamed of being a horse vet since I was four years old, and I have to tell myself that I'm still me even though I'm not an equine practitioner. It is heartbreaking."

4. Conclusion

These stories highlight the fact that even the "best in class" are affected by our industry's longstanding workplace traditions and outdated cultural morés. In 2018, the AVMA reports that there were 3,142 US veterinary school graduates and that 42 (1.3%) took an equine job at graduation. Another 146 entered equine internships.[4] Many AAEP members are over the age of 50 years, and many are approaching retirement. Recent numbers of jobs on the AAEP Career Center have well exceeded 200. Our profession cannot continue to stay strong into the coming decades with the loss of exceptional talent that we are now experiencing. New paradigms must evolve that allow our changing workforce to have the flexibility and support that they need while still keeping practices financially healthy. We must all contribute to bringing about the changes that will keep the equine veterinary industry viable for the future.

Acknowledgments

Declaration of Ethics

The Author has adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Author has no conflicts of interest.

References and Footnote

1. American Association of Equine Practitioners. 2016 AVMA AAEP Equine Economic Survey. Available from: https://aaep.org/sites/default/files/Documents/2019%20FINAL_AMVA_AAEP_Equine_Report.pdf. Accessed March 7, 2020.
2. Hansen C. The market for veterinarians. AVMA Economic Summit, Rosemont, IL, October 22, 2019.
3. Larkin M. Salaries, debt for new graduates continue to increase. November 28, 2018. Available from: https://www.avma.org/News/JAVMANews/Pages/181215f.aspx. Accessed March 11, 2020.
4. Bain B, Salois M. Employment, starting salaries, and educational indebtedness of year 2018 graduates of US veterinary medical colleges. *J Am Vet Med Assoc* 2019;254:1061–1066.

[a]Nick Altwies, AAEP Director of Membership, personal communication, November 1, 2019.

How to Employ the Four-Principles Approach for Resolving Ethical Dilemmas in Equine Practice

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1. Introduction

Equine veterinarians consistently cite ethics as one of their primary issues of concern[a]. This concern is well justified. The horse industry currently faces intense public scrutiny following widespread publicity in mass media about horse racing deaths. This attention could easily turn toward perceived mistreatment or abuse of horses in other disciplines, or even horse ownership in general. Public perception is crucial for maintaining a social license to operate in today's society, and without societal support horse sports are at risk of traveling the same path as Barnum and Bailey's circus, which closed down in 2017 after 146 years of operation, in large part due to protracted legal battles with animal rights organizations over the use of elephants in their performances.[1] Ethical decision making by equine veterinarians is not only important for maintaining a high standard of care, it is essential for maintaining public support of the horse industry.

While bioethics is an important and well-developed field in the human medical realm, formal training in ethics is sorely lacking in both veterinary school training and continuing education opportunities for veterinarians. Discussions about ethics in equine practice to date have focused primarily on educating practitioners about following guidelines outlined in the American Association of Equine Practitioners' (AAEP's) Ethical and Professional Guidelines or in the American Veterinary Medical Association's (AVMA) Principles of Veterinary Medical Ethics. However, these documents are limited in scope. Although they do offer concrete solutions to many specific ethical questions, they are less useful when practitioners are faced with more complex dilemmas.

Equine veterinarians need better training and a more extensive toolbox in order to effectively analyze and make decisions when faced with difficult ethical dilemmas. This effort can begin by examining well-established methods in bioethics used in human medicine and adapting them to meet the needs of the veterinary profession. The four-principles approach to bioethics proposed by Beauchamp and Childress[2] provides just such a practical framework that could prove useful for application to veterinary practice.

2. Discussion

The Four-Principles Approach

The basis of the four-principles approach introduced by Tom Beauchamp and James Childress[2] assumes a "common morality," or set of moral standards upon which most reasonable people would agree. Few

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would argue that outright killing of horses for insurance money is unethical ("Thou shalt not kill"), or that it is unacceptable to alter medical records to conceal a chronic soundness problem on a horse being offered for sale ("Thou shalt not lie"). For less black-and-white questions, the four principles of autonomy, beneficence, nonmaleficence, and justice can be applied to help make a decision about the most ethical course of action.

Autonomy

In human medicine, the principle of autonomy protects a patient's right to make decisions regarding their own care. It protects the right of a patient to refuse treatment as well as to make choices regarding diagnostic tests, participation in clinical trials, and therapeutic options offered by physicians and caregivers.

Rights related to patient autonomy are protected by protocols involving informed consent and documents such as advanced directives. If a patient is determined to be incompetent to make decisions on their own behalf (including infants, very young children, or patients with conditions such as dementia or a state of unconsciousness), a surrogate such as a parent or spouse is recognized. A surrogate is expected to make decisions on behalf of the patient first using a "substituted judgment" standard; the surrogate chooses options based on what they believe the patient would have wanted, even if that option may not be what the surrogate would prefer. For example, using a substituted judgment standard, an adult child might opt to forego ventilator support for a parent at the end of life based on that parent's previously stated desires, even if the child is reluctant to make that decision knowing it may hasten the death of their parent.

When a substituted judgment standard is not possible due to lack of knowledge of what the patient would have wanted, as is often the case with infants or severely mentally disabled patients, the "best-interest" standard is applied. Using the best-interest standard, the surrogate is expected to make decisions based on what they believe would be best for the patient. For example, discontinuing futile treatment for a severely impaired newborn.

In veterinary medicine, respect for autonomy becomes more complicated to navigate. Patients are incapable of making any decisions on their own behalf, requiring that the practitioner immediately skip ahead to surrogate decision making. Not only that, it is impossible for a surrogate to apply a substituted judgment standard as there is no way of knowing what the horse's preferences would be. In all cases, the principle of autonomy in veterinary medicine depends on a surrogate making health care decisions based on the best-interest standard.

The next question one must ask is "who is the appropriate surrogate?" In equine practice, the medical decision making often falls to the trainer. Trainers of athletic horses are expected to produce winning results. Owners hope to win prize money, see the value of an investment horse increase, and proudly watch their children earn accolades in the show ring. Faced with these expectations, trainers commonly feel the pressure to get a horse "back to the ring," which can represent a conflict of interest when faced with soundness or health issues that threaten that possibility. Unless owners question the medication charges on their training bill or communicate directly with the veterinarian, they are often kept in the dark about their horse's health. This situation begs the question of whether owners would be more appropriate surrogates than trainers. Would owners be more inclined to make health care decisions for their horses based on the best interest standard if they were fully informed of the potential positive and negative consequences of those decisions?

Beneficence and Nonmaleficence

The next two principles outlined by the four-principles method are beneficence ("do good") and nonmaleficence ("do no harm"). These two principles are often considered together, as making an ethical decision often requires balancing them against one another. The goal is to determine whether the benefits of a chosen course of action outweigh the negatives. Cases in human medicine commonly test these principles when questioning whether treatment that prolongs life in the face of pain and suffering should be pursued. Simple examples in equine practice would include making difficult decisions regarding euthanasia (does the positive effect of relieving suffering outweigh the negative of ending life?), or whether to pursue treatments such as colic surgery (does the positive outcome of saving the horse's life outweigh the negative impacts of prolonged recovery, including financial burdens to the owner?). The answers to these questions typically require consideration of a number of mitigating factors including age and overall health of the horse, prognosis, and the owner's personal situation.

Justice

Finally, the principle of justice tells us that all patients deserve equal treatment and addresses widespread challenges in health care disparities among different populations in human medicine. Racially driven health care disparities and availability of health care in impoverished areas are examples of problems where the principle of justice is applied in the human medical world.

The principle of justice can be adapted to veterinary medicine when considering what treatment options are offered to different categories of patients. Is referral offered to every patient that has the potential to benefit from specialist expertise? Or should patients be chosen for more advanced diagnostics based on their perceived value? Efforts such as the Equitarian Initiative to improve health care for working equids in third-world countries are another example where the principle of justice is applied in veterinary medicine.

Case Examples

The Black-and-White

At the 2019 AAEP ethics session, a case was discussed where a trainer in a large barn requested that a Dr. X, a young veterinarian newly employed by a large practice, dispense antibiotics to a new horse with a nasal discharge that had never been seen by the veterinarian or the practice. The trainer, a long-term client and large source of income to the practice, claimed that Dr. Y, the practice owner, "does this all the time," and was resistant to Dr. X's request to perform an examination on the patient. Dr. X felt torn between pleasing the trainer and meeting the expectations of her new boss, and insisting on performing the examination before dispensing the requested medication.

The appropriate course of action in this case is clearly supported simply by adhering to the AVMA's Principles of Veterinary Medical Ethics, which clearly states, "A veterinarian shall provide competent veterinary medical clinical care under the terms of a veterinarian-client-patient relationship (VCPR)."[3] Particularly in light of current concerns regarding antibiotic stewardship, Dr. X would be making the most ethical decision by refusing to dispense the medications. One would hope that Dr. Y would support this decision.

The Gray

Case #1. A mid-level junior hunter presents with an acute right front lameness 2 weeks prior to an important competition. The horse flexes off with distal flexion of the limb, and the trainer requests that Dr. X perform a coffin-joint injection in an effort to restore the horse to soundness prior to the competition. The trainer at this large competition barn typically makes all of the medical decisions on behalf of the horse owners. Dr. X agrees that a coffin-joint injection will most likely help relieve symptoms, but has concerns that there could be a soft-tissue injury in the foot underlying the lameness. Dr. X recommends radiographs and possibly magnetic resonance imaging (MRI) to rule-out a soft-tissue injury prior to providing treatment. The trainer refuses further diagnostics.

As outlined previously, under the principle of autonomy, the first question in this case should be who is the appropriate surrogate, and are the decisions being made in the best interest of the horse? If the owner of the horse were made aware of the potential risks of treating the horse and proceeding to the competition, would they choose to take the diagnostic steps recommended by the veterinarian? The veterinarian could address this question by speaking directly to the owner of the horse regarding exam findings and recommendations rather than relying on communication with the trainer.

When balancing the principles of beneficence and nonmaleficence, does the benefit of treating the joint, relieving pain, and allowing the horse to go to the show outweigh the risk that a career-ending injury could result if an underlying soft-tissue injury is present but unidentified? If the veterinarian determines that the risk of a more serious injury is significant, this would help justify a decision to refuse treatment without the benefit of further diagnostics.

Finally, under the principle of justice, if this horse were a young Grand Prix jumper with potential for international success instead of an older junior hunter, would the decision change? The veterinarian should take care to offer the same level of care for every horse.

Case #2. An older amateur dressage horse has had 3 colic episodes during the past month. All have been uncomplicated and resolved with a single dose of flunixin meglumine administered by the trainer, who communicated with the veterinarian over the phone. After the third episode, the trainer requests that the veterinarian prescribe an omeprazole/ranitidine powder from a compounding pharmacy that the trainer believes he has had good luck with in "ulcery horses." The veterinarian suggests that gastroscopy would be the best next step in order to make a definitive diagnosis, and that treatment recommendations would depend on the results. Furthermore, the veterinarian informs the trainer that compounded omeprazole/ranitidine products are not reliably effective for treating ulcers. The trainer refuses the gastroscopy and persists in demanding the prescription.

Once again, the first question in this case is whether the trainer is the appropriate surrogate decision maker for this horse. If informed about the value of gastroscopy for making a diagnosis and distinguishing between squamous and glandular ulcers for the purposes of determining the best course of treatment, the owner of the horse might make a different decision. In addition, the owner, who will be financially responsible for the medications, should have the option of choosing whether to treat the horse with an effective medication that may be more expensive in place of the unreliable product requested by the trainer. The veterinarian should communicate directly with the owner rather than relying on the decisions of the trainer.

What happens if the owner is involved in the decision-making process and aligns with the trainer's request for compounded omeprazole/ranitidine without gastroscopy? Adherence to the principle of nonmaleficence would guide the veterinarian to refuse this prescription request, as treating with an ineffective medication could cause harm to the horse. This should outweigh the benefit of making the trainer and owner happy.

Finally, the request for a less effective medication because of cost raises the question of justice. Would the owner or trainer of a successful international Grand Prix horse choose to treat that horse differently?

Case #3. A middle-aged pony hunter is reported to be drinking and urinating more than normal. Routine lab work indicates that the pony has renal insufficiency. The pony competes heavily, and the barn program includes administration of phenylbutazone every night during competitions for every horse. Veterinarians dispense medications to trainers in bulk, and owners see only a "medication" charge on their monthly bills.

Could this situation have been averted if the owner had been acting as the surrogate decision maker for the pony instead of the trainer? If the owner were aware that the pony was being administered medications on a regular basis, and that those medications could have adverse side effects such as renal damage, would they have opted to continue daily administration? Alternatively, would they have sought out other ways to manage the pony's long-term soundness such as pursuit of diagnostics that might have led to targeted treatments? Veterinarians should take care to establish relationships and communicate with horse owners directly regarding routine care decisions.

In terms of benevolence vs nonmaleficence, should the veterinarian continue to support the trainer's routine administration of non-steroidal anti-inflammatory drugs (NSAIDs) by dispensing large quantities of medications? Does the benefit of providing pain relief to older campaigners and keeping trainers happy outweigh the risk of doing harm to a horse that might suffer serious side effects or that would be better served with diagnostics? The veterinarian can adhere to the principle of nonmaleficence by dispensing medications only to specific horses based on those horse's individual circumstances.

Finally, considering justice, how does the practice of routine administration of medications to national level competition horses compare with the medication controls in place for horses competing internationally? Should international-level competition horses be treated differently?

3. Conclusion

Equine veterinarians face ethical dilemmas every day. Some are easy to recognize and answer, others are much less clear. Everyday issues that may not even be identified as problems can raise ethical questions, and society is watching the equine industry. The time is now to begin developing methods and formalizing education in ethics for veterinarians. This can begin by looking at the different theories and methods that have been established for decades in the field of human bioethics.

Acknowledgments

Declaration of Ethics

The Author has adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Author has no conflicts of interest.

References and Footnote

1. Solis S. Ringling Bros. circus to close after 146 years. January 14, 2017. Available from: USAToday.com. Accessed February 16, 2020.
2. Beauchamp TL, Childress, JF. *Principles of biomedical ethics*. 8th ed. New York, NY: Oxford University Press; 2019, 3–5.
3. Principles of veterinary medical ethics of the AVMA. Available from: avma.org. Accessed March 8, 2020.

[a]Morgan, Kenton (personal communication) 2020.

Use of the Net Promoter Score Survey to Improve Business Growth, Profitability, and Client Loyalty

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1. Introduction

In any business, loyal clients are everyone's favorite clients. They share many characteristics: they buy more, they are easier to work with, they pay their bills on time, and they tend to refer new clients. Having more loyal clients, stands to reason that businesses would grow and be more profitable. Not only do loyal clients spend more but they also refer more new clients, which reduces the cost to get new clients. Studies show that clients with high levels of customer loyalty increase sales more than 2.5 times others in comparable industries and have 2 to 5 times more profitability over a 10-year period[a]. The problem is how can the loyalty of clients be measured? Veterinary practices tend to send surveys to their clients that are focused on customer satisfaction, the quality of service they received, and the cleanliness of their facility. These surveys give results that are not quantifiable. The answers are either descriptive or vague. It is nice to know that a facility is clean, and the receptionist greeted clients warmly, but there is nothing measurable that practice owners and managers can use to improve the business or give them a score of how loyal their clients are.

There is a broadly used client survey called the Net Promoter Score (NPS)[b]. It is a system used to measure client loyalty by the majority of Fortune 500 companies, including Costco, Apple, Amazon, and Enterprise[c]. The latter value the score so much that they use it as the basis for bonuses and promotions at each rental car location.

Solution

The basic premise of the NPS is that only one question needs to be asked to determine client loyalty—how likely is it that one would recommend a company/product/service to a friend or colleague? A recommendation to a friend or a colleague is the highest form of support for a company because their reputation is on the line. Nobody would recommend a terrible company to a friend or family member. This is why online reviews are so popular. When planning a vacation, it is wise to scour online travel sites to evaluate the best restaurants or attractions at the destination. Imagine buying something on Amazon without reading a review of the product first.

The NPS is measured from 0 to 10, with 0 suggesting "not very likely" and 10 indicating that someone is "very likely" to recommend the company.

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On this scale, there are three categories of results: Promoters score a 9 or 10 and exhibit all of the positive behaviors of a very loyal client. Passives give a score of 7 or 8 and are on the fence. They like the company a lot but are open to other opportunities. Detractors score from 0 to 6 and, depending on how low a score they give, are actively looking to use another company. These are the people that will bad mouth businesses, argue over prices, or do the minimal required for their pets. The NPS is determined by subtracting the percentage of responses that are detractors from the those that are promoters. This means scores can range from −100 to 100.

2. Results

The author's 3-location practice has been consistently sending the survey via an online survey platform to clients on a monthly basis for the past 2 years and intermittently for the previous 10 years. In 2018, practice A had a score of 84%, and practices B and C shared a score of 73%. In 2019, practice A increased their score to 85%, practice B rose to 80%, and Practice C increased their score by 1% to 74%.

A couple of open-ended questions asking why someone scored 9 or above and why someone scored 6 or below were added. For those offering a low score they were asked if they would supply their name and contact information so the practice could discuss where it had failed.

Some of the typical comments that were received are listed below.

Positive

- Peace of mind knowing best possible diagnosis, prognosis, and treatment will be offered.
- Very good at communicating with clients so they can make informed decisions.
- Have the best interest in the horse and client.
- Knowledgeable, on time, and reliable.
- Great service from vets, techs, and office staff.
- Availability of great equipment to be able to diagnose the problem right away.
- Explains everything very well, from procedure to next steps.
- Excellent care and follow up.

Areas for Improvement

- Cost.
- If a new vet examines a horse, they should know the history and not ask the client for it.
- Send out invoices quicker.
- Saturday or weekend appointments.
- Easy access to the same vet.
- Reminders on when vaccinations are due and follow up when booster or other follow ups are due or recommended.
- Better quoting.
- Finally, a 33% response rate was typically received, far higher than the 10% of previous client satisfaction surveys.

3. Discussion

The survey was first used during the Great Recession, and the high scores were very comforting during that scary time. Positive results provided confidence that the practice's clients were very loyal and would not flee for cheaper alternatives at the first opportunity. This high level of loyalty confirmed another benefit discussed by the authors of the original study on the NPS survey: good profits. They concluded that profits in a company that has a high NPS score are sustainable and will not easily shrink in the face of new competitors or an economic downturn.

The comments were valuable because of the specific reasons people gave for their score. Trends were identified within a practice and between the practices on areas where performance was good and needed improvement. For example, comments over a couple of months identified that quoting for services needed to be improved. The author's practice was able to take immediate action to resolve that shortcoming and were rewarded with an absence of comments on the subject in successive surveys.

There are challenges using the NPS survey in that sending the survey to every person that uses the practice could become annoying because some clients have frequent visits. So it's better to filter client visits and only send the survey every 6 months to frequent clients. Getting client visit information is not easy with all practice management software programs, so it may be easier to find someone who is very comfortable using spreadsheets to modify this information to send the survey in an appropriate manner.

There is also not an industry standard for the NPS for practices to use for benchmarking purposes. Until a standard is established, practices should use the survey to compare against themselves.

Using the NPS has given the author's practice a consistent quantifiable tool to appreciate the level of client loyalty. Over some months, the numbers have gone down at times, which serves as a wake up call from complacency to look at why the score was declining. The practice was able to look at the comments and make adjustments.

Loyal clients help keep businesses growing and profitable. The NPS is a tool validated by numerous companies in many surveys and is easily applicable to veterinary practices. Having a simple tool that uses one question is invaluable to help veterinarian practice owners and managers understand their level of client loyalty, which can make a huge difference on the financial health of a practice and help understand what needs to be done to continue strong growth.

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Mike Pownall is a partner in McKee-Pownall Equine Services and is also a partner of Oculus Insights LLP that provides the Net Promoter Score Survey as a service to their clients.

Declaration of Ethics

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Conflict of Interest

The Author has no conflicts of interest.

Footnotes

[a]https://hbr.org/2020/01/the-loyalty-economy.
[b]https://hbr.org/2003/12/the-one-number-you-need-to-grow.
[c]https://www.jrni.com/blog/3-companies-using-nps.

Review of Equine Hospital Design Techniques for Controlling Infectious Disease

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Hospital design is a key component of effective infection control prevention and biosecurity plans. Understanding the ways diseases spread must be part of the hospital planning. Veterinarians should collaborate with architects to design hospitals that are functional and effective in reducing the chances for hospital infections. Authors' addresses: 306 Blue Spruce Court, Versailles, KY 40383 (Pantaleon); 4520 Broadway, Boulder, CO 80304 (Lewis); e-mails: lucaspantaleon@gmail.com; heather@animalarts.com.

1. Introduction

Infectious pathogens are a serious threat to humans and animals. In human medicine, the improvements in medicine, public health, and social standards have led to a paradoxical increase in exposure and susceptibility to pathogens.[1] In veterinary medicine, increased knowledge and specialization has allowed veterinarians to improve the way animals are treated and cared for at equine hospitals. However, hospitalized horses are at a higher risk of being infected by a healthcare-associated infection. Thus, preventing infectious diseases must be a key component for providing the highest quality of care to hospitalized horses. Protecting the care team from acquiring zoonotic diseases is also of paramount importance when developing and implementing a disease-prevention plan.

To implement effective measures for controlling the spread of disease, one must understand modes of transmission.[2] This paper concentrates on 3 modes of disease transmission in equine veterinary facilities: fomite, oral, and aerosol. The paper also covers the basics of cleaning and disinfection. Linking hospital design with ways to minimize disease transmission creates a safer environment for patients and allows practices to more easily manage biological risk and reinforce their infection control, prevention, and biosecurity (ICPB) protocols.

This review paper presumes correlation between built environments for humans, companion animals, and equids because classes of pathogens and infection control protocols share many commonalities between species. It is accepted that there are also some critical differences between equine facilities and those for other animals, including but not limited to, acceptable methods for cleaning, readily available materials and finishes, and unique operational requirements.

2. Fomite Transmission

Fomites are inanimate objects (i.e., twitches, diagnostic equipment, shoes, etc.) that if contaminated

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and in contact with a susceptible host, are capable of spreading disease. A common pathogen transmitted via contaminated fomites is *Salmonella* spp.[2] Fomite transmission is an important area of focus because it involves many design and operational choices.

Hand Hygiene

Every major healthcare agency, human and animal, as well as myriad human hospital groups such as the Mayo Clinic, emphasize the critical importance of hand hygiene in controlling the spread of infectious disease. Nevertheless, many of the nuanced design decisions regarding hand hygiene are not commonly understood. Below are some of the important concepts for incorporating effective hand hygiene into an equine hospital design:

- *Hand washing.* Hand sanitizers can be used when hand washing is not available. However, alcohol sanitizers are not effective against non-enveloped viruses or bacterial spores.[3] Furthermore, soiled hands will render hand sanitizers ineffective.[4] Proper hand washing with soap and water is the best protocol for hygiene regardless of the circumstance because it removes soil and microorganisms.
- *Paper towels versus hand dryers.* Some businesses choose to put in hand dryers to reduce waste from paper towels. However, paper towels are best for two reasons. First, the mechanical action of drying hands makes them cleaner and drier, and second, hand dryers aerosolize droplets and spray them against adjacent surfaces.[5]
- *Sink placement.* Make hand washing easy. If it is not easy, compliance will be low. Install hand wash sinks with soap dispensers around critical areas. Transmission of diseases becomes more likely if an animal care team member touches one or more door handles in between the area where his or her hands got soiled and the nearest sink.
- *Sink design.* Sink design should be an important part of ICPB design protocols. Use touchless faucets: these are readily available for health care applications and work well for all locations, including surgery scrubbing. Ensure the faucet is directed in a way that allows the sink to contain splashing water. Several human hospital infection outbreaks have been linked to sinks that splash water from the drains, thereby recontaminating hands.[6] As an example of proper design, a scrub sink is often manufactured with a sloping front face, which allows water to hit the interior of the sink at an obtuse angle, directing it safely to the bottom of the basin.

Separate Patients and Patient Care Items Based on Risk

Separating patients based on risk is a common practice for managing potential disease outbreak in a facility. For example, inpatients need to be separated from outpatients. High-risk patients such as mare and foal, ICU patients, or patients with colic should be hospitalized in separate areas. Horses with fever and leukopenia should be hospitalized in isolation.

High-risk patients should have their own grooming, care, feeding, and cleaning items.[7] These items should be stored in individual prep areas that are assigned to individual stalls. In facilities with larger isolation barns, it is not unusual to designate each stall prep area with its own set of cleanable booties that are used by staff for caring for that one particular horse throughout its stay. Provide infrastructure such as wall-mounted hangers to store items off the floor or where they will be out of the way for cleaning.

Design Cleaning Infrastructure with Fomites in Mind

As mentioned above, improperly designed sinks could facilitate disease spread by splashing and contaminating surrounding areas. Hoses can have similar problems. Hoses are commonly dragged across the floors in the hospital. In this way, a hose could become a highly contaminated fomite, allowing for disease dissemination across the hospital. Below are some design considerations that reduce this problem:

- For high-risk patients, provide a hose bib in each individual patient prep area. Hang the hose on the wall above each hose bib. This way, each hose bib and hose are separated between patients, just as are all other patient care items.
- For common-use areas such as corridors, provide one of the following:
  —Ceiling or high wall–mounted hose reel to minimize the hose dragging on the floor, and to allow the hose to be stored off the floor when not in use.
  —Some animal care facilities are plumbed with integral cleaning systems that feature both remote power and remote disinfectant injection. Hoses are plugged into remote outlets. In addition to reducing the dragging of hoses, integral cleaning systems can be adjusted to various chemical dilution ratios to match infection risk. While they may seem to be ideal, cleaning systems require maintenance, are very expensive compared with standard hose reels, and they must be designed to be compatible with the disinfectant to be used. For example, cleaning systems utilizing accelerated hydrogen peroxide require stainless steel or cross-linked polyethylene (PEX) piping with stainless steel fittings for corrosion resistance.

3. Oral Transmission

Oral transmission involves the ingestion of pathogens from contaminated food, water, or licking surfaces. The contamination of the environment with exudates, feces, urine, or saliva containing an infectious dose of a pathogen can infect susceptible hosts. *Salmonella* spp. and *Clostridium* spp. are examples of orally transmitted diseases.[2]

Oral transmission prevention follows similar guidelines as for fomite transmission, but in addition, special attention is paid to the quality of materials and finishes within the environment, cleaning systems, and manure disposal.

Nonporous Materials and Systems

It is more difficult to design and construct nonporous materials and surfaces than it might seem to be. Numerous disease outbreaks have been correlated with environments that are either improperly cleaned or are impossible to clean. For example, *Salmonella* spp. can persist on surfaces for long periods and is a notorious cause of nosocomial infections in equine hospitals.[8] The following materials are acceptable depending on the circumstance:

- Seamless flooring.
  —For low-cost installations in lower-risk spaces such as healthy horse treatment rooms in smaller hospitals, rubber mats may be installed if they are manufactured from virgin rubber (as opposed to recycled rubber which is porous), are thoroughly adhered to each other with a high-performance, flexible joint sealant, and are sealed to the slab below. Loose rubber mats are unacceptable because they can trap moisture and encourage biofilms to form.
  —For highest-quality flooring installations, utilize poured equine floors. These are manufactured from recycled rubber (which is porous) and then sealed with polyurethane binders. Because the installation of a poured floor depends on many factors from the condition and preparation of the underlying slab to the skill of the installation crew, specific manufacturers are not listed here. Nevertheless, it is important to specify products from the most reputable companies for the equine market. The benefits of properly installed poured floors include the following:
- A longer-lasting solution.
- A complete seal from wall to wall, and around drains.
- The ability to provide a seamless joint between the floor and wall.
  —The most sanitary design for the joint between the floor and wall is a cove (rounded) profile, with the flooring continuing onto the wall surface several inches.[9]

Industrial Coatings for Walls

Most equine facility medical areas are constructed of concrete block and sealed with various coatings, most of which are ineffective and require frequent recoating. Anecdotal evidence suggests that the best long-term option is a cementitious block filler that fills the concrete pores, followed by two coats of an industrial marine coating developed to coat metal ships at sea. A system like this can remain intact on the walls over the lifetime of an equine hospital facility and decrease the chance for infectious disease to remain in the environment, because the pores in the wall are sealed, leaving an easy-to-clean-and-disinfect surface.

Match the Materials with the Cleaning Protocol

One of the problems that facilities have is that installed materials degrade over time in the presence of water and disinfectants. Degraded materials are more likely to become porous and allow biofilms to form.[9] Be aware of the effect of the cleaning and disinfection protocols on materials and select materials that can withstand them. Below are some principles to consider:

- Cleaners and disinfectants should always be diluted properly. Using more disinfectant than necessary is not only expensive, it is ineffective. Many surfaces repopulate themselves with pre-cleaning microbial colonies within a few hours of cleaning, regardless of the vigor of the cleaning efforts.[9]
- Bleach degrades all finishes but especially steel. Exposed steel should ideally be galvanized and painted with a high-performance coating such as a urethane. Fiberglass man doors hold up better than their steel counterparts.
- Accelerated hydrogen peroxide has less effect on materials, but if not properly diluted, it degrades some lower-quality metals, as well as concrete and epoxy coatings. If the hospital plans to use poured epoxy floors for the cleanable areas where horses are anesthetized and are therefore not standing on the floors (an example is surgery), then specify a urethane-based, poured-floor coating instead, which withstands peroxide-based cleaning agents.
- Utilize moisture-resistant cabinetry in wet/dry zones such as medical barn nursing stations or in treatment rooms. Suitable products include stainless steel or powder-coated metal casework and plastic medical casework made by companies such as Midmark.

Manure Management

Control of oral transmission requires design for careful manure handling. The hospital should have a designated, restricted area for containment of contaminated manure. The path to this contaminated manure storage should be disconnected from primary healthy horse circulation paths. Place the containment dumpster downwind of all facilities. Plan traffic flow so that the containment dumpster is the last to be picked up with the trash service.

4. Aerosol Transmission

Aerosolized particles can be inhaled, deposited on mucus membranes or contaminate surfaces. Pathogens transmitted via this route include influenza or equine herpesvirus-1.[2] Methods for management of these diseases include physical isolation and careful air system design. Note that diseases that spread via aerosolized particles also spread via other means such as fomite transmission, and so all previously discussed practices apply.

Isolation Barns

Infectious disease can spread via fomites or aerosol over long distances. For example, equine influenza virus spreads effectively as an aerosol over distances up to 50 yards.[10] Isolation facilities for horses should be placed at a distance from other buildings on the site. While recommendations vary, a minimum of 60 feet is a useful guideline to minimize spreading of infectious diseases. Controlling the spread of diseases via aerosols within the isolation building requires several steps, including the following:

- Providing a solid barrier between patients and between patients and the human access areas. Windows are acceptable for looking into stalls but maintain a solid front on the stalls.
- Providing direct exhaust for each equine isolation stall. This ensures separated ventilation and negative pressure. The largest hospitals go to great lengths to ensure that ventilation systems are highly cleanable so they may be regularly purged of reservoirs of microbes.
- Differentially pressurize the isolation stalls, which should be negative, to the surrounding spaces, which should act as buffers, to prevent air from isolated patients from flooding into the surrounding areas.
- Consider properly designed air treatment systems within the isolation facility. These systems are not intended to replace proper air handling and exhaust systems, but to treat air that is in the surrounding partial-recirculated zones, such as nursing stations. The most effective systems utilize a combination of filtration and ultraviolet (UV) light and can be effective in eliminating 90% or more of aerosolized viruses and bacteria in laboratory conditions.[a]

Methods for Ventilating Hospitals Outside of the Isolation Zone

Equine hospitals tend to be less rigorously conditioned and ventilated than their small-animal hospital counterparts. Some ideas, however, should always be implemented to reduce the risk of aerosol transmission and for basic healthy indoor air:

- Surgery rooms should be positively pressurized and highly filtered. MERV 13 filters provide 80% to 90% filtration, which contains and controls droplet nuclei. If using a filter like this, ensure the engineer who is designing the HVAC system is accounting for the pressure drop across the filter. HEPA filters are unnecessary for most hospitals, except ones with very heavy orthopedic caseloads.
- Ventilate conditioned medical areas at least to 8 to10 air changes per hour and 40% to 60% outside air. Medical barns can be vented at four to six air changes per hour and may not need to condition the air except in very hot or cold weather.
- Control and reduce humidity. Humidity has a tremendous impact on the growth of microorganisms in the built environment. Humidity should not exceed 60%, which is the level past which American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) deems the growth of molds on surfaces to be inevitable.[9]

5. Cleaning and Disinfection

Cleaning is defined as the removal of visible soil (e.g., organic and inorganic material) from objects and surfaces. Normally it is accomplished manually or mechanically using water with detergents or enzymatic products. Thorough cleaning is essential before disinfection because inorganic and organic materials that remain on the surfaces interfere with the effectiveness of these processes.[11] Cleaning is a very important step that assures the removal of organic and inorganic materials from surfaces and devices, hence allowing for maximal disinfection efficacy.[11] The microbicidal efficacy of disinfectants is inversely proportional to the degree of soiling on the targeted surface.[12] It has been shown that experimentally, cleaning can eliminate approximately 90% of bacteria on concrete surfaces, hence the importance of physically removing pathogens from surfaces prior to disinfection.[13]

Disinfection describes a process that eliminates many or all pathogenic microorganisms, except spores, on inanimate objects.[11] Objects and surfaces are normally disinfected with liquid chemicals.[11] There are several factors that affect the efficacy of disinfectants such as prior cleaning, organic and inorganic load, type and level of microbial contamination, concentration and contact time of the disinfectant, physical nature of the object, presence of biofilm, and temperature and pH of the disinfection process.[11]

It is well established that environmental contamination leads to hospital-associated infections. Therefore, implementing a well-designed disinfection protocol reduces the risk of acquiring pathogens from environmental surfaces.[14,15] A recent study demonstrated that the daily use of a cleaner disinfectant wipe on all patient areas produced a significant reduction in methicillin-resistant *Staphylococcus aureus* (MRSA), vancomycin-resistant Enterococci (VRE), and Clostridium difficile (*C. diff.*) hospital-acquired infections when housekeeping compliance was at least 80% or greater.[16] This example illustrates that education, training, and feedback can help improve results and provide a more successful infection-control plan.

Veterinarians and animal caregivers need to understand the role that disinfectants play when developing an ICPB plan. Disinfectants should not just be selected based on cost or tradition, but on safety and efficacy, since the use of the wrong formulation for an inappropriate contact time generates a false sense of security, which in turn risks the spread of pathogenic organisms over a wider area during the disinfection process. Therefore, regardless of all other design considerations and operational protocols, the hospital must use disinfectants properly and clean effectively to maintain a safe environment for horses and humans.

6. Discussion

The following are the four key factors that influence how disease spreads in a hospital:

- *The patient population.* The colonized or infected patient plays a key part in contamination of environmental surfaces and fomites.
- *The operations.* If personnel are not following ICPB practices such as maintaining hand hygiene and footwear cleanliness, these problems can aid with the dissemination of environmental pathogens.
- *The design.* Poor hospital design, such as lack of stall drains or porous stall walls, make the implementation of ICPB protocols such as cleaning and disinfection unrealistic or cumbersome, hence decreasing the chance for team adoption and success.
- *Cleaning and disinfection.* Proper cleaning and disinfection as a key part of an ICPB protocol.

Maintaining a comfortable, clean, and disinfected environment is critical for the health and welfare of patients visiting the veterinary hospital, as well as for the animal care team's safety and wellbeing. A hospital that looks sanitary and smells clean also reflects well on the practice and fosters a professional impression for clients.

In veterinary hospitals, nosocomial infections have a negative impact on patient outcomes and client experience. Infectious disease outbreaks have a negative effect for hospital operations by negatively affecting revenue, client confidence, public image, and staff morale.[17] Therefore, the goals of properly implemented ICPB protocols are to reduce infection rates, morbidity and mortality, to improve personnel safety, and to reduce costs. A properly designed hospital makes achieving these goals easier.

In a recent consensus statement, it was concluded that veterinarians and managers need to be aware that there is a recognizable standard of care with regard to infection control, meaning that measures geared toward minimizing the spread of contagious infectious diseases and education must be part of the care provided by veterinarians to their patients and clients. Not meeting these standards constitutes malpractice and represents a failure to meet the ethical responsibilities to patients and clients.[18,19]

Acknowledgments

Declaration of Ethics

The Authors have adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

Dr. Pantaleon is an advisor for Ogena Solutions, a biosecurity company. Ogena Solutions commercializes Accelerate Hydrogen Peroxide disinfectants in Canada. He has served as an advisor for Virox Animal Health, a manufacturer of Accelerated Hydrogen Peroxide disinfectants. Ms. Lewis is a principal of Animal Arts, an architecture firm that designs animal hospital facilities.

References and Footnote

1. Sattar SA. Allen Denver Russell memorial lecture, 2006. The use of microbicides in infection control: A critical look at safety, testing and applications. *J Applied Microbiol* 2006; 101:743–753.
2. Stull J, Bjorvk E, Bud J, et al. 2018 AAHA infection control, prevention, and biosecurity guidelines. *J Am Anim Hosp Assoc* 2018;54:1–30.
3. Gold NA, Mirza TM, Avva U. Alcohol sanitizer. Treasure Island, FL: StatPearls Publishing; 2020.
4. Rappaport L. Hand washing beats sanitizer for killing flu virus on hands. *Rueters*, Sept 29, 2019.
5. Huang C, Ma W, Stack S. The hygienic efficacy of different hand-drying methods: A review of the evidence. *Mayo Clinic Proc* 2012:878:791–798.
6. Snitkin ES. Contamination of hospital plumbing: A source or a sink for antibiotic-resistant organisms. *J Am Vet Med Assoc Netw Open* 2019;2:e187660.
7. Corley K, Stephan J, eds. *The equine hospital manual*. Oxford, UK; Ames, IA. Blackwell Publishing; 2008, 193.
8. Slovis N. Biosecurity on horse farms. In: Sprayberry KA, Robinson NE, eds. *Robinson's current therapy in equine medicine*. Elsevier, 2009.
9. Sehulster LM, Chinn RYW, Arduino MJ, et al. Guidelines for environmental infection control in health-care facilities. Recommendations from CDC and the Healthcare Infection Control Practices Advisory Committee (HICPAC). Chicago IL; American Society for Healthcare Engineering/American Hospital Association; 2004, Updated 2019.
10. Biosecurity Guidelines. 2017. Available from: https://aaep.org/sites/default/files/Guidelines/BiosecurityGuidelinesFinal1.pdf.
11. Rutala WA, Weber DJ. Guideline for disinfection and sterilization in healthcare facilities. 2008. Available from:

http://www.cdc.gov/hicpac/pdf/guidelines/disinfection_nov_2008.pdf.
12. Sattar SA. Promises and pitfalls of recent advances in chemical means of preventing the spread of nosocomial infections by environmental surfaces. *Am J Infect Control* 2010;38:S34–S40.
13. Dwyer RM. Environmental disinfection to control equine infectious diseases. *Vet Clin North Am Equine Pract* 2004;20:531–542.
14. Rutala WA. Does improving surface cleaning and disinfection reduce HAI? In: Rutala WA, ed. Webber Training Teleclass; 2012.
15. Donskey CJ. Does improving surface cleaning and disinfection reduce health care-associated infections? *Am J Infect Control* 2013;41:S12–S19.
16. Alfa MJ, Lo E, Olson N, et al. Use of a daily disinfectant cleaner instead of a daily cleaner reduced hospital-acquired infection rates. *Am J Infect Control* 2015;43:141–146.
17. Morley PS. Biosecurity of veterinary practices. The Veterinary clinics of North America Food animal practice 2002;18:133–155, vii.
18. Morley PS. Evidence-based infection control in clinical practice: If you buy clothes for the emperor, will he wear them? *Vet Clin North Am Food Anim Pract* 2013;27:430–438.
19. Morley PS, Anderson ME, Burgess BA, et al. Report of the third Havemeyer workshop on infection control in equine populations. *Equine Vet J* 2013;45:131–136.

[a]RxAir.com, a healthcare air purifying technology company.

Neurologic Examination in the Foal

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The neurologic examination of the foal can be easily performed concurrently with the physical examination and provides a more comprehensive assessment of the overall clinical status. The evaluation should include an assessment of behavior, state of consciousness, cranial nerves, posture and postural reactions, segmental (spinal) reflexes, palpation, and gait evaluation. The examiner requires their vision (observation essential!), touch (palpation), and listening. In order to identify abnormalities, it is essential to become familiar with what constitutes normal for the neonatal and developing foal. Author's address: University of California-Davis, School of Veterinary Medicine, Department of Medicine and Epidemiology, Tupper Hall 2108, One Shields Avenue, Davis, CA 95616; e-mail: mraleman@ucdavis.edu.

1. Introduction

There are important evolutionary differences between prey and predator animals.[1] Horses as a precocious species are born with a more developed brain and fully functional vision and hearing than altricious species, such as humans. Although brain development continues after birth, the cerebellar layers in prey animals, such as the neonatal foal, are already distinct histologically at birth compared to predators' brains.[1] However, cerebellar cell migration continues to occur in the neonatal period (Fig. 1). Cerebellar development and myelination in various parts of the nervous system explain the "bouncy" gait typical of neonatal foals. This bouncy gait becomes less apparent as the foal matures. Neonatal foals are not just little adult horses, and major physiological and neurological differences exist compared to older foals and adult horses.[2–5] Therefore, recognition of what is normal according to age is essential. Alertness, response to the environment, and movement are different in utero, during birth, and in extra-uterine life. Foals respond and move in utero but not to the extent that is seen in extra uterine life. In the birth canal, foals are in a drowsy state and become minimally responsive and movement is depressed. During the first few hours of extra uterine life, important milestones must occur for successful functioning and survival of the neonatal foal. This rapid transition is remarkable (Fig. 2). As prey animals, horses must develop a menace response relatively quickly after birth (within 7 to 10 days) compared to predators (several weeks).

Many neonatal diseases present with similar clinical signs, such as lethargy, recumbence, weakness, and reduced or lack of suckle reflex, among others. These signs could be caused by systemic or neurologic disease, or both. Therefore, a complete thorough history must be obtained, followed by a comprehensive physical examination to determine overall health status. Do not forget signalment (breed, sex, and age) because there are disorders that can be seen in specific breeds. A few examples include juvenile epilepsy and lavender foal syndrome in Egyptian Arabian foals. These two disorders are phenotypically and genotypically different.

NOTES

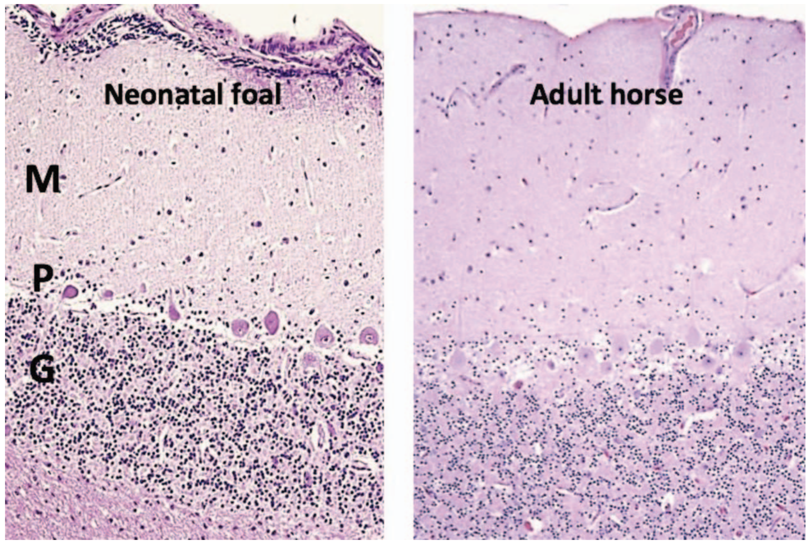

Fig. 1. Cerebellum. Note the 3 layers of the cerebellum (molecular [M], purkinje [P], and granular [G]) organized in the neonatal foal are similar to the adult cerebellar layers. Cell migration and organization continue in the neonatal period.

The principles on how to perform the neurologic examination are the same across species. The neurologic examination in foals can be done concurrently with the physical examination. Neurologic assessment must include the evaluation of behavior, state of consciousness, cranial nerves, posture and postural reactions, segmental (spinal) reflexes, palpation, and gait evaluation. The tools required for the examination are vision (lots of observation), touch (palpation), and listening. The main goal of the neurologic examination is to determine if the foal is normal or abnormal. The second goal of the examination is to determine the anatomical location of the deficits within the nervous system and, finally, to consider possible causes of disease. It is critical to rule out other disorders that might present with similar signs, especially in the neonatal foal (e.g., obtundation, dysphagia, and recumbency weakness).

Fig. 2. Note this 32-hour-old Quarter Horse colt during movement following his mother (not shown), fully functional and coordinated.

2. Neurologic Examination in Neonatal Foals

The most important component in performing the neurologic examination in foals is the practitioner's senses for observation, listening, and palpation; then, a light source to examine the eyes (dazzle reflex [subcortical reflex to bright light] and pupillary light reflexes) and ears; and needle holders, forceps, or a pleximeter to check for segmental (spinal) reflexes. Know what is normal and do more than one examination. Once more, observation is paramount. The neurologic status of the normal neonatal foal goes through a transition from in utero to extra utero life. The APGAR (appearance, pulse, grimace, activity, respiration) score developed for the assessment of neonates in the post-foaling period (1 minute post-foaling) consists of the following variables:

1. Heart rate (normal: regular, ≥60 beats per minute [abnormal if undetectable, irregular, or <60 bpm]).
2. Respiration (normal: regular, ≥60 respirations per minute [abnormal if undetectable, irregular, or <60 rpm]).
3. Mucous membranes (normal: pink; abnormal if blue, bright red, or yellow).
4. Muscle tone (normal: strong enough to be in sternal recumbency).
5. Responsiveness.
   A. Nasal stimulation (expected response: strong grimace, sneeze).
   B. Ear tickle (expected response: head shake).
   C. Back scratch (expected response: attempts to stand).

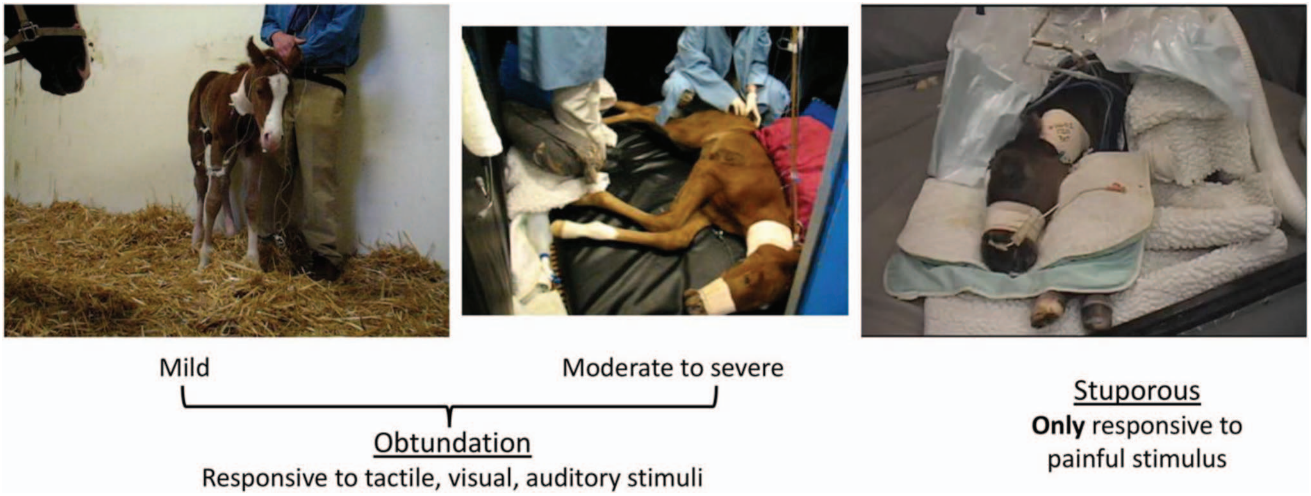

Fig. 3. States of consciousness (brainstem): obtundation, stuporous, and comatose.

This evaluation can be repeated at 5 and 15 minutes post-foaling to determine if veterinary intervention is needed. Important milestones include time to sternal recumbency (1–2 minutes), alertness and responsiveness to external (tactile, visual, and auditory) stimuli (within 5 minutes), suckle reflex present (within the first 20 minutes), vocalizing in response to the dam's nickering (within 30 minutes), time to stand (60 minutes [longer than 2 hours is considered abnormal]), and time to nurse (2 hours [longer than 3 hours is abnormal]) post-birth. The author performs neurologic evaluation concurrently with the physical examination in neonatal foals. Similarly, multiple assessments of the neurologic status can be done concurrently with physical examination. The examination consists of evaluating the neurologic status while the foal is at rest (static) and during movement (dynamic) if ambulatory. The examination could be divided in the following:

1. Behavior and mentation
   A. Behavior (examples of deficits):
      a. Aberrant vocalization (e.g., barking or honking sounds).
      b. Walking compulsively.
      c. Lack of mare bonding.
      d. Sleeping behavior while standing. Neonatal foals must lay down to sleep (drowsy to slow wave sleep and rapid eye movement sleep); this behavior changes as the foal matures.
   B. Mentation (Fig. 3):
      a. Normal, bright, alert, responsive.
      b. Obtunded. This could range from mild to moderate to severe obtundation: from standing quietly to recumbent but responsive to physical stimulus (tactile, auditory, visual). In this state, foals should always respond to non-painful stimulus.
      c. Stuporous. Recumbent, only responsive to profoundly painful stimulus and only while this stimulus is applied.
      d. Comatose. Not responsive at all, including to profoundly painful stimulus.
2. Cranial nerves and responses, reactions, and reflexes.
   A. Afferent, central, and efferent pathways must be intact for proper function.
   B. These can be evaluated individually (I through XII) or grouped into functions (e.g., olfaction [I], vision [II], menace response [II, VII])
3. Posture (head, neck, trunk, limbs, and tail).
4. Postural reactions (i.e., proprioceptive positioning [foot placement]).
5. Segmental (spinal) reflexes.
   A. Cervicofacial
   B. Thoracolaryngeal
   C. Thoracic and pelvic limb reflexes
   D. Anal and perineal
6. Palpation
   A. Muscle asymmetry
   B. Painful areas
7. Gait evaluation
   A. Consider age of foal (bouncy in neonates)
   B. Consider breed for specific gait
8. Nociception
   A. Evaluate for pain perception (conscious perception = cerebrocortical acknowledgment of pain) only in foals with no apparent voluntary movement.
   B. Reflexive movement while applying a painful stimulus does not equal a conscious response.

The determination of mentation, behavior, and posture can be done as the history is being taken or as the foal is being examined. States of consciousness include bright, alert and responsive, and obtunded,

Fig. 4. Dazzle reflex. Note the foal is blinking as a strong light is applied to the eye.

stuporous, and comatose (Fig. 3). Normal behavior is a bright, alert foal that is responsive to the environment; who has mare attachment; is udder seeking and nursing, curious of the environment; and who sleeps. Head posture in neonatal foals has a “flexed” appearance at the atlanto-occipital joint compared to adults, and their stance is wide-based, which becomes narrower within days of age. The menace response (a learned response) develops at approximately 7–10 days. Foals under 10 days of age are visual but have not learned to blink in response to an approaching or menacing object. However, if a strong light is applied to the eye, the foal is able to blink because this involves a subcortical reflex (dazzle reflex, Fig. 4) already present at birth. Furthermore, cranial nerve reflexes are also present in neonatal foals at the time of birth (e.g., pupillary light reflex). Cranial nerve deficits might be apparent during the initial observation before approaching the patient. As mentioned earlier, auditory function is fully developed in the neonatal foal (Fig. 5).

Palpation is essential to detect areas of apparent pain, local temperature, muscle tone and symmetry, joint extension and flexion, and tail tone among other findings. Tactile stimuli results in brisk exaggerated responses and reactions in normal foals compared to older animals. Segmental (spinal) reflexes that can be evaluated in foals include cervicofacial, cutaneous trunci, biceps, triceps, patellar, gastrocnemius, flexor (withdrawal), anal, and perianal (Fig. 6). In order to assess segmental reflexes involving the thoracic and pelvic limbs, foals must be in lateral recumbency and relaxed. It is not possible to properly evaluate these in the standing foal. Also, if the foal is in lateral recumbency but thrashing or with increased muscle tone or rigidity, evaluation and interpretation of reflexes will be compromised, faulty, inaccurate, or simply not possible to perform. The cross-extensor reflex may or may not be present in the neonatal period. If present, it is not considered abnormal, and as the foal ages, this reflex becomes inapparent. Extensor thrust reflex can also be seen in normal neonatal foals. Neonatal foals have a hypermetric gait that becomes more coordinated by 3 days of age. Effects of systemic disease, orthopedic disease, congenital anomalies, motor deficits (from initiation of movement by the cerebrothalamus [forebrain] all the way to the nerves, neuromuscular junction, and muscle

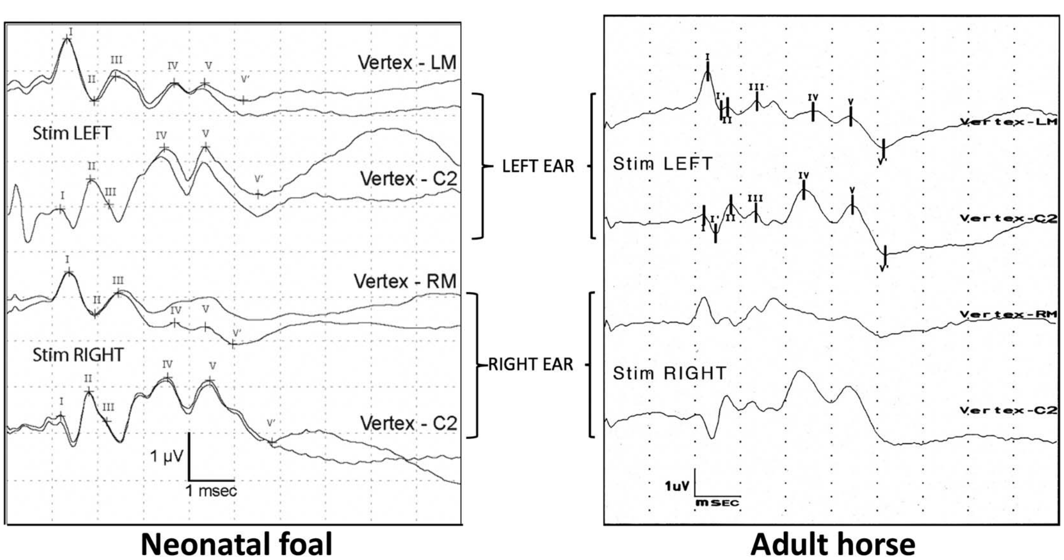

Fig. 5. Auditory function. Note this auditory test (brainstem auditory evoked responses [BAERs]) in a neonatal foal (left) showing no differences compared to that shown for adults (right). Top 2 tracings are left ear; bottom 2 tracings are right ear for both figures.

Fig. 6. Segmental (spinal) reflexes. Note the foal has to be in lateral recumbency and relaxed. Whenever possible, support the limbs to assess the reflexes to avoid weight bearing or increased muscle tone in the limbs tested. A, Triceps reflex, B, Patellar reflex, C, Cross extensor reflex.

as the executers), and weakness can result in recumbency. Cutaneous sensation can be evaluated to investigate the presence or absence of sensory function. Nociception (conscious perception of pain) is only evaluated if voluntary motor function is absent or difficult to interpret. It is important to consider congenital or hereditary disorders and other common neonatal diseases that might affect the overall neurologic condition in foals. For examples see Table 1.

3. Neuroanatomical Localization

There are 3 major divisions of the nervous system: brain, spinal cord, and peripheral. These divisions are further divided into various functional areas as follows:

1. Brain
   A. Cerebrothalamic
   B. Brainstem
   C. Cerebellum
2. Spinal cord (spinal cord segments): cervical (C), thoracic (T), lumbar (L), and sacral (S)
   A. C1–C5/C6
   B. C6–T2
   C. T3–L3
   D. L4–S2
   E. S1–S5
   F. Caudal

Precise location of neurologic deficit or pathology caudal to T3 could be challenging to further localize at times if segmental reflexes cannot be examined due to patient cooperation, increased muscle tone, or in larger patients. However, alteration in cutaneous trunci reflex and alterations in skin sensation can be helpful.

3. Peripheral
   A. Nerve rootlets and roots
   B. Ganglia
   C. Nerves (motor and sensory)
   D. Neuromuscular junction
      a. Presynaptic
      b. Synaptic
      c. Postsynaptic (muscle membrane)

When localization to a specific or single area of the functional areas of the nervous system is not possible, consider diffuse or multifocal localization. Do not forget to evaluate the autonomous nervous system: sympathetic, parasympathetic, and intrinsic enteric. Sympathetic denervation of the head, for example, presents as miosis, ptosis, protrusion of the 3rd eyelid with eye lashes pointing down, increased skin temperature and redness apparent in foals with depigmented skin, and sweating of the head due to vasodilation ipsilaterally. Parasympathetic denervation of the head as a single problem is

Table 1. Neurologic Disorders In Foals

Anomalous Malformation	Degenerative	Encephalopathy	Familial Hereditary	Iatrogenic	Infectious	Toxic	Trauma	Vascular
Hydrocephalus	NAD	Hypoxic ischemic encephalopathy	Juvenile epilepsy	Salt poisoning (milk replacer)	Meningitis	Polioencephalomalacia	Traumatic brain injury	Aneurysms
Hydranencephaly	EDME	Neonatal encephalopathy (non-hypoxic)	Lavender foal syndrome (*MYO5A*)	Drugs, fluids	Meningoencephalomyelitis	Leukoencephalomalacia	Spinal cord injury	Malformation
Anencephaly		Hepatic encephalopathy	Hydrocephalus Friesian foals *B3GALNT2*		Discospondylitis	Nigropallidal encephalomalacia	Nerve injury	Hematoma
Encephalomeningocele		Bilirubin encephalopathy	Narcolepsy cataplexy		Osteomyelitis compromising neural structures	Botulism		
Cyclopia		Sodium disorders (hyponatremia, hypernatremia)	Sensorineural deafness (association with *EDNRB*)		Equine protozoal myeloencephalitis	Tetanus		
Cerebellar hypoplasia		Hypoglycemia: Neuroglycopenia	Lethal white foal syndrome (*EDNRB*)		*Halicephalobus gingivalis* meningoencephalomyelitis	Ionophores		
Occipito-atlanto-axial malformation			NAD		Rabies	Moxidectin		
Meningocele			EDME			Organophosphates		
Spina bifida			Cerebellar abiotrophy (genetic marker)					
Syringohydromyelia			CVM (variants)					
CVM and variants								
Vertebral column anomalies			Occipito-atlanto-axial malformation					

Abbreviations: CVM, cervical vertebral malformation; NAD, neuroaxonal dystrophy; EDME, equine degenerative myeloencephalopathy; EDNRB, endothelin β-receptor gene mutation.

extremely rare, but if it is present, functions such as salivation and lacrimation would be reduced or absent and mydriasis would be observed. Lesions of the intrinsic enteric system would result in ileus and colic that, if congenital, are incompatible with life.

4. Functional Neuroanatomy

For more detail of functional anatomy, refer to AAEP 2015 proceedings by Aleman.[2]

5. Localizing the Lesion Based on Functional Anatomy

Cerebrothalamus

One or more signs might be observed, such as behavior alterations (compulsive, bizarre, manic, and vocalization), lack of mare bonding and udder seeking, lack or delayed initiation of movement, central blindness, wide circles ipsilateral to the lesion, seizures, contralateral decreased nociception, and contralateral proprioceptive deficits. Examples of diseases that can cause these deficits include hypoxic/ischemic encephalopathies, metabolic encephalopathies (hyperammonia, sodium disorders, hyperbilirubinemia [neonatal isoerythrolysis], hypoglycemia [neuroglycopenia = low glucose concentration in the brain]), bacterial meningoencephalomyelitis, trauma, and hereditary epilepsies (Egyptian Arabian foals), among others.

Brainstem

Signs that might be observed when there is pathology in this location include an altered state of consciousness or mental status (obtunded, stuporous, and comatose), altered sleep, multiple cranial nerve deficits, and proprioceptive deficits. It is important to note that cranial nerves have nuclei and tracts within the brain (central components). All nerves are always peripheral. A description of cranial nerves is provided below. Vestibular nuclei are located in the caudal brainstem; therefore, diseases affecting the caudal brainstem could cause central vestibular disease (i.e., infection and trauma). Pathologic nystagmus, strabismus, ipsilateral head tilt, ipsilateral leaning to one side, ipsilateral circling (small circles) to one side, and lack of balance and incoordination (vestibular ataxia) are all signs of vestibular disease. Proprioceptive deficits are also observed with central vestibular disease.

Cranial Nerves

Responses, reactions, and reflexes can be evaluated in the standing or recumbent foal. Cranial nerves can be evaluated in order from I to XII or by functional regions. The author prefers functional regions starting with the sense of smell (subjective); all eye functions (menace, palpebral fissure, palpebral reflex, corneal reflex, dazzle reflex, pupillary light reflex, adaptation to light and darkness, eye globe position and retraction, physiologic nystagmus, and tear production); jaw/facial motor, sensation, and symmetry; and eating/drinking (prehension, suction, tongue tone and movement, and gag reflex). For clarification, dazzle reflex is a subcortical reflex that does not involve the brainstem. To check for dazzle and pupillary light reflexes, a strong light source must be used (Fig. 4). This section does not include a full description of the central components in the brainstem involved in cranial nerve function. A brief description of functions associated with cranial nerves is provided below.

- Olfaction (smell): CN I, subjective evaluation and interpretation.
- Menace response: CN II and VII, cerebral cortex, and cerebellum.
- Palpebral fissure: CN III, VII, sympathetic innervation.
- Palpebral reflex: CN V and VII (tap gently the medial and lateral parts of the eyelids separately, the normal result is blinking).
- Trigeminal facial reaction/reflex: CN V and VII (touch face, nasal mucosa, and inner pinnae).
- Mastication: CN V motor part (mandibular branch). Examine in older foals.
- Facial and nasal sensation: CN V (VII for inner pinnae).
- Pupillary light reflexes (direct and indirect): CN II and III.
- Corneal reflex: CN V, VI, and VII (avoid if the horse has corneal disease or risk of contamination).
- Eye globe position: CN III, IV, and VI (also contribution of VIII, rule out extraocular muscle disease or retrobulbar or periocular mass). Upon head elevation, foals will have mild ventral strabismus which is considered normal.
- Eye globe retraction: CN VI.
- Tear production: CN VII (Schirmer's test on both eyes, compare).
- Physiological nystagmus: CN VIII vestibular. Both eyes should move with the direction of the head movement in a synchronized manner.
- Pathologic nystagmus, occurring at rest or when the head is held in a certain position, is an indication of vestibular disease (central or peripheral).
- Audition: CN VIII cochlear (Fig. 5, auditory function is fully developed in neonates and similar to the adult horse).
- Gag reflex: IX, X, XI, XII (observe swallowing).
- Cervical spinal musculature: CN XI.
- Tongue tone and movement: CN XII.

Cerebellum

Common signs of cerebellar pathology include intention tremors (tremors upon intended movement), hypermetria of all limbs (more pronounced in the thoracic limbs), ataxia, and plus or minus menace deficits. Examples of diseases include cerebellar abiotrophy in Arabian horses and cerebellar hypoplasia. Dandy-walker syndrome is a congenital malformation consisting of partial or complete absence of the cerebellar vermis, resulting in the aforementioned signs. Cerebellar cysts have also been seen by this author.

Spinal Cord

Deficits, such as general proprioceptive ataxia, paresis, and upper motor neuron (UMN) or lower motor neuron (LMN) signs, depending on location within specific spinal cord segments, will be observed. Sensory deficits include general proprioceptive ataxia (manifested as incoordination and body sway side to side) and proprioceptive deficits. General proprioceptive ataxia is commonly known as spinal ataxia. If ataxia is noted, rule out other causes of ataxia, such as cerebellar or vestibular. To determine the "type" of ataxia, look at the rest of the neurologic status of the foal. Does the foal have cerebellar (hypermetria, intention tremors, and lack of menace response) or vestibular (pathologic nystagmus, head tilt, body lean, and circling in the direction of the head tilt) signs? If the answer is yes to one of these, then you can answer the question.

Motor deficits include paresis (i.e., paraparesis, hemiparesis, and tetraparesis) or paralysis (i.e., paraplegia, hemiplegia, and tetraplegia), UMN or LMN signs, dysmetria, hypermetria (UMN) or hypometria (LMN), and decreased muscle tone and weakness (more profound with LMN). Segmental reflexes might be decreased or absent if LMN are involved. Sensory and/or motor deficits will be observed depending on the location of injury within the spinal cord. For example, compressive myelopathies present with a combination of sensory and motor deficits, whereas neuroaxonal dystrophy primarily affects sensory tracts within the spinal cord in addition to brainstem nuclei.

Peripheral Nervous System

This includes all areas of the nervous system that are outside the brain and spinal cord. Note that all nerves are always peripheral (cranial nerves and spinal nerves). Therefore, it is redundant to say peripheral nerves. Cranial nerve deficits will be those pertaining to specific nerves (described above). Similarly, specific gait deficits will be observed depending which nerves are affected in the thoracic and pelvic limbs. The brachial and lumbosacral plexuses are also part of the peripheral nervous system (outside the spinal cord).

Neuromuscular System

The neuromuscular system has central (LMNs) and peripheral (nerve rootlets, roots, ganglia, nerves, and neuromuscular junction) components.[6] Neuromuscular disorders can be diffuse or focal. Signs of diffuse neuromuscular disease include generalized weakness, difficulty supporting weight, paresis or paralysis, muscle fasciculations, and a tendency to become recumbent. Dysphagia, dysphonia, laryngeal collapse, and dyspnea could be clinical manifestations of neuromuscular disease. Segmental (spinal) reflexes can be decreased or absent in neuromuscular disease. An example of a common diffuse neuromuscular disorder in foals is botulism. Electrolyte derangements can affect the function of nerves and neuromuscular junction. Ionized calcium and magnesium are particularly important for proper neurotransmission. Note that alterations in pH affect the binding of calcium and magnesium to proteins, resulting in a decrease or increase of available ionized calcium and magnesium. It is important to practice caution with the use of drugs and fluids that could further alter neuromuscular function if neuromuscular disease is present. For instance, hypermagnesemia can cause similar signs to botulism. Therefore, fluids containing magnesium might not be the ideal type of therapy for foals with botulism or other causes of neuromuscular weakness. Examples of drugs that might contribute to or exacerbate neuromuscular dysfunction include procaine penicillin, lidocaine, tetracyclines, aminoglycosides, erythromycin, and metronidazole, among others. Focal LMN disease or neuropathies lead to specific signs pertaining to the region affected, such as specific gait deficits, decreased muscle tone, decreased or absent tendon reflexes, and focal muscle atrophy.

Neuromuscular Disease of Critical Illness

Acquired neuromuscular dysfunction in the critical care setting is a recognized problem in human medicine, with an estimated prevalence of 46% in critical patients. Acquired disorders include critical illness myopathy, critical illness polyneuropathy, or a combination of both. These disorders are associated with sepsis, systemic inflammatory response syndrome, multi-organ dysfunction, and/or prolonged mechanical ventilation. The clinical hallmark of these is weakness. Weakness is a common clinical sign in diseased neonatal foals, and recognition of acquired neuromuscular disease might be challenging. An increased risk of acquired neuromuscular disease has been associated with hyperglycemia and mechanical ventilation for over 7 days. Dysregulation of calcium and magnesium concentrations might contribute to neuromuscular weakness. Such dysregulation has been reported in foals with septicemia, endotoxemia, and gastrointestinal disease.

6. What Is Next?

Once it is determined that the foal has a neurologic problem alone or concurrent with other illness, a diagnostic work up can be performed. The diagnostic approach should be tailored to the specific problem of the foal and what is going to provide more information or guidance for diagnosis, therapy, and prognosis in a low-risk and cost-effective way. It is not necessary to run all the tests available, and risks and benefits of certain diagnostic aids must be considered (e.g., procedures that require anesthesia may be contraindicated in severely compromised foals due to neuromuscular disease). A full description and indication of diagnostic modalities are beyond the scope of this text. A brief description is provided.

Full blood work (complete blood count, chemistry panel, blood gases, and pH), and urinalysis should be part of a minimum data base collection in critically ill foals. Although myopathies will not be discussed here, for the purpose of clarification, muscle enzymes within reference values do not rule out a myopathic disorder (e.g., hyperkalemic periodic paralysis disease and myotonia congenita). Neuromuscular disorders on which muscle enzymes may be elevated include ionophores, organophosphate toxicity, and those associated with tick infestation. Electrolyte analysis must also include ionized calcium (Ca^{++}) and magnesium (Mg^{++}) because they are physiologically active ions essential for neuromuscular homeostasis and function. Cerebrospinal fluid collection for cytology, biochemistry panel, serology, neural biomarkers, PCR, and antimicrobial culture can be performed. Collection of cerebrospinal fluid must be performed closer to the lesion to increase the chances of finding abnormalities. Meningitis or meningoencephalomyelitis in neonatal foals is usually caused by pathogens causing sepsis. Imaging such as radiography and ultrasonography can be easily performed in the field. Other imaging modalities include computed tomography and magnetic resonance that are available in some referral institutions. Electrophysiology, such as electroencephalography, brainstem auditory evoked responses, visual evoked potentials, retinography, repetitive nerve stimulation, and electromyography have been proven essential in the understanding of neurologic and neuromuscular disease. However, these techniques are only available in academic institutions.

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Declaration of Ethics

The Author has adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Author has no conflicts of interest.

References

1. de Lahunta A, Glass E. *Veterinary neuroanatomy and clinical neurology 3rd ed.* St. Louis: Saunders, 2014;487–501.
2. Aleman M. Neurologic examinations of horses, in *Proceedings*. Am Assoc Equine Pract 2015;61:181–190.
3. Mayhew J. *Large animal neurology 2nd ed.* Ames: Wiley-Blackwell, 2009;11–46.
4. MacKay RJ. Neurologic disorders in neonatal foals. *Vet Clin N Am Equine Pract* 2005;21:387–406.
5. Adams R, Mayhew IG. Neurological examination of newborn foals. *Equine Vet J* 1984;16:306–312.
6. Aleman M. Miscellaneous neurologic or neuromuscular disorders in horses. *Vet Clin N Am Equine* 2011;27:481–506.

Quality Control: Genetic Testing in Foals

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1. Introduction

Genetic testing typically involves the analysis of an animal's DNA to determine the individual's genotype for an inherited disorder or trait. Genetic testing may be used for permanent individual identification and parentage determination. Breed registries, including the Thoroughbred Jockey Club and, in certain instances, the American Quarter Horse Association, now require such verification to ensure the accuracy of their pedigrees. Genetic testing is also used to test for specific diseases or traits. To interpret genetic testing results for future breeding, an understanding of the mode of inheritance is required. At this time, many of the genetic tests available for horses are for an autosomal-recessive disorder to determine whether an animal is a carrier. Carriers are usually phenotypically normal but have the potential to produce diseased progeny. Dominant disorders also exist in the horse and genetic tests may be used to definitively diagnose affected horses.

2. Materials and Methods

This presentation will focus on recently available genetic disease tests specific to foals and yearlings in the United States, including the five-panel genetic test in the American Quarter Horse (QH) and Paint Horse; lavender foal syndrome (LFS), cerebellar abiotrophy (CA), and occiptoatlantoaxial malformation in Arabian Horses; dwarfism and hydrocephalus in Friesians; hoof wall separation disease in Connemara ponies; Warmblood fragile foal syndrome in Warmblood foals; junctional epidermolysis bullosa (JEB) in Belgian and Saddlebred foals; and immune-mediated myopathy (IMM) in QH and QH-related breeds.

3. Results

Five-Panel Genetic Test

The American Quarter Horse Association has mandated that all breeding stallions have a five-panel genetic test on file prior to registration of foals resulting from breedings after January 1, 2015. This panel includes genetic tests for hyperkalemic periodic paralysis (HYPP), glycogen branching enzyme deficiency (GBED), hereditary equine regional dermal asthenia (HERDA), type 1 polysaccharide storage myopathy (PSSM1), and malignant hyperthermia (MH). As of 2018, the American Paint Horse Association also requires breeding stallions to have the five-panel genetic disease test results on file, plus lethal white foal syndrome prior to the registration of their foals.

HYPP

HYPP is inherited as an autosomal-semi-dominant trait and results in episodic weakness and paralysis. Episodes typically last between 15 and 60 minutes and horses may appear completely normal between

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episodes. Muscle fasciculations and sweating in flanks, necks, and shoulders may be observed. During severe attacks, horses may dog-sit or become recumbent. Homozygous foals may demonstrate respiratory stridor, dysphagia, or respiratory distress.[1] The genetic etiology is a missense mutation in the voltage-dependent skeletal muscle sodium channel alpha-subunit (*SCN4A*).[2] The mutation results in failure of a subpopulation of sodium channels to inactivate when serum potassium concentrations are increased. The excessive influx of sodium and efflux of potassium results in persistent depolarization of muscle cells followed by temporary weakness. Treatment includes feeding grain or corn syrup to stimulate insulin-mediated movement of potassium across cell membranes, acetazolamide (3 mg/kg every 8–12 hours orally) or, in severe cases, calcium gluconate, dextrose, or sodium bicarbonate administered intravenously. With severe dyspnea, a tracheostomy may be required. Long-term management includes regular exercise and frequent turnout and feeding a balanced diet containing between 0.6% and 1.1% to 1.5% total potassium concentrations and meals containing <33 g of potassium.[3]

GBED

GBED is inherited as an autosomal-recessive trait. Clinical signs include stillbirth, transient flexural limb deformities, seizures, and respiratory or cardiac failure.[4,5] GBED is caused by a nonsense mutation in the glycogen branching enzyme gene (*GBE1*).[6] The mutation results in the inability to create a branched structure of glycogen. As a result, cardiac and skeletal muscle, liver, and brain cannot store or mobilize glycogen to maintain normal glucose homeostasis. There is no effective treatment.

Hereditary Equine Regional Dermal Asthenia

Hereditary equine regional dermal asthenia (HERDA) is inherited as an autosomal-recessive trait. Clinical signs, including seromas, hematomas, open wounds, or sloughing skin, are typically not evident until about 1.5 years of age and are often associated with initial saddling or trauma.[7] Skin is often loose and easily tented, primarily along the dorsum. HERDA is due to a missense mutation in the cyclophilin B gene (*PPIB*).[8] The mutation is hypothesized to affect protein folding of collagens. There is currently no targeted treatment for HERDA. Prevention involves maintaining horses indoors and away from other horses to prevent development of progression of lesions.

PSSM1

PSSM1 is inherited as an autosomal-dominant trait and affects QH-related breeds, in addition to draft breeds, Rocky Mountain Horses, Tennessee Walking Horses, Morgans, and Haflingers. Horses may be asymptomatic or demonstrate signs of exertional rhabdomyolysis.[9] Draft breeds may demonstrate muscle fasciculation and gait abnormalities. The genetic mutation is a missense mutation in the glycogen synthase 1 gene (*GYS1*).[10] The mutation results in unregulated glycogen synthesis and potentially impaired aerobic glycogen metabolism. For treatment of acute episodes, stall confinement may be indicated for <48 hours. Hydration status should be assessed and sedatives and anti-inflammatories administered to well-hydrated horses to relieve anxiety and pain. For the prevention of future episodes, owners should follow a gradual return to exercise, using incremental training along with dietary management aimed at providing adequate, but not excessive calories, by decreasing glucose load (dietary starch <10% daily digestible energy) and providing fat as an alternate energy source (up to 13% of daily digestible energy).[11]

MH

MH is inherited as an autosomal-dominant trait and only the heterozygous state has been described. Clinical signs, including hyperthermia, lactic acidosis and muscle rigidity, are initiated by exposure to halogenated anesthetics or upon stress/excitement.[12] Episodes may lead to death. The genetic etiology is a missense mutation in the ryanodine receptor type 1 gene (*RYR1*).[13] The mutation results in excessive release of calcium into the myoplasm and a hypermetabolic state. To prevent an episode, pre-treatment with dantrolene (4 mg/kg) 30–60 minutes prior to anesthesia is advised.[14] During an episode, hyperthermia and acidemia should be treated with alcohol, chilled intravenous fluids with sodium bicarbonate, and mechanical ventilation.

Arabian and Related Breeds

Genetic tests are currently being offered for four genetic diseases in Arabians and Arabian crosses; CA, LFS, occipitoatlantoaxial malformation, and severe combined immunodeficiency (SCID).

CA

CA affects Arabians and carriers have been identified in Bashkir Curly Horses, Trakehners, and Welsh ponies, most likely due to Arabian ancestry. The mode of inheritance is autosomal recessive. Clinical signs are consistent with a cerebellar ataxia, including dysmetria, spasticity, wide-based stance, intention tremors and a lack of menace response, with an age of onset around 2.5 to 6 months of age. The genetic etiology was discovered in 2011 as a missense mutation located in exon 4 of *TOE1* (Target of EGR1) and approximately 1200 bp upstream from *MUTYH* (MutY Homolog).[15] *TOE1* is expressed in the central nervous system, though not at high levels in the cerebellum, and is involved in cell cycle regulation. As the missense mutation does not appear to cause a deleterious amino acid change (arginine to histidine), its role in the development of the CA phenotype is the subject of ongoing research. *MUTYH* is highly expressed in the cerebellum and encodes for a DNA glycosylase involved in post-replicative repair in the nuclei of rapidly proliferating Purkinje cells as well as DNA repair due to oxidative damage of mitochondrial genomes. There is no available treatment for CA.

LFS

LFS, also referred to as lethal LFS or coat color dilution lethal, affects Egyptian lineage Arabian neonates. Foals have a silver, pewter, lavender, or pale chestnut (pink) coat color and demonstrate tetanic episodes with opisthotonus, paddling and extensor rigidity from birth.[16] Foals cannot become sternal or stand and suckling may be strong, weak, or absent. Direct and indirect pupillary light responses are generally present, although ventral strabismus and nystagmus may be observed. Reflexes may be present but result in an exaggerated response characterized by increased paddling and rigidity.[16] It is unclear if paddling episodes are due to seizure activity or attempts for the foal to stand, as electroencephalograms have not been performed. There are no specific clinicopathologic abnormalities, unless other conditions are present. Radiographs of skull and cervical spine are normal. A definitive diagnosis requires genetic testing. Treatment consists mainly of supportive care. Diazepam and phenobarbital may provide temporary relief; however, whether this is due to sedative or anticonvulsant effects of these drugs is unknown. The clinical condition deteriorates despite treatment, necessitating euthanasia.

LFS is inherited as an autosomal-recessive trait and was the first equine disease to have the molecular genetic mutation mapped utilizing a single nucleotide polymorphism (SNP)–based genome-wide association study approach with the first-generation equine SNP array.[a,16] Six LFS-affected and 30 healthy relatives were genotyped and 14 highly significant SNPs were identified on chromosome 1 spanning a region of 10.5 Mb. Homozygosity mapping further narrowed the region to a 1.6-Mb block that was homozygous in all six affected horses and heterozygous in obligate carriers. Ten genes fell into this region, including one of the two candidate genes for the disease, myosin Va (*MYO5A*). Sequencing of the 39 exons of *MYO5A* revealed a single base pair deletion in exon 30, causing the reading frame to shift and creating a premature stop codon in the translation of exon 30. Based upon the known function of the gene in other species and high conservation across the mutated region, it is hypothesized that the mutation impairs binding of myosin Va to organelles with appropriate receptors, which leads to the loss of vesicle traffic (melanosomes and dendritic cargo) and interferes with the function of melanocytes and neurons.[16] A genetic test for LFS is available. This test can be used to definitively diagnose LFS and determine carrier status, especially of Egyptian lineage Arabian horses.

A possible relationship between LFS and juvenile idiopathic epilepsy (JIE) has been postulated, as both conditions occur in Arabian foals of Egyptian breeding and overlap between mares producing both LFS- and JIE-affected foals has been reported. In a study investigating known genetic mutations of Arabians, the *MYO5A* mutation was not found in 10 Egyptian Arabian foals with confirmed JIE via electroencephalogram.[17] The clinical presentation of JIE and LFS is distinct. Foals with JIE demonstrate seizures during the first year of life that spontaneously resolve at 1 year of age. By contrast, seizures associated with LFS are present at birth and foals cannot survive past a few days of age, even with supportive care. Additionally, the dilute coat color phenotype observed with LFS is not seen with JIE. There is strong evidence that JIE is inherited[18] and two candidate genes were excluded.[19] A recent publication documented a putative genetic mutation for JIE,[20] but this was disproven in a stringently phenotyped population.[21] Research into the genetic etiology of JIE is therefore ongoing.

Occipitoatlantoaxial Malformation of Arabians

Familial occipitalization of the atlas with atlantalization of the axis in Arabian horses leads to either stillborn foals or foals with neurologic abnormalities at birth. Clinical signs include symmetrical upper motor neuron signs and general proprioceptive deficits. An extended neck posture may be observed, with an audible "click" heard during neck movement due to movement of the dens. A diagnosis can be made using cervical radiography. For one variant of Occipitoatlantoaxial Malformation of Arabians (OAAM), a genetic test is available.[22]

OAAM is suspected to be inherited as an autosomal-recessive trait in the Arabian breed. Familial OAAM seen in Arabian horses is very similar to that described in *Hoxd*$3^{-/-}$ mice, which are homozygous for a targeted disruption of the homeobox containing gene, *Hoxd3*.[23] Mice homozygous for this mutation demonstrate occipitilization of the atlas and atlantization of the axis, an aspect of the phenotype that is fully penetrant. The homeobox (HOX) gene cluster is involved in the development of the axial and appendicular skeleton. In 2017, whole-genome sequencing was performed in an OAAM-affected horse and a 2.7-kb deletion was located 4.4 kb downstream of the end of *HOXD4* and 8.2 kb upstream of the start of *HOXD3*.[22] Both parents of the OAAM-affected horse were heterozygous for the deletion while the affected foal was homozygous. The deletion was not found in 371 horses of other breeds. While the variant was found in the carrier state in two other unaffected Arabians, two additional Arabian OAAM-affected foals did not have the 2.7-kb deletion. An in-depth examination of the foals' phenotypes revealed notable variation, including cardiac deformities, and it is postulated that genetic heterogeneity may exist across the HOXD locus in Arabian foals with OAAM.[22]

SCID

SCID is inherited as an autosomal-recessive trait in Arabian horses. At birth, foals appear normal but develop infections by 6 to 10 weeks postpartum when colostral antibodies decline. The genetic mutation is a 5-bp deletion resulting in a frameshift mutation and a 967-amino-acid deletion in DNA-protein kinase catalytic subunit (*DNA-PKcs*).[24] The mutation results in the ability to recombine particular gene segments in order to form coding sequences of immunoglobulin and T-cell antigen receptor variable regions [i.e., V(D)J recombination]. SCID-affected foals lack both B and T lymphocytes. Due to infection, SCID-affected foals typically die by 5 months of age.

Friesians

In the Friesian foal, there are currently two genetic tests available: hydrocephalus and dwarfism.

Hydrocephalus

Friesian hydrocephalus affects Friesian fetuses and foals, with no sex predilection. Affected Friesian foals are aborted, stillborn, or born with severe neurologic debilitation and cranial distention, often as a dystocia. The phenotype is clinically apparent, and radiographs can support a diagnosis. Definitive diagnosis can be achieved through genetic testing. There are no treatment options available.

Hydrocephalus, an accumulation of cerebrospinal fluid (CSF) within the central nervous system (CNS), is rarely encountered in the horse. It is associated with known genetic mutations in mice, cattle, and humans. Friesian hydrocephalus is inherited as an autosomal-recessive trait. In 2015, a genome-wide association study of hydrocephalus in 13 affected Friesians and 69 control Friesians found that a nonsense mutation (EquCab3.0 c.1423C>T) in exon 12 of the β-1,3-N-acetylgalactosaminyltransferase 2 (*B3GALNT2*) gene on chromosome 1 was associated with Friesian hydrocephalus.[25] The mutation is identical to a *B3GALNT2* mutation identified in a human case of muscular dystrophy-dystroglycanopathy with hydrocephalus. *B3GALNT2* is involved in glycosylation of dystroglycans, which are present in skeletal muscle but also in many tissues like the brain, where it impacts morphogenesis and early development. Immunohistochemical examination of muscle biopsies from Friesians with hydrocephalus would need to be performed to determine whether muscular dystrophy is also present in these horses. From this study, the estimated allele frequency in Friesians was determined to be 8.5%.[25] Genetic testing for hydrocephalus in Friesians is available. Recently, the *B3GALNT2* mutation was identified in an aborted Belgian draft horse fetus.[26] Further work is necessary to evaluate the inheritance of hydrocephalus across other breeds.

Dwarfism

Dwarfism is inherited as an autosomal-recessive trait in the Friesian. Clinical signs include disproportionate dwarfism characterized by a severely shortened stature, shortened limbs relative to overall body size, bowed forelegs, shortened neck and a disproportionally large cranium. The genetic mutation in Friesians is a splice site mutation in the *B4GALT7* gene.[27]

Other Breeds

Hoof Wall Separation Disease of Connemara Ponies

Hoof wall separation disease is an autosomal-recessive trait affecting Connemara ponies. Clinical signs include separation and cracking of the outer hoof wall. This can lead to ponies having to support their weight on the sole of the hoof instead of the hoof wall, which, in some cases, can result in chronic inflammation, severe lameness, and laminitis. Affected ponies typically show clinical signs within the first 6 months of life and all four feet are typically affected. The genetic defect is a 1-bp insertion in *SERPINB11*, leading to a premature stop codon.[28]

Warmblood Fragile Foal Syndrome (Type 1)

Warmblood fragile foal syndrome type 1 is an autosomal-recessive trait affecting Hanoverians, Selle Francais, KWPN, Oldenburg, and Westphalian horses. Clinical signs include hyperextensible, abnormally thin, fragile skin and mucous membranes that are subject to open lesions.[29] Affected horses may also have hyperextensible limb joints, floppy ears, accumulation of fluid (hydrops), subcutaneous emphysema, hematomas, and premature birth.[30] The disease is present at birth and affected newborn foals are euthanized shortly after birth due to the poor prognosis of this untreatable condition. The genetic defect is a missense mutation in the equine lysyl hydroxylase gene (*LH1*), the orthologous gene responsible for human cases of Ehlers-Danlos syndrome VI.[30]

Junctional Epidermolysis Bullosa

Genetic testing for junctional epidermolysis bullosa (JEB) became mandatory for Belgian stallions as of November 1, 2002 and for breeding-age mares in 2015. This autosomal-recessive disease, caused by a cytosine (C) insertion in exon 10 of the *LAMC2* gene, is characterized by extensive and debilitating blistering of the skin and mouth epithelium as well as hoof sloughing. Affected foals eventually succumb to infection or are euthanized before 10 days of age.[31] The same mutation has also been found to be associated with the JEB phenotype in other draft horse breeds.[32]

Genetic testing is available for a second form of JEB (termed JEB2) identified in the American Saddlebred. This disorder is associated with a ~6.5-kb deletion spanning exons 24 to 27 of the *LAMA3* gene that was identified exclusively in this breed.[33]

Immune-Mediated Myositis

Immune-mediated myositis of QH and QH-related breeds is a semi-dominant trait leading to either widespread muscle atrophy following an infection or vaccination, or a nonexertional rhabdomyolysis. In 2018, a missense mutation in myosin heavy chain 1 (*MYH1*) was associated with IMM in the QH.[34] This mutation is also associated with nonexertional rhabdomyolysis in this breed.[35] Allele frequencies were estimated to be 0.034 in the general QH population and highest among reining, working cow, and halter horses and was not detected in the barrel racing and racing QH's subpopulations studied.[36]

4. Discussion

It is important to realize that no association or committee evaluates quality control of DNA tests that are available in animals. Most tests are published in the scientific literature not as tests, but as articles describing the discovery of the mutation. In 2018, the horse genomics research community developed a consensus statement on the application of research for commercial use, which may assist animal owners and clinicians in choosing a laboratory for testing and help in deciding which tests may be most appropriate (https://img1.wsimg.com/blobby/go/3ed25c45-16f5-4198-9333-2dd4d2feeafa/downloads/1cq72554i_382106.pdf?ver=1551977123053). Some key principles identified were that scientific discovery should be reproducible and subject to the peer-review process and clear differentiation should be made between scientific developments, commercial opportunity, and opinion.

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Declaration of Ethics

The Author has adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Author has no conflicts of interest.

References and Footnote

1. Carr EA, Spier SJ, Kortz GD, et al. Laryngeal and pharyngeal dysfunction in horses homozygous for hyperkalemic periodic paralysis. *J Am Vet Med Assoc* 1996;209:798–803.
2. Rudolph JA, Spier SJ, Byrns G, et al. Periodic paralysis in Quarter Horses: a sodium channel mutation disseminated by selective breeding. *Nature Genet* 1992;2:144–147.
3. Reynolds JA, Potter GD, Green LW, et al. Genetic-diet interactions in the hyperkalemic periodic paralysis syndrome in Quarter horses fed varying amounts of potassium: III. The relationship between plasma potassium concentration and HYPP Symptoms. *J Equine Vet Sci* 1998;18:731–735.
4. Valberg SJ, Ward TL, Rush B, et al. Glycogen branching enzyme deficiency in Quarter horse foals. *J Vet Intern Med* 2001;15:572–580.
5. Wagner ML, Valberg SJ, Ames EG, et al. Allele frequency and likely impact of the glycogen branching enzyme deficiency gene in Quarter horse and Paint horse populations. *J Vet Intern Med* 2006;20:1207–1211.
6. Ward TL, Valberg SJ, Adelson DL, et al. Glycogen branching enzyme (GBE1) mutation causing equine glycogen storage disease IV. *Mamm Genome* 2004;15:570–577.
7. White SD, Affolter VK, Schultheiss PC, et al. Clinical and pathological findings in a HERDA-affected foal for 1.5 years of life. *Vet Derm* 2007;18:36–40.
8. Tryon RC, White SD, Bannasch DL. Homozygosity mapping approach identifies a missense mutation in equine cyclophilin B (PPIB) associated with HERDA in the American Quarter Horse. *Genomics* 2007;90:93–102.
9. Firshman AM, Valberg SJ, Bender JB, et al. Epidemiologic characteristics and management of polysaccharide storage myopathy in Quarter Horses. *Am J Vet Res* 2003;64:1319–1327.
10. McCue ME, Valberg SJ, Miller MB, et al. Glycogen synthase (GYS1) mutation causes a novel skeletal muscle glycogenosis. *Genomics* 2008;91:458–466.
11. Ribeiro WP, Valberg SJ, Pagan JD, et al. The effect of varying dietary starch and fat content on serum creatine kinase activity and substrate availability in equine polysaccharide storage myopathy. *J Vet Intern Med* 2004;18:887–894.
12. Aleman M, Brosnan RJ, Williams DC, et al. Malignant hyperthermia in a horse anesthetized with halothane. *J Vet Intern Med* 2005;19:363–366.
13. Aleman M, Riehl J, Aldridge BM, et al. Association of a mutation in the ryanodine receptor 1 gene with equine malignant hyperthermia. *Muscle Nerve* 2004;30:356–365.
14. Valverde A, Boyd CJ, Dyson DH, et al. Prophylactic use of dantrolene associated with prolonged postanesthetic recumbency in a horse. *J Am Vet Med Assoc* 1990;197:1051–1053.
15. Brault LS, Cooper CA, Famula TR, et al. Mapping of equine cerebellar abiotrophy to ECA2 and identification of a potential causative mutation affecting expression of MUTYH. *Genomics* 2011;97:121–129.
16. Brooks SA, Gabreski N, Miller D, et al. Whole-genome SNP association in the horse: Identification of a deletion in myosin Va responsible for lavender foal syndrome. *PLoS Genet* 2010;6:e1000909.
17. Aleman M, Finno CJ, Weich K, et al. Investigation of known genetic mutations of Arabian horses in Egyptian Arabian foals with juvenile idiopathic epilepsy. *J Vet Intern Med* 2018;32:465–468.
18. Aleman M, Gray LC, Williams DC, et al. Juvenile idiopathic epilepsy in Egyptian Arabian foals: 22 cases (1985–2005). *J Vet Intern Med* 2006;20:1443–1449.
19. Lichter-Peled A, Polani S, Stanyon R, et al. Role of KCNQ2 and KCNQ3 genes in juvenile idiopathic epilepsy in Arabian foals. *Vet J* 2013;196:57–63.
20. Polani S, Dean M, Lichter-Peled A, et al. Sequence variant in the TRIM39-RPP21 gene readthrough is shared across a cohort of Arabian foals diagnosed with juvenile idiopathic epilepsy. *J Gene Mutat* 2018;1:103.
21. Rivas VN, Aleman M, Peterson JA, et al. TRIM39-RPP21 Variants (19InsCCC) are not associated with juvenile idiopathic epilepsy in Egyptian Arabian horses. *Genes (Basel)* 2019;10:816.
22. Bordbari MH, Penedo MCT, Aleman M, et al. Deletion of 2.7 kb near HOXD3 in an Arabian horse with occipitoatlantoaxial malformation. *Anim Genet* 2017;48:287–294.
23. Condie BG, Capecchi MR. Mice homozygous for a targeted disruption of Hoxd-3 (Hox-4.1) exhibit anterior transformations of the first and second cervical vertebrae, the atlas and the axis. *Development* 1993;119:579–595.
24. Shin EK, Perryman LE, Meek K. A kinase-negative mutation of DNA-PK(CS) in equine SCID results in defective coding and signal joint formation. *J Immun* 1997;158:3565–3569.
25. Ducro BJ, Schurink A, Bastiaansen JW, et al. A nonsense mutation in B3GALNT2 is concordant with hydrocephalus in Friesian horses. *BMC Genomics* 2015;16:761.

26. Kolb DS, Klein C. Congenital hydrocephalus in a Belgian draft horse associated with a nonsense mutation in B3GALNT2. *Can Vet J* 2019;60:197–198.
27. Leegwater PA, Vos-Loohuis M, Ducro BJ, et al. Dwarfism with joint laxity in Friesian horses is associated with a splice site mutation in B4GALT7. *BMC Genomics* 2016;17:839.
28. Finno CJ, Stevens C, Young A, et al. SERPINB11 frameshift variant associated with novel hoof specific phenotype in Connemara ponies. *PLoS Genet* 2015;11:e1005122.
29. Aurich C, Muller-Herbst S, Reineking W, et al. Characterization of abortion, stillbirth and non-viable foals homozygous for the Warmblood fragile foal syndrome. *Anim Reprod Sci* 2019;211:106202.
30. Monthoux C, de Brot S, Jackson M, et al. Skin malformations in a neonatal foal tested homozygous positive for Warmblood fragile foal syndrome. *BMC Vet Res* 2015;11:12.
31. Spirito F, Charlesworth A, Linder K, et al. Animal models for skin blistering conditions: absence of laminin 5 causes hereditary junctional mechanobullous disease in the Belgian horse. *J Invest Derm* 2002;119:684–691.
32. Milenkovic D, Chaffaux S, Taourit S, et al. A mutation in the LAMC2 gene causes the Herlitz junctional epidermolysis bullosa (H-JEB) in two French draft horse breeds. *Genet Sel Evol* 2003;35:249–256.
33. Graves KT, Henney PJ, Ennis RB. Partial deletion of the LAMA3 gene is responsible for hereditary junctional epidermolysis bullosa in the American Saddlebred Horse. *Anim Genet* 2009;40:35–41.
34. Finno CJ, Gianino G, Perumbakkam S, et al. A missense mutation in MYH1 is associated with susceptibility to immune-mediated myositis in Quarter Horses. *Skelet Muscle* 2018;8:7.
35. Valberg SJ, Henry ML, Perumbakkam S, et al. An E321G MYH1 mutation is strongly associated with nonexertional rhabdomyolysis in Quarter Horses. *J Vet Intern Med* 2018; 32:1718–1725.
36. Gianino GM, Valberg SJ, Perumbakkam S, et al. Prevalence of the E321G MYH1 variant for immune-mediated myositis and nonexertional rhabdomyolysis in performance subgroups of American Quarter Horses. *J Vet Intern Med* 2019;33:897–901.

[a] EquineSNP50 Beadchip, Illumina, San Diego, CA 92122.

Hormones in Critically Ill Foals: The Good, the Bad, and the Ugly

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Critical illness in newborn foals activates multiple endocrine systems, with the ultimate goal of maintaining organ function to assure survival in the immediate post-natal period. Depending on the disease process and foal maturity, endocrine dysregulation may develop, which can further impair behavior, immunity, energy homeostasis, fluid and electrolyte balance, oxygen and nutrient delivery, tissue differentiation, cell function, and the likelihood of survival. Therefore, a better understanding of these endocrinopathies can improve preventative and therapeutic approaches to disorders of the equine neonate. Some of this information is already improving therapeutics in hospitalized foals. To move this field forward and enhance understanding on endocrine regulation and dysregulation in the equine neonate, additional research will be needed to better elucidate the role of factors for which some information is available, but in particular for systems for which knowledge is minimal and could have clinical implications. Author's address: College of Veterinary Medicine, The Ohio State University, College of Veterinary Medicine, Columbus, OH 43210; e-mail: toribio.1@osu.edu.

1. Introduction

Prematurity, failure of transfer of passive immunity, neonatal maladjustment syndrome (NMS)/neonatal encephalopathy, and infections place the equine neonate at a disadvantage, often resulting in sepsis and death.[1–8] Sepsis remains the main cause of mortality in newborn foals, with a prognosis for survival ranging from 35% to 60%.[1–7] Critically ill foals present to intensive care units with bacteremia, endotoxemia, evidence of systemic inflammation, hypotension, tissue hypoperfusion (↑lactate), energy dysregulation (↓glucose), acid-base and electrolyte abnormalities (acidosis, ↓Na^+, ↓Cl^-, ↓Ca^{2+}, ↓Mg^{2+}), and organ failure (cerebral, renal, intestinal, hepatic, pulmonary, immune).[1–7] The survival rate under these conditions is dictated by the ability of various homeostatic systems to coordinate and overcome these derangements. Unfortunately, some foals remain refractory to aggressive therapies and succumb to sepsis, in part due to endocrine failure.

In foals, the maturation of a number of endocrine systems occurs in late gestation and continues in the early post-natal period.[9–14] These adaptations are accompanied by changes in the hypothalamus-pituitary-adrenal axis (HPAA), energy metabolism, and cardiovascular system.[11–17] Research on hormonal dysregulation of critically ill foals has been minimal, but advances are being made in understanding various endocrine systems in healthy and sick newborn foals. It is reasonable to assume that as knowledge of equine neonatal endocrine pathophysiology improves, better therapeutic strategies to reduce mortality will be developed.

NOTES

This document provides an overview of endocrine imbalances of newborn foals, with emphasis on sepsis, dysmaturity, and NMS. Information about many endocrine systems is lacking, but some progress with clinical value has been made in recent years.

2. Adrenal Insufficiency

The HPAA represents a complex regulatory system that modulates multiple physiological functions (metabolism, pain, hunger, thirst, blood pressure, autonomic activity, immunity, inflammation) as well as the stress response. Under stress or physiological needs, the hypothalamus secretes corticotropin-releasing hormone and arginine-vasopressin (AVP), which stimulate the pituitary gland (pars distalis; adenohypophysis) to release adrenocorticotrophic hormone (ACTH), which in turn acts on the adrenal cortex to release cortisol. Cortisol regulates energy metabolism, modulates immune and inflammatory processes, and contributes to tissue differentiation and function.

A disruption of the HPAA (adrenal insufficiency), which results in inappropriately low cortisol concentrations could have negative consequences. In fact, recent studies have shown that some critically ill foals develop adrenal insufficiency, which is linked to disease severity and mortality.[7,12,18–21] Despite disease severity, these foals do not have the expected increased cortisol secretion (normal = 1 to 70 μg/dL)[12,22,23] and the cortisol response to exogenous ACTH stimulation is poor (relative adrenal insufficiency [RAI]).[12,19,24] A more recently adopted term for RAI is critical illness-related corticosteroid insufficiency, which, in addition to endocrine abnormalities, also takes into consideration clinical findings, an exaggerated pro-inflammatory response, and tissue refractoriness to corticosteroids.[25,26] A number of foals with RAI also have low aldosterone concentrations (normal = 55–1175 pg/mL),[12,18,22] which could contribute to hypovolemia, tissue hypoperfusion, and electrolyte abnormalities.

Clinical Relevance

Abnormally low corticoid concentrations in sick foals could exacerbate the systemic inflammatory response, reduce tissue perfusion, disrupt energy homeostasis, and alter a number of tissue functions. This opens the question on the justification of replacement therapy. Glucocorticoid therapy can be considered in critically ill foals with endocrine or clinical evidence of RAI, including tissue hypoperfusion, poor response to vasopressors, persistent hypoglycemia, and protracted hyperkalemia associated with hyponatremia. In foals with evidence of dysmaturity, glucocorticoid therapy can be beneficial to promote tissue differentiation and function. Hydrocortisone (cortisol) is the preferred glucocorticoid because it is an endogenous steroid with a short half-life in foals (0.43 hours),[27] but dexamethasone or prednisolone are valid alternatives, although their stronger immune-suppressive effects should be taken into consideration depending on the underlying disease process (septicemia, bacteremia, prematurity). A tapering course of hydrocortisone (1.3 mg/kg/day divided q4h IV) may have beneficial anti-inflammatory effects without major immune suppression in sick foals.[21] Glucocorticoid therapies have not been prospectively evaluated in foals with RAI to further support their potential benefits. Therefore, recommendations are based on the current understanding of perinatal diseases and endocrine dysregulation.

3. Progestogens

Progestogens include pregnenolone, progesterone, 17α-hydroxyprogesterone, 5α-dihydroprogesterone, and allopregnanolone. Progesterone concentrations in healthy newborn foals (range = 0.2 to 30 ng/mL) are similar or higher than values measured in mares in their luteal phase and throughout pregnancy.[12,28,29] The adrenal gland and gonads are the main source of progestogen precursors (pregnenolone) in the equine fetus, which are further metabolized to other steroids by the placenta. The fetal adrenal gland and gonads also produce large quantities of dehydroepiandrosterone, which is used by the placenta to produce androgens and estrogens. However, information in sex steroids in healthy and sick foals remains scarce.[29] Days before foaling there is an adrenal shift from progestogen to glucocorticoid synthesis, reflected as a drop in progestogens with a parallel increase in fetal ACTH and cortisol concentrations, indicating maturation of the HPAA.[8] This maturation is essential for foal survival (tissue perfusion, energy homeostasis, tissue differentiation). Interference with fetoplacental or adrenocortical function could keep progestogen concentrations elevated, delaying the neonate postpartum arousing response, with implications to fetal to neonatal transition and adaptation to extrauterine life.[8,19,30,31] Progestogens have sedative effects because they activate gamma-aminobutyric acid (GABA) type A ($GABA_A$) receptors, similar to diazepam and barbiturates, which could explain the lethargic behavior or disorientation developed by some sick newborn foals.[31] Moreover, increased progesterone concentrations during hospitalization is a consistent finding in septic foals, which is linked to severity of illness and mortality.[12,19,29,30,32] In other words, progesterone concentrations in hospitalized foals could have prognostic value.

Allopregnanolone, which is a progesterone metabolite and a potent $GABA_A$ receptor agonist, has sedative effects in foals.[31] Recent studies have shown that septic foals and foals with evidence of NMS often have abnormally elevated progestogen concentrations.[8,12,19,30] One can speculate that by activating $GABA_A$ receptors, this could contribute to lethargy, disorientation, and abnormal behavior in these foals. The use of 5α-reductase inhibitors (finasteride, dutasteride) to block the synthesis of allopregnanolone has been used anecdotally by some practitioners to treat NMS foals with mixed results.

If progestogens contribute to disorders in the equine neonate, this opens the question as to whether exogenous progestogens such as altrenogest could alter the endocrine balance in foals. A recent study showed that septic foals born to altrenogest-treated mares have lower ACTH and higher progesterone concentrations than those born to untreated mares[29]; however, no association with survival was found.

Clinical Relevance

Increased concentrations of progestogen (progesterone in particular) is a frequent finding in critically ill foals; however, it remains unknown whether they contribute to disease progression or reflect severity of disease and organ dysfunction. Elevated progestogens may play a role in the pathogenesis of NMS and could have prognostic value.

4. Energy Homeostasis

The energy regulatory systems are complex and comprise multiple axes (pancreatic, enteroinsular, somatotropic, orexigenic, thyroid, HPAA). A number of organs/cells with endocrine function are involved in energy homeostasis, including the pancreas (α- and β-cells), fat (adipocytes), hypothalamus, pituitary gland (pars distalis), adrenal gland (medulla and cortex), stomach (glandular cells), intestine (L and K cells), thyroid gland (follicular cells), liver (hepatocytes), and bone (osteoblasts). Disorders of energy regulation are common in critically ill foals. Despite the clinical significance of energy dysregulation in sick foals, just recently some hormones involved with energy metabolism were investigated in hospitalized foals.[9,33–36]

Hypoglycemia is more frequent than hyperglycemia, and both are linked to mortality.[9,37] Septic foals often have low insulin,[9,33] but increased glucagon and triglyceride concentrations,[9] which likely reflects their metabolic balance and energy needs. The main function of glucagon is to increase blood glucose concentrations by promoting gluconeogenesis and glycogenolysis, which in sick foals could be seen as an appropriate response. The low insulin concentrations in septic foals is likely a response to hypoglycemia; however, in foals with hyperglycemia, low insulin values should be considered inadequate. These are the foals that could not regulate glycemia and may require insulin therapy. This is also an indication of disease severity that often results in death.

The enteroinsular axis (EIA) is comprised of intestinal factors that stimulate the pancreas to secrete insulin. These include glucose-dependent insulinotropic polypeptide and glucagon-like peptide 1 secreted by K and L cells, respectively. These factors are also known as incretins and represent the basis for the new generation of drugs used to treated diabetes in people. The EIA seems to be more important than glucose in promoting insulin secretion.[38] Horses have a functional EIA and it has been proposed that increased EIA activity may contribute to the pathogenesis of equine metabolic syndrome.[39] It has been shown that the dynamics of the EIA in healthy newborn foals is different from horses, likely due to their diet (type and composition) and perhaps influenced by other endocrine factors in the immediate post-partum period.[36] Information on the EIA in healthy and sick foals is lacking. A recent study found that some septic foals have high glucagon-like peptide 1, but low insulin concentrations, despite their normo- to hyperglycemia.[40] This indicates a "disconnect" between the intestine (incretins) and insulin secretion, which could explain glucose intolerance in some severely ill foals (e.g., hyperglycemia in premature or septic foals).

The somatotropic axis consists of growth hormone (GH) from the pituitary gland, insulin-like growth factor 1 (IGF-1), mainly produced by the liver, and ghrelin from the stomach. The peripheral actions of GH are mediated IGF-1, therefore, an increase in GH should be followed by elevations in IGF-1 levels. Ghrelin is produced by gastric glandular cells in response to anorexia to promote hunger, but is also a potent GH secretagogue. Critically ill foals often have increased concentrations of GH,[35] but reduced levels of IGF-1, suggesting abnormal somatotropic axis signaling. This phenomenon has been termed "somatotropic axis resistance,"[35] which appears to be similar to insulin resistance in horses, but its clinical implications remain to be elucidated. This is supported by the fact the same foals with high GH also have increased ghrelin concentrations, indicating that the pituitary component of the axis is functional. Therefore, the evidence points at impaired signaling at the hepatocyte level. This is likely a consequence of systemic inflammation or endotoxemia, which are frequent findings in septic foals.

Leptin is an adipocyte-derived hormone (adipokine) considered to be the main regulator of satiety (anorexigenic factor; high leptin suppresses hunger) and its blood concentrations correlate with total body fat in horses, humans, dogs, and other species.[41] Leptin increases insulin sensitivity in different species. In newborn foals, leptin concentrations rise after birth to decline few days later.[42] No differences in blood leptin concentrations were found between healthy and sick foals.[9] However, leptin concentrations were lower in septic foals that died.[9] Information on this factor in foals remains minimal to determine its role in energy metabolism during health and disease.

Adiponectin is another adipocyte-derived peptide hormone, which is negatively correlated with body fat mass in horses and other species, but also increases insulin sensitivity.[41,43] Adiponectin promotes the cell membrane translocation GLUT4, increases glycolysis and fatty acid oxidation.[41] In neonatal foals, blood adiponectin concentrations were not different between healthy, sick non-septic, and septic foals.[44] Therefore, its role in the pathogenesis of energy dysregulation and systemic inflammation in the equine neonate remains to be elucidated.

Clinical Relevance

Critically ill foals often develop hypoglycemia due to energy deprivation, minimal energy reserves, bacteremia, or endocrine dysregulation. In foals with hypoglycemia or under a negative energy balance, low insulin, high glucagon, and high triglyceride concentrations indicate a proper homeostatic response to restore energy balance[9]; however, a failure of these mechanisms could be detrimental. In sick foals with persistent hyperglycemia (when blood glucose concentrations remain elevated for hours without minimal to no energy supplementation), reduced insulin secretion rather than insulin resistance should be suspected.[9,33] Insulin resistance does occur in critically ill foals, but recent studies have shown that most septic foals have low insulin concentrations.[9,33] In these cases, insulin replacement therapy to restore glycemia should be considered. Care should be taken with insulin administration to newborn foals because most are insulin sensitive and hypoglycemia may develop. It is advisable to use continuous-rate infusions (CRI) over intravenous or subcutaneous administration, with some exceptions (e.g., severe hyperglycemia). The recommended starting CRI for regular insulin is 0.0025 to 0.01 IU/kg/hour with steady increases every 2 to 4 hour to 0.2 IU/kg/h, even higher until normoglycemia is restored.[45–49] Glucose concentrations must be monitored closely to avoid hypoglycemia. It is important to mention that the concept of hyperglycemia and its implications differ between sick and healthy foals. Glucose concentrations of 200 to 250 mg/dL (11.1–13.9 mmol/L) in healthy foals can be normal, in particular after nursing, but in septic foals, these values are abnormal, in particular when receiving enteral feeding, parenteral dextrose or parenteral nutrition. Hyperglycemia in these animals is a consequence of endocrine dysregulation, organ dysfunction, or iatrogenic.

Incretin analogs to enhance insulin secretion have not been evaluated in horses or foals; however, they have become central to diabetes management in people and cats. The functionality of the EIA in healthy foals suggests that incretins could be a therapeutic alternative to insulin in sick foals with persistent hyperglycemia.

5. Thyroid Hormones

Thyroid hormones (THs) modulate cell growth, differentiation, thermogenesis, and energy metabolism. THs also influence the differentiation of other endocrine systems (adrenal gland, pancreas). Therefore, THs are essential for fetal development and subsequent survival. The secretion of THs is under the control of the hypothalamic-pituitary-thyroid axis. THs are produced by the follicular cells of the thyroid gland. THs include total T4, free T4, total T3, free T3, and reverse T3. Of these, free T3 is the active hormone. The secretion of THs is influenced by a number of factors, including age, physiological status, season, caloric intake, exogenous compounds, and diseases. Due to their pleiotropic functions, it is reasonable to assume that low TH concentrations in the developing fetus and newborn foal could have negative consequences. This is evident in foals with congenital hypothyroidism, which have musculoskeletal anomalies (tendon rupture, bone dysgenesis, angular/flexural deformities), prognatism, respiratory failure, inappropriate nervous tissue development, as well as other abnormalities. Recent studies have shown that premature, septic, and maladjusted foals often have low TH concentrations that are linked to disease severity and mortality.[35,50,51] Low thyroid hormone concentrations during critical illness does not equate to hypothyroidism. This condition is known as “euthyroid sick syndrome,” but in human medicine the term, “non-thyroidal illness syndrome,” is preferred. The clinical relevance of NTIS remains unclear.

Clinical Relevance

Low TH concentrations in sick newborn foals are associated with disease severity and mortality, which supports their importance in tissue development and differentiation. The value of TH replacement therapy has not been evaluated in hospitalized foals, but should be considered in foals with evidence of dysmaturity and severe sepsis. This subject remains controversial in human intensive care medicine.

6. Calcium and Magnesium

Total calcium (TCa) in circulation exists bound to proteins (albumin), in a free/ionized form (Ca^{2+}), and chelated to anions (lactate, bicarbonate, citrate). Calcium has multiple functions and its extracellular concentrations are regulated by parathyroid hormone (PTH), calcitonin, and 1,25-dihydroxyvitamin D_3 ($1,25(OH)_2D_3$; calcitriol). Low Ca^{2+} stimulates PTH secretion, which promotes renal reabsorption of Ca^{2+}, synthesis of $1,25(OH)_2D_3$, as well as bone resorption. Calcitriol inhibits parathyroid cell function and PTH secretion. Blood concentrations of TCa and Ca^{2+} are lower in foals (TCa = 10 to 13 mg/dL; Ca^{2+} = 4.1 to 7 mg/dL) than horses (TCa = 11 to 13.2 mg/dL; Ca^{2+} = 5.8 to 7 mg/dL),[52–56] which is important to know when assessing normal from abnormal or using horse-specific reference ranges. While TCa is reported in most biochemistry profiles, Ca^{2+} is seldom measured in foals. Foals with hypoproteinemia can have low TCa concentrations, but not have clinical hypocalcemia because Ca^{2+} concentrations are normal.[55,57] The same principles apply to magnesium (below).

Hypocalcemia is frequent in critically ill equine patients (foals and horses).[7,56,58] In foals with sepsis, hypocalcemia could lead to a number of abnormalities in other body systems (ileus, dysrhythmias, hyperexcitability, seizures). Most foals with hypocalcemia have an appropriate PTH response. However, there are few foals with low PTH (inappropriate secretion).[53,54,58] There are also foals with an exaggerated PTH secretion, which could be reflecting low vitamin D levels (see vitamin D section below).[54,58]

Other conditions associated with calcium dysregulation in newborn foals include idiopathic hypocalcemia and hypercalcemia/asphyxia syndrome. Idiopathic hypocalcemia refers to foals born hypocalcemic or that develop signs of hypocalcemia in the immediate post-partum period, are refractory to medical treatment, can be hypomagnesemic, and usually die.[55] A putative gene mutation for this condition was recently identified in Thoroughbred foals and this disorder was renamed equine familial isolated hypocalcemia.[59] Hypercalcemia of unknown reasons (idiopathic hypocalcemia) has been reported in a subset of sick foals. Some of these foals have a history of placental disease, dystocia, or perinatal asphyxia.

Total magnesium (TMg), similar to TCa, exists bound to proteins, free/ionized (Mg^{2+}), and chelated to anions.[60] Functions of magnesium include ion transport, energy generation/use, nucleic acid synthesis, neuromuscular excitability, and calcium homeostasis. Measurement of blood TMg and Mg^{2+} concentrations is becoming more common, in part result of the increasing awareness of magnesium disorders in horses and foals. Blood concentrations of TMg and Mg^{2+} tend to be similar between foals (TMg = 0.54 to 1.1 mmol/L; Mg^{2+} = 0.46 to 0.8 mmol/L) and horses (TMg = 0.53 to 1.2 mmol/L; Mg^{2+} = 0.46 to 0.8 mmol/L).[52,53,56,60,61]

Hypomagnesemia is frequent in septic foals, but rarely diagnosed because it is not reported in most chemistry profiles or considered a problem by clinicians.[53,60] Low magnesium could interfere with calcium homeostasis and energy regulation.[57,60]

Clinical Relevance

Parenteral calcium supplementation is rarely done in critically ill foals, but should be considered in severe hypocalcemia A standard treatment protocol is to add 10 to 20 mL of 23% calcium gluconate per liter of parenteral fluids and administer as a CRI or intermittent boluses.[55] Measurement of Ca^{2+} and Mg^{2+} concentrations is recommended to adjust dosing. Intravenous administration of magnesium sulfate ($MgSO_4$) is indicated for hypomagnesemia, refractory hypocalcemia, extended fasting, prolonged fluid therapy, and electrolyte abnormalities associated with parenteral nutrition and hyperglycemia (hypokalemia, hypophosphatemia, hypomagnesemia). It is also used to treat neurological disorders such as NMS and brain trauma.[8,60] A CRI of $MgSO_4$ (40 to 60 mg/kg/IV, loading dose; 50 to 150 mg/kg/day/IV, CRI) is the best way to supplement magnesium to hospitalized foals.[8,60] One practical approach is to add 2 grams of $MgSO_4$ per liter of isotonic solution and administer intermittently (500 to 1000 ml/IV, every 4 to 6 hours).

7. Vitamin D

Vitamin D derives from dietary sources (vitamin D_2 or ergocalciferol from fungi and plants; vitamin D_3 or cholecalciferol from animal-based diets) and from cutaneous activation of 7-dehydrocholesterol. Vitamin D_3 (cholecalciferol) is synthesized in the skin after photolytic cleavage of 7-dehydrocholesterol. Subsequently, cholecalciferol is converted in the liver to 25-hydroxyvitamin D_3 [25(OH)D_3] by 25-hydroxylase, which is transported to the kidneys to be converted by 1α-hydroxylase to the active metabolite, 1,25$(OH)_2D_3$ (calcitriol). Vitamin D_2 (ergocalciferol) is a major source of vitamin D for horses[55,62]; however, its relevance in foals, based on their type of diet, remains unclear. Once in circulation, ergocalciferol follows the same processing steps as cholecalciferol in the liver and kidney. Hepatic activation of vitamin D is poorly regulated and blood levels of 25(OH)D reflect total body stores.[55] In contrast, renal activation of 25(OH)D to 1,25$(OH)_2$D is highly regulated by PTH, calcium, phosphorus, fibroblast growth factor-23 (FGF-23), and 1,25$(OH)_2$D.[55] Therefore, 1,25$(OH)_2$D concentrations reflect daily homeostatic adjustments more than the vitamin D status.

Vitamin D promotes intestinal absorption and renal reabsorption of calcium and phosphorus, modulates bone remodeling, and suppresses PTH synthesis. Other functions of vitamin D include immune modulation, antimicrobial actions (via cathelicidins and β-defensins; both antimicrobial peptides), anti-inflammatory properties, epithelial/endothelial integrity, and energy metabolism. Vitamin D concentrations are lower in healthy foals (25[OH]D = 9.3 to 22 ng/mL) compared to horses (25[OH]D = 14.3 to 37.2 ng/mL).[54,63]

Hypovitaminosis D is highly prevalent in critically ill foals and associated with mortality.[54,58] Dysregulation of the FGF-23/klotho axis seems to contribute to the pathogenesis of hypovitaminosis D in sick foals.[58] Septic foals have high concentrations of FGF-23, which is a potent inhibitor of 1α-hydroxylase, the enzyme responsible for vitamin D activation in the kidney.

Due to its pleiotropic actions, vitamin D deficiency could contribute to hypocalcemia, bone abnormalities, epithelial disruption, loss of endothelial integrity, bacterial infections due to reduced antibacterial peptides, impaired immune response, energy dysregulation, and a pro-inflammatory state (relevant to sick foals). This opens the question as to whether vitamin D replacement therapy should be investigated in hospitalized foals. In human medicine, there are a number of clinical trials evaluating the benefits of vitamin D therapy in critically ill adults and children.[64,65]

Clinical Relevance

Based on recent studies in foals[54,58] as well as controlled human trials,[64,65] there is a valid justification to evaluate the potential benefits of vitamin D therapy in sick newborn foals.

8. Other Endocrine Systems

Recent studies in newborn foals have documented dysregulation in other endocrine systems;[14,22,58,66,67] however, their clinical implications remain to be elucidated.

The renin-angiotensin-aldosterone system (RAAS) is activated in most critically ill hypotensive foals,[22] which is an adequate response to improve intravascular volume and tissue perfusion. Foals with very cold extremities and a poor RAAS response are less likely to survive.[22,68] The RAAS and HPAA are highly interactive systems and factors from one can activate the other. As mentioned in the HPAA section, a subset of septic foals with RAI have low cortisol and aldosterone secretion,[7,12,18,19,22,23] which directly and indirectly impairs tissue perfusion and organ function. Vasopressin (AVP; antidiuretic hormone) is a potent vasopressor and its concentrations are increased in most critically ill foals[7]; however, low concentrations could contribute hypovolemia, tissue hypoperfusion, and foal mortality.[18] In fact, AVP and analogs are used to increase blood pressure and tissue perfusion in septic foals.[7,49] It has been shown that adrenomedullin, a potent vasodilator, can be increased in critically ill foals.[66] This, combined with reduced vasopressors (angiotensin-II, vasopressin), can further impair the effective circulating blood volume and organ function.

Catecholamines have a multitude of functions; they are essential in the transition from intrauterine to extra-uterine life, energy regulation, cardiovascular activity, and tissue perfusion. Some data on adrenaline and noradrenaline is available in healthy foals,[14] but not much in sick ones. For example, the sympathoadrenal response to stress (e.g., insulin-induced hypoglycemia) in equine fetuses at the end of gestation is noradrenergic, while in the post-partum period it is mainly adrenergic.[14] Considering that noradrenaline is more effective before birth, it has been proposed to be the vasopressor of choice for premature and critically ill foals.[14]

One study found minimal differences in atrial natriuretic peptide (ANP) in hospitalized foals compared with horses.[67] The main function of ANP is to increase renal excretion of sodium; however, the clinical relevance of this peptide in sick foals remains to be determined.

The FGF-23/klotho axis is a recently described system with central functions in calcium, phosphorus, vitamin D, and PTH regulation.[69] FGF-23 is considered the main phosphorus-regulating hormone and is secreted by osteocytes and osteoblasts in response to $1,25(OH)_2D$, PTH, and phosphorus concentrations.[55,69] It promotes renal phosphorus excretion by decreasing its renal reabsorption and suppressing 1α-hydroxylase activity, therefore, $1,25(OH)_2D$ synthesis. It also inhibits PTH synthesis and secretion. Klotho is a transmembrane protein that is also found in circulation and functions as the co-receptor for FGF-23.[69,70] It was recently shown that critically ill foals have increased FGF-23 and reduced klotho concentrations that are linked to hypovitaminosis D, disease severity, and mortality.[58] In human medicine, there has been extensive research on the FGF-23/klotho axis, showing that it has major clinical and prognostic implications, in particular in renal and cardiovascular disease.[69,70]

9. Take-Home Message

- The central goal of the endocrine systems in the developing equine fetus and neonate is to promote tissue differentiation and maintain homeostasis to assure survival in the transition from a protected intrauterine environment to the challenges of extrauterine life.
- Endocrine dysregulation is frequent in critically ill foals, often associated with disease severity and outcome. While information for some endocrine factors is available, data for most is lacking, and their interplay could be central to disease progression and survival.
- Endocrinopathies during critical illness contribute to imbalances of behavior, energy, fluid and electrolytes, oxygen and nutrient delivery, immunity, inflammation, cardiovascular function, neuromuscular activity, and tissue differentiation, ultimately reducing the odds of survival if homeostatic systems fail or therapies are not implemented timely and appropriately.
- Additional research on endocrinopathies impacting the newborn foal (e.g., sepsis, dysmaturity, maladjustment syndrome) could have preventative, therapeutic, and financial implications.

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Declaration of Ethics

The Author has adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Author has no conflicts of interest.

References

1. Barton MH, Morris DD, Norton N, et al. Hemostatic and fibrinolytic indices in neonatal foals with presumed septicemia. *J Vet Intern Med* 1998;12:26–35.

2. Cohen ND. Causes of and farm management factors associated with disease and death in foals. *J Am Vet Med Assoc* 1994;204:1644–1651.
3. Furr M, Tinker MK, Edens L. Prognosis for neonatal foals in an intensive care unit. *J Vet Intern Med* 1997;11:183–188.
4. Gayle JM, Cohen ND, Chaffin MK. Factors associated with survival in septicemic foals: 65 cases (1988–1995). *J Vet Intern Med* 1998;12:140–146.
5. Hoffman AM, Staempfli HR, Willan A. Prognostic variables for survival of neonatal foals under intensive care. *J Vet Intern Med* 1992;6:89–95.
6. Stewart AJ, Hinchcliff KW, Saville WJ, et al. Actinobacillus sp. bacteremia in foals: Clinical signs and prognosis. *J Vet Intern Med* 2002;16:464–471.
7. Hurcombe SD, Toribio RE, Slovis N, et al. Blood arginine vasopressin, adrenocorticotropin hormone, and cortisol concentrations at admission in septic and critically ill foals and their association with survival. *J Vet Intern Med* 2008;22: 639–647.
8. Toribio RE. Equine neonatal encephalopathy: Facts, evidence, and opinions. *Vet Clin North Am Equine Pract* 2019; 35:363–378.
9. Barsnick RJ, Hurcombe SD, Smith PA, et al. Insulin, glucagon, and leptin in critically ill foals. *J Vet Intern Med* 2011;25:123–131.
10. O'Connor SJ, Fowden AL, Holdstock N, et al. Developmental changes in pulmonary and renal angiotensin-converting enzyme concentration in fetal and neonatal horses. *Reprod Fertil Dev* 2002;14:413–417.
11. O'Connor SJ, Gardner DS, Ousey JC, et al. Development of baroreflex and endocrine responses to hypotensive stress in newborn foals and lambs. *Pflugers Arch* 2005;450:298–306.
12. Dembek KA, Timko KJ, Johnson LM, et al. Steroids, steroid precursors, and neuroactive steroids in critically ill equine neonates. *Vet J* 2017;225:42–49.
13. Toribio RE. Endocrine dysregulation in critically ill foals and horses. *Vet Clin North Am Equine Pract* 2011;27: 35–47.
14. Fowden AL, Forhead AJ, Ousey JC. Endocrine adaptations in the foal over the perinatal period. *Equine Vet J Suppl* 2012:130–139.
15. Giussani DA, Spencer JAD, Hanson MA. Fetal cardiovascular reflex responses to hypoxaemia. *Fetal Matern Med Rev* 1994;6:17–37.
16. Silver M, Fowden AL. Prepartum adrenocortical maturation in the fetal foal: Responses to ACTH. *J Endocrinol* 1994;142:417–425.
17. Wood CE. Baroreflex/chemoreflex control of fetal hormone secretion. *Reprod Fertil Dev* 1995;7:479–489.
18. Dembek KA, Hurcombe SD, Stewart AJ, et al. Association of aldosterone and arginine vasopressin concentrations and clinical markers of hypoperfusion in neonatal foals. *Equine Vet J* 2016;48:176–181.
19. Dembek KA, Johnson LM, Timko KJ, et al. Multiple adrenocortical steroid response to administration of exogenous adrenocorticotropic hormone to hospitalized foals. *J Vet Intern Med* 2019;33:1766–1774.
20. Hart KA, Barton MH. Adrenocortical insufficiency in horses and foals. *Vet Clin North Am Equine Pract* 2011;27:19–34.
21. Hart KA, Barton MH, Vandenplas ML, et al. Effects of low-dose hydrocortisone therapy on immune function in neonatal horses. *Pediatr Res* 2011;70:72–77.
22. Dembek K, Onasch K, Hurcombe SD, et al. Renin-angiotensin-aldosterone system response and ratios in hospitalized newborn foals. *J Vet Intern Med* 2013;27:331–338.
23. Hart KA, Heusner GL, Norton NA, et al. Hypothalamic-pituitary-adrenal axis assessment in healthy term neonatal foals utilizing a paired low dose/high dose ACTH stimulation test. *J Vet Intern Med* 2009;23:344–351.
24. Hart KA, Slovis NM, Barton MH. Hypothalamic-pituitary-adrenal axis dysfunction in hospitalized neonatal foals. *J Vet Intern Med* 2009;23:901–912.
25. Marik PE. Critical illness–related corticosteroid insufficiency. *Chest* 2009;135:181–193.
26. Moraes RB, Czepielewski MA, Friedman G, et al. Diagnosis of adrenal failure in critically ill patients. *Arq Bras Endocrinol Metabol* 2011;55:295–302.
27. Hart KA, Dirikolu L, Ferguson DC, et al. Daily endogenous cortisol production and hydrocortisone pharmacokinetics in adult horses and neonatal foals. *Am J Vet Res* 2012;73: 68–75.
28. Conley AJ. Review of the reproductive endocrinology of the pregnant and parturient mare. *Theriogenology* 2016;86: 355–365.
29. Swink JM. MS Thesis:—Sex steroids and the effect of in-utero altrenogest exposure in neonatal foals, College of Veterinary Medicine, The Ohio State University; 2020.
30. Aleman M, Pickles KJ, Conley AJ, et al. Abnormal plasma neuroactive progestagen derivatives in ill, neonatal foals presented to the neonatal intensive care unit. *Equine Vet J* 2013;45:661–665.
31. Madigan JE, Haggettt EF, Pickles KJ, et al. Allopregnanolone infusion induced neurobehavioural alterations in a neonatal foal: Is this a clue to the pathogenesis of neonatal maladjustment syndrome? *Equine Vet J Suppl* 2012:109–112.
32. Muller V, Curcio BR, Toribio RE, et al. Cortisol, progesterone, 17αOHprogesterone, and pregnenolone in foals born from mare's hormone-treated for experimentally induced ascending placentitis. *Theriogenology* 2019;123:139–144.
33. Armengou L, Jose-Cunilleras E, Rios J, et al. Metabolic and endocrine profiles in sick neonatal foals are related to survival. *J Vet Intern Med* 2013;27:567–575.
34. Barsnick RJ, Hurcombe SD, Dembek K, et al. Somatotropic axis resistance and ghrelin in critically ill foals. *Equine Vet J* 2014;46:45–49.
35. Himler M, Hurcombe SD, Griffin A, et al. Presumptive nonthyroidal illness syndrome in critically ill foals. *Equine Vet J Suppl* 2012:43–47.
36. Rings LM, Swink JM, Dunbar LK, et al. Enteroinsular axis response to carbohydrates and fasting in healthy newborn foals. *J Vet Intern Med* 2019;33:2752–2764.
37. Hollis AR, Furr MO, Magdesian KG, et al. Blood glucose concentrations in critically ill neonatal foals. *J Vet Intern Med* 2008;22:1223–1227.
38. Holst JJ. The incretin system in healthy humans: The role of GIP and GLP-1. *Metabolism* 2019;96:46–55.
39. de Laat MA, McGree JM, Sillence MN. Equine hyperinsulinemia: Investigation of the enteroinsular axis during insulin dysregulation. *Am J Physiol Endocrinol Metab* 2016; 310:E61–E72.
40. Rings LM. MS Thesis—Enteroinsular axis response to carbohydrates and fasting in healthy neonatal foals, College of Veterinary Medicine, The Ohio State University; 2019.
41. Barsnick RJ, Toribio RE. Endocrinology of the equine neonate energy metabolism in health and critical illness. *Vet Clin North Am Equine Pract* 2011;27:49–58.
42. Berg EL, McNamara DL, Keisler DH. Endocrine profiles of periparturient mares and their foals. *J Anim Sci* 2007;85: 1660–1668.
43. Kearns CF, McKeever KH, Roegner V, et al. Adiponectin and leptin are related to fat mass in horses. *Vet J (London, England: 1997)* 2006;172:460–465.
44. Barsnick RJ, Hurcombe SD, Saville WJ, et al. Endocrine energy response in septic foals: insulin, leptin and adiponectin, in *Proceedings*. Am Coll Vet Int Med Forum, 2009 (Abstr 117).
45. Buechner-Maxwell VA. Nutritional support for neonatal foals. *Vet Clin North Am Equine Pract* 2005;21:487–510, viii.
46. Han JH, McKenzie HC, McCutcheon LJ, et al. Glucose and insulin dynamics associated with continuous rate infusion of dextrose solution or dextrose solution and insulin in healthy and endotoxin-exposed horses. *Am J Vet Res* 2011;72:522–529.

47. Krause JB, McKenzie HC 3rd. Parenteral nutrition in foals: A retrospective study of 45 cases (2000–2004). *Equine Vet J* 2007;39:74–78.
48. McKenzie HC 3rd, Geor RJ. Feeding management of sick neonatal foals. *Vet Clin North Am Equine Pract* 2009;25: 109–119, vii.
49. Palmer J. Update on the management of neonatal sepsis in horses. *Vet Clin North Am Equine Pract* 2014;30:317–336, vii.
50. Breuhaus BA. Thyroid function and dysfunction in term and premature equine neonates. *J Vet Intern Med* 2014;28: 1301–1309.
51. Pirrone A, Panzani S, Govoni N, et al. Thyroid hormone concentrations in foals affected by perinatal asphyxia syndrome. *Theriogenology* 2013;80:624–629.
52. Berlin D, Aroch I. Concentrations of ionized and total magnesium and calcium in healthy horses: Effects of age, pregnancy, lactation, pH and sample type. *Vet J* 2009;181:305–311.
53. Hurcombe SD, Toribio RE, Slovis NM, et al. Calcium regulating hormones and serum calcium and magnesium concentrations in septic and critically ill foals and their association with survival. *J Vet Intern Med* 2009;23:335–343.
54. Kamr AM, Dembek KA, Reed SM, et al. Vitamin D metabolites and their association with calcium, phosphorus, and pth concentrations, severity of illness, and mortality in hospitalized equine neonates. *PLoS One* 2015;10:e0127684.
55. Toribio RE. Disorders of calcium and phosphorus. In: Reed SM, Bayly WM, Sellon DC, eds. *Equine internal medicine*. 4th ed. St. Louis, MO: Elsevier; 2018, 1029–1052.
56. Toribio RE, Kohn CW, Chew DJ, et al. Comparison of serum parathyroid hormone and ionized calcium and magnesium concentrations and fractional urinary clearance of calcium and phosphorus in healthy horses and horses with enterocolitis. *Am J Vet Res* 2001;62:938–947.
57. Toribio RE. Disorders of calcium and phosphate metabolism in horses. *Vet Clin N Am Equine Pract* 2011;27:129–147.
58. Kamr AM, Dembek KA, Hildreth BE 3rd, et al. The FGF-23/klotho axis and its relationship with phosphorus, calcium, vitamin D, PTH, aldosterone, severity of disease, and outcome in hospitalised foals. *Equine Vet J* 2018;50:739–746.
59. Finno CJ, Rivas V, Slovis N, et al. Identification of a putative genetic mutation for idiopathic hypocalcemia in Thoroughbred foals, in *Proceedings*. Am Coll Vet Int Med Forum, 2019.
60. Toribio RE. Magnesium and disease. In: Reed SM, Bayly WM, Sellon DC, eds. *Equine internal medicine*. 4th ed. St. Louis, MO: Elsevier; 2018, 1052–1058.
61. Mariella J, Isani G, Andreani G, et al. Total plasma magnesium in healthy and critically ill foals. *Theriogenology* 2016;85:180–185.
62. Azarpeykan S, Dittmer KE, Gee EK, et al. Influence of blanketing and season on vitamin D and parathyroid hormone, calcium, phosphorus, and magnesium concentrations in horses in New Zealand. *Domest Anim Endocrinol* 2016; 56:75–84.
63. Pozza ME, Kaewsakhorn T, Trinarong C, et al. Serum vitamin D, calcium, and phosphorus concentrations in ponies, horses and foals from the United States and Thailand. *Vet J* 2014;199:451–456.
64. Amrein K, Schnedl C, Holl A, et al. Effect of high-dose vitamin D3 on hospital length of stay in critically ill patients with vitamin D deficiency: The VITdAL-ICU randomized clinical trial. *JAMA* 2014;312:1520–1530.
65. McNally D, Amrein K, O'Hearn K, et al. Study protocol for a phase II dose evaluation randomized controlled trial of cholecalciferol in critically ill children with vitamin D deficiency (VITdAL-PICU study). *Pilot Feasibility Study* 2017; 3:70.
66. Toth B, Slovis NM, Constable PD, et al. Plasma adrenomedullin concentrations in critically ill neonatal foals. *J Vet Intern Med* 2014;28:1294–1300.
67. Hollis AR, Boston RC, Corley KT. Plasma aldosterone, vasopressin and atrial natriuretic peptide in hypovolaemia: A preliminary comparative study of neonatal and mature horses. *Equine Vet J* 2008;40:64–69.
68. Dembek KA, Hurcombe SD, Frazer ML, et al. Development of a likelihood of survival scoring system for hospitalized equine neonates using generalized boosted regression modeling. *PLoS One* 9:e109212, 2014.
69. Kuro-o M. Overview of the FGF23-Klotho axis. *Pediatr Nephrol* 2010;25:583–590.
70. Hu MC, Kuro-o M, Moe OW. The emerging role of Klotho in clinical nephrology. *Nephrol Dial Transplant* 2012;27: 2650–2657.

Diarrhea in the Neonate: Is There Anything Really New?

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1. Introduction

Gastrointestinal failure is associated with a variety of disorders in foals. Failure of this organ system may manifest as diarrhea, ileus, abdominal pain, obstipation, and weight loss. Clinical syndromes associated with gastrointestinal failure include enteritis, colic, meconium impactions, gastric reflux, and necrotizing enterocolitis. The following will review the pathogenesis, clinical manifestation, diagnosis, and treatments for equine neonatal diarrhea.

Infectious causes of enteritis in neonates include Rotavirus, Coronavirus, *Salmonella, Clostridium perfringens A* and *C* (*C. perfringens*), *Clostridium difficile* (*C. difficile*), *Campylobacter, Enterococcus durans* (*E. durans*), *Bacteroides fragilis*, and *Rhodococcus equi*.

2. Rotavirus

Foals are most susceptible to viral diarrheas during the neonatal, perinatal, and suckling periods by virtue of being immunological naïve.[1] *Rotavirus* is a genus within the family Reoviridae. By electron microscopy, the viruses are noted to be about 70 to 80 nm in size and look like wheels (*rota* is derived from the latin word "wheel") with short spokes radiating from a wide central hub. Rotaviruses are all double stranded, ribonucleic acid (RNA), non-enveloped viruses. Rotavirus is subdivided into several groups (A through G) based on differences in the group specific inner capsid protein, VP6. There are three rotavirus groups (A, B, and C) that cause disease in humans compared to only 1 group that affects the equine species (Group A).[2] Equine rotavirus can be further subdivided using neutralizing antibodies to the VP4 and VP7 outer capsid proteins into P (proteinase sensitive, VP4 positive) and G (Glycoprotein, VP-7 positive) serotypes.[3] Five P serotypes (P1, P6, P7, P12, and P18) and eight G serotypes (G1, G3, G5, G8, G10, G13, G14, and G16) have been identified in horses.[3] In 2017, Dr. Udeni Balasuriya processed 108 diarrhea samples from foals $<$ 6 months of age located at 38 farms in Central Kentucky, and 23/108 (21%) of the diarrheal samples were positive for Equine Rotavirus Type A.[4] Further assessment detected that 17/23 (74%) were the G14 Strain, 6/23 (26%) were the G3 Strain, while one foal was coinfected with both. Previous studies conducted in Kentucky noted that 100% of the Equine Rotavirus Type A were the G3 Strain. This is particular disturbing because various genetic and antigenic variants of G3 and G14 are circulating in the horse population in Central Kentucky, and they significantly differ from the vaccine strain currently used in the field.

NOTES

Clinical Signs

Clinical signs of disease have been reported only among foals < 6 months old and most often among foals < 3 months old.[5] Signs include diarrhea, lethargy, anorexia, and abdominal tympani. A 3-year study of horse farms in central Kentucky during the 1980s noted that rotavirus was the most common cause of diarrhea in foals.[5] Rotavirus is species specific with an incubation period of 1 to 2 days. The virus invades the intestinal epithelium on the sides and the tips of the villi. The brush border epithelium of the small intestine synthesizes disaccharides to monosaccharides (glucose and galactose), which are absorbed in the gut. Destruction of the brush border villi results in decreased lactase formation, which results in lactose not being digested. This sugar remains in the lumen of the gut, osmotically attracting more fluid. This effect is compounded as bacteria in the large intestine ferment the lactose into acetate, propionate and butyrate, which increase osmolality of the colonic contents.[6]

Foals infected with rotavirus may shed the virus for up to 10 days.[7,8] Some horses may shed the virus for up to 8 months. The virus can persist in the environment for up to 9 months.[8]

Diagnosis

Diagnosis requires detection of the virus in feces. The tests include electron microscopy, enzyme-linked immunoassay (ELISA), polymerase chain reaction (PCR), and latex agglutination virogen rotatest.[a] In a recent study by the author it was noted that when comparing the human specific rotavirus antigen detection (Rotatest) with an equine specific real-time PCR (IDEXX Equine Diarrhea Panel RealPCR™) we uncovered the inadequacy of using some human diagnostic tests in veterinary medicine (false negatives). Analysis of 35 samples with the human specific rotavirus immunoassay resulted in no positive results. Within that group of samples, 13 tested positive by real-time PCR. Real-time was confirmed by resequencing VP4 and VP7 genes with outside primers. Sequences showed 98% identities to equine rotavirus isolates deposited in GenBank. These results suggest that the immunoassay with human specificity may not detect some of the equine isolates.

Treatments

Treatments are generally empirical and symptomatic including precautionary antibiotics and antiulcer medications (Carafate, 1 gram per 50-kg body weight PO q6h and/or omeprazole, 1 to 4 mg/kg PO q24h). Lactase[b] 6,000 food chemical codex lactase U/50 kg PO q3-8h for 10 to 14 days have been used to improve digestion of milk lactose. Antidiarrheal medications such as bismuth subsalicylate (1 to 3 mL/kg PO q24h to q6h) may help reduce bowel inflammation and provide for secondary toxin absorption and resorption when combined with activated charcoal (1 gram/kg q24h). Neostigmine (1 mg SQ q1-8h, IV if severe tympany) is often used to help relieve gastrointestinal tympany. Fluid therapy is necessary to correct hydration, shock, and electrolyte imbalances. Prevention of this disease includes proper hygiene and the use of phenol disinfectants because bleach is ineffective against this virus. A commercial modified live vaccine[c] is currently available for use in mares prior to foaling to help accentuate colostral antibodies.[5] It has been noted that foals from vaccinated mares can still become infected with rotavirus although the clinical signs may be attenuated. One novel treatment plan that may be used as an adjunctive treatment for viral causes of diarrhea is the use of Bentonite clay.[d9]

3. Coronavirus

Equine coronavirus was isolated and characterized only recently in 2000 but described as an infectious agent in sick foals in 1976.[10,11] Several studies and case reports have identified coronaviruses in foals with enteric disease but the pathogenicity and its etiologic role in enteric disease have not been examined. A recent prevalence study in Central Kentucky by the author clearly shows that healthy foals without signs of GI disease are equally infected with equine coronavirus as sick animals. This finding suggests low pathogenicity of ECoV in foals. However, when analyzed as a coinfecting agent, ECoV was significantly associated with diseased animals: all ECoV infections in the GI diseased group were associated with coinfections (15 of 15) while foals in the healthy group were mostly monoinfected (8 of 10).[12] This finding would support the theory that (certain) viruses primarily act as immune suppressing agents allowing opportunistic infections to take place.[13] Opportunistic infections can be of different origin, including bacterial or protozoal, as shown in this study. Coinfection data in piglets clearly indicate that coronavirus and bacterial coinfections have a significant effect on the magnitude of the inflammatory immune response and the amount of tissue damage compared to single infected animals.[14] Furthermore, in young turkeys, coronavirus, and enteropathogenic *Escherichia coli* (EPEC) were shown to synergistically interact and cause severe growth depression and high mortality when compared to monoinfected turkeys.[15] In this study, turkeys infected first with coronavirus and then with EPEC developed numerically greater mortality, significantly lower survival probability, and increased frequency of attaching and effacing lesions than that observed in turkeys inoculated with EPEC prior to turkey coronavirus or simultaneously inoculated with these agents; these observations not only suggest a role for coronavirus in foals, they also suggest diagnostic value of detecting ECoV in apparently healthy foals to assess their susceptibility for potentially detrimental coinfections. In coronavirus-infected healthy foals, the focus could be directed toward epidemiological aspects in order to reduce the likelihood of coinfections. Clearly, additional studies are needed to determine equine coronavirus virulence factors and the relative importance as a coinfecting agent to contribute to GI disease in foals.

Diagnosis

Diagnosis can be made using polymerase chain reaction, virus isolation, or electron microscopy.

Treatment

Refer to the Rotavirus section for treatment. Currently there is an ultra-purified Bentonite clay that is available for the use in horses that has the same composition as a product being investigated for human rotavirus or coronavirus.[d,11]

4. *C. difficile*

C. difficile is the agent that causes pseudomembranous colitis associated with antibiotics in humans. It is now being identified in recent years as a significant nosocomial pathogen for equine as well as human patients. First described in 1935 by Hall and O'Toole, this gram-positive anaerobic bacillus was named "the difficult clostridium" because it resisted early attempt at isolation and grew very slowly. The organisms were found in stool specimens from healthy human neonates (up to 50%), which led to its classification as a commensal and was subsequently ignored as a potential pathogen. In the 1960s and 1970s, antibiotic-associated pseudomembranous colitis became a major clinical problem, which was attributed to mucosal ischemia or viral infection. In 1977, Larson et al[16] reported that stool specimens from affected patients contained a toxin that produced cytopathic changes in tissue culture cells. *C. difficile* was identified as the source of the cytotoxin. It is now clear that *C. difficile* is responsible for virtually all cases of human pseudomembranous colitis and 20% of the cases of antibiotic-induced colitis.

Pathogenesis

Pathogenesis of antibiotic-associated diarrhea/colitis begins with a disruption of colonization resistance (disruption of the normal colonic flora) of *C. difficile*. Colonization occurs by the oral-fecal route. *C. difficile* forms heat-resistant spores that can persist in the environment for years. These spores can survive the acid environment of the stomach and convert to vegetative forms in the colon. Environment contamination by *C. difficile* is particularly common in human hospitals that have reported isolation rates of 11.7% to 29%.[17] Health care personnel may carry bacteria on their hands, under rings, or on stethoscopes, but fecal carriage by staff is rare. High rates of infection can be isolated from stalls (hospital rooms), scales, thermometers, and surgical preparation room.[17] *C. difficile* has also been implicated in an outbreak of colitis.[17,18]

When established in the colon, pathogenic strains of *C. difficile* produce toxins that cause diarrhea and colitis. **Strains that do not produce toxins are not pathogenic.** Two large exotoxins, toxin A (enterotoxin) and toxin B (cytotoxin) are produced by *C. difficile.* Toxins A and B appear to act synergistically which cause fluid secretion, mucosal damage, and intestinal inflammation. Toxin A is also a chemoattractant for human neutrophils *in vitro*.[19] A third toxin, an actin-specific ADP-robosyltransferase (binary toxin), has been identified in certain strains of *C. difficile* isolated from human patients. The role and the pathogenesis of binary toxin is unclear, but it may act synergistically with toxins A and B.[20,21] The toxic effects appear to follow binding of toxins to membrane receptors. After binding to its intestinal receptor, Toxin A enters the cell and alters the actin cytoskeleton, leading to cell rounding. Toxin B causes the identical rounding.

In human medicine, *difficile* is generally acquired in the hospital setting. Neonatal colonization is common but almost invariably asymptomatic despite stool cytotoxin levels may be similar to those in adults with severe colitis. Over 50% of healthy human infants have transient colonies of toxicogenic *C. difficile*. Baverud et al[22] demonstrated that neither *C. difficile* or cytotoxin B was found in the fecal flora of 56 healthy foals (14 days to 4 months of age) not being treated with antibiotics. Similarly, a small percentage of foals are reported to be asymptomatic carriers with reported rates ranging from 0% to 3%. Reported rates of asymptomatic carriers in adult horse populations are very similar to that of humans (<1% to 15% of healthy adults) range from 0% to 4%.[6,20] This organism, therefore, is most likely a minor and uncommon component of the usual gastrointestinal tract flora. Diarrhea and fatal hemorrhagic necrotizing enterocolitis have been reported to occur in neonatal foals infected with toxigenic strains of *C. difficile*, and *C. difficile* may be a primary pathogen in foals, not requiring prior antimicrobial use for development of the disease.[20]

Clinical Presentation

Clinical presentation of *C. difficile* in foals range from low-grade diarrhea to fulminate colitis with ileus. The foals with severe colitis become anorexic and dehydrated. In addition to the diarrhea, foals become tachypneic, which may be, secondary to discomfort associated with the enteritis, pyrexia, metabolic acidosis, or the anxiety of being in the hospital. Hypoproteinemia is also a feature of *C. difficile* secondary to the effects of toxins A and B leading to extravasation of plasma proteins. Metabolic acidosis is also consistent with clostridial enterocolitis and hypovolemia or gastrointestinal tract loss of bicarbonate. Hyponatremia may also be attributable to the gastrointestinal tract losses, as well as to an excess of free water associated with water consumption by these foals.

Diagnosis

Diagnosis of *Clostridium difficile* infection (CDI) depends on the demonstration of *C. difficile* toxins in the stool. Fecal PCR that incorporates primers for genes of toxins A and B can also be utilized. The cytotoxin assay that uses tissue cell culture had been the gold standard for diagnosis. It is the most sensitive test (sensitivity, 94% to 100%; and specificity, 90%), detecting as little as 10 pg of toxin B (this test is not used commonly because it is time consuming and expensive). Two enzyme immunoassays have been introduced that 1) detect toxin A/toxin B (*C. difficile* TOX A/B test, Techlab, Blacksburg VA) or 2) detect antigen of *C. difficile* and toxin A (TRIAGE® Micro; BIOSITE, San Diego CA 1–888-BIOSITE). These tests have a good sensitivity (69% to 87%) and specificity (99% to 100%). *C. difficile* TOX A/B test, Techlab has been validated for use in feces of horses.[23] PCR that incorporates primers to detect the genes for Toxin A and Toxin B can be used for diagnosis.

The author has conducted a study evaluating fecal samples that were *C. difficile* ELISA antigen positive and toxin negative compared to culture. In that study a 54% toxigenic (confirmed with PCR of the culture) recovery rate of *C. difficile* from antigen positive, toxin negative samples is similar to the 63% rate from a recent study of humans,[24] and these results can represent a diagnostic challenge. Overdiagnosis can lead to failure to investigate the true cause or unnecessary treatment, while underdiagnosis may result in missed treatment and infection control intervention opportunities. These results indicate that the presence of toxigenic *C. difficile* was not uncommon in those samples, suggesting the results were due to lower sensitivity of the toxin ELISA compared to the antigen ELISA or lack of production of toxins in the gut. Differentiating these two is difficult. While the clinical relevance of antigen positive, toxin negative results needs further study. Foals in this study all had enteritis that could be consistent with CDI, and few had other potential causes of disease identified. As a disease that is potentially treatable and a pathogen with infection control concerns, the presence of toxigenic *C. difficile* in a foal with signs consistent with CDI likely warrants treatment and use of appropriate infection control measures. Therefore, in the presence of clinical signs consistent with CDI in horses, it is prudent to consider an antigen-positive, toxin-negative result to be supportive of CDI.[24]

Treatment

Treatment in managing diarrhea and colitis with confirmed or suspected CDI is to discontinue antibiotic therapy, if possible. Specific therapy is aimed at eradicating *C. difficile* from the intestinal tract. Oral metronidazole is the drug of first choice. Foals less than 6 months of age are dosed at 10 to 15 mg/kg q12h to q8h.[25] The response rate for *C. difficile* in patients (humans) taking metronidazole is 98%. Patients who cannot tolerate oral medication because of an ileus may either receive the same dose per rectum or can be effectively treated with intravenous metronidazole at 10 mg/kg q8h to q6h. Excretion of the drug into bile and exudation from the inflamed colon results in bactericidal levels in the feces.[19] Metronidazole resistant strains of *C. difficile* have been isolated, and there are even reports of metronidazole inducing colitis. It is recommended that treatment be continued for 5 days past the resolution date of the diarrhea. A substantial number of human patients (10% to 20%) will have a relapse of *C. difficile* diarrhea. Various other approaches have been suggested for the management of relapses, including slow tapering of metronidazole therapy, bacteriotherapy with the use of nasogastric fecal transfaunation or fecal enemas, oral administration of nontoxigenic *C. difficile,* and treatment with the yeast *Saccharomyces boulardii* (may compete with *C. difficile* toxin A for binding sites on the intestinal epithelium).[26] *Saccharomyces boulardii* anecdotally can be given to a foal at a dose rate of 5 billion colony-forming units orally 2 times a day. One novel treatment plan currently used as an adjunctive treatment for both viral and bacterial causes of diarrhea is the use of Bentonite clay. Bentonite is effective because it bonds to a variety of toxins and prevents the absorption of toxins by coating the intestinal wall.[27] There is a hyperimmunized *Clostridium diffcle* Toxin A and B plasma that is currently available.[e] The efficacy of the plasma in resolving diarrhea/toxic insult is currently anecdotal.

5. *C. perfringens*

C. perfringens is a relatively ubiquitous bacterium that has been associated with enteric diseases in a number of diverse species.[28] It is widespread in the soil and is found in the alimentary tract of nearly all warm-blooded species. *C. perfringens* is a frequent postmortem invader in the alimentary tract's tissues of bloating cadavers. Therefore, one must be cautious about drawing conclusions based on the presence of the organisms in the tissues of these animals. Types of *C. perfringens* are differentiated (5 major types A, B, C, D, and E) based on the production of 4 major toxins; alpha, beta, epsilon, and iota. In addition, isolates may have the toxin genes known as CPE and NetF. It is produced by sporulating cells in an alkaline environment and is released upon lysis of these cells. It is resistant to proteolytic enzymes and will bind and insert on the brush border membrane causing pore formation in cells leading ultimately to cell lysis. Enterotoxin can be produced by all types of *C. perfringens* but is most commonly associated with type A. Many factors are involved in the production of enterotoxin by *C. perfringens*. In one study, the prevalence of CPE in feces of adult horses with diarrhea was 16% and detected in only 10% of the horses with colic regardless of whether or not they had diarrhea.[29] Studies investigating CPE in feces of adult horses and foals with diarrhea have produced variable results. CPE has been detected in the feces of 7% to 33% of adult horses with diarrhea and 28% of the foals with diarrhea.[28–30] Furthermore, out of 843 *C. perfringens* type A isolates from dogs, people, and horses that were genotyped, only 62 (7.3%) contained the CPE gene.[30]

Other toxins have been described associated with an unassigned type of *C. perfringens* that produces alpha-toxin and a β2-toxin was described.[31] It was isolated from piglets with necrotic enterocolitis and was also found in horses with enterocolitis. Since the alpha toxin, which is produced by all types of *C. perfringens* including non-pathogenic type A strains, is not considered a primary cause of digestive lesions, it was suggested that the β2-toxin, which is present in this new type of C. *perfringens,* is responsible for the lesions. In one study[31] β2-toxin was found in 52% of the horses with typical and atypical typhlocolitis. To a lesser extent, they were also isolated from horses with other intestinal disorders, in which they represented 37% of the isolates. No β2-toxinigenic *C. perfringens* has been found in healthy horses or in horses hospitalized for reasons other than intestinal problems.[31] Recently, a novel spore-forming toxin NetF has been strongly associated with foal-necrotizing enteritis.[32]

Pathogenesis

Pathogenesis of *C. perfringens* is based on their production of one or more of the 4 major exotoxins or enterotoxin. The factors that lead to the development of disease are not clear, but it is believed that there is an alteration of the normal flora that allows overgrowth of the clostridia. Proposed causes include diet changes, antibiotic therapy, stress, or concurrent infection. In adult ponies, enterocolitis has been produced when antibiotics (clindamycin or lincomycin) were given to the animals orally with a fecal cocktail containing clostridium.[33] However, fecal cocktail alone did not cause disease. Other factors that may play a role in the development are host factors such as age, immunity, and the presence or absence of intestinal receptors for the perfringens toxins. Beta toxin–producing types of *C. perfringens* (Type C) appear to cause enterocolitis in neonatal animals only. The digestive enzyme trypsin is produced by older animals and can inactivate the toxin. Neonatal animals have a less developed digestive enzyme production, thus may be more susceptible to disease caused by this toxin.[33] Most of the affected foals in one study had serum IgG concentrations of > 800 mg/dL, indicating adequate passive transfer. This finding helps support a theory that trypsin inhibitor in the dam's colostrum, which protects immunoglobulins from gastrointestinal breakdown, may potentially allow *C. perfringens* type C β-toxin to persist in foals with adequate passive transfer and may allow type C bacteria to overgrow.

Clinical Appearance

Clinical appearance of the disease is usually associated with foals < 5 days of age with a history of being obtunded, colicky, and/or having diarrhea for less than 24 hours. The animals usually present dehydrated with a severe colitis. Some of the animals may develop an ileus with evidence of colonic distention. Specific diagnosis and definitive diagnosis of equine clostridial enterocolitis requires both identification of toxins **and** isolation of the organism from intestinal contents. Isolation of the organism without the analysis for toxins is considered inappropriate because of the possibility of isolating a non-enterotoxigenic *C. perfringens* type A which can be isolated from normal horses' manure. In a population study of fecal shedding of *C. perfringens* in 128 broodmares and foals, *C. perfringens* was isolated from 90% of the normal 3-day-old foals: 85% were identified as type A; 12% of the samples had type A with the β2-toxin gene isolated; *C. perfringens* with the enterotoxin gene was identified in 2.1% of samples, and *C. perfringens* type C was identified in <1% of the samples. A presumptive diagnosis may be made (until culture and toxin analysis) by demonstration of abundant gram-positive bacteria in a fecal smear. However, this test did not appear to be sensitive because *C. perfringens* was isolated from 59% of samples in which no gram-positive rods were seen.[34] The diagnosis is supported by culture of fecal clostridia and further verify the isolates as *C. perfringens* by the use of a polymerase chain reaction method that incorporated primers that allowed for classification of *C. perfringens* types A, B, C, D, and E, as well as genes for β2-toxin and enterotoxin (CPE). However, toxin detection kits are commercially available for identification of CPE (*C. perfringens* enterotoxin test, ELISA, Techlab®, Blacksburg).

Treatment

Treatment for neonatal *C. perfringens* is considered a medical emergency. Even with the best care, many foals can die if infected with *C. perfringens type C*. Neonates with clostridiosis are at a higher risk for the development of peritonitis. When there is a large volume of peritoneal exudate, the prognosis is grave, and euthanasia would be recommended. If attempted, the treatment plan should be aggressive and aimed at the following areas: abdominal pain, septic shock, clostridial infection and toxin production, and maintenance of nutrition. The use of oral metronidazole 10 to 15 mg/kg 3 to 4 times daily (dose depends on severity) for foals and 15 mg/kg 3 to 4 times daily for adults. If the animal has an ileus and is intolerant of oral feeding, then the use of intravenous metronidazole is recommended at a dose of 10 mg/kg IV 4 times daily. Should the foal develop an ileus with marked colonic distention, the author has used neostigmine 1 to 2 mg (2 mg for foals greater than 250 pounds) SQ with good clinical response. So far subjectively, foals given the hyperimmunized plasma appeared to have their manure become formed faster than the patients not treated with the plasma.

Bentonite clay can also be used for treatment since it has been shown to adsorb *Clostridium perfringens* alpha, beta, and beta-2 exotoxins without interfering with absorption equine colostral antibodies.[35]

Numerous prophylactic measures can be instituted on farms with a history of *C. perfringens*–associated enterocolitis in foals. Optimal hygiene efforts to ensure cleanliness of the foaling stall and the mare (clean udder before and after birth, clean the perineal and hind-limb region) at parturition should be undertaken to decrease the degree of exposure of the foal to pathogens in the feces.[36] Some farms have stopped their outbreak of foal diarrhea by foaling the mares out in pasture. Specific preventative methods addressing *C. perfringens* include immunizing mares with the use of a toxoid vaccine (aluminum hydroxide–adsorbed culture supernatant plus recombinant β2-toxoid). The vaccine strain is a *C. perfringens* Type A that carries genes for Alpha, β2, NetF, and CPE that has been developed (2007) by Hagyard Equine Medical Institute. Other oral enteric protectants include the oral and/or administration of hyperimmunized plasma, which was previously mentioned. Specific immune treatments for *C. perfringens* types C and D do provide some protection against alpha-toxin, but it is generally believed that this protection would be inadequate against *C. perfringens* type A organisms.

6. Salmonella

Salmonella are gram negative, facultative, anaerobic bacteria, which usually can access the intestinal tract via the fecal-oral route. *Salmonella* commonly infects foals between 12 hours and 4 months of age. Young animals are more susceptible to *Salmonella* infections maybe because of a less sophisticated or less well established microflora within the gastrointestinal tract. The most common source of exposure and infection in the foal is another horse. Often, the mare herself is an asymptomatic carrier. Mares have been shown to shed *Salmonella* at or shortly after parturition despite having as many as 19 negative cultures before foaling.[37] Observations of foalings revealed that all mares defecate during stage 2 labor and that contamination of fetal membranes and the perineum/udder of the mare was possible if *Salmonella* was in the feces. During udder-seeking, the newborn foals will have extensive contact with the perineum and therefore may be at risk of *Salmonella* ingestion.

Once *Salmonella* has overcome the host defense mechanisms (gastric acidity, intestinal flora, peristalsis, intestinal mucus, and lactoferrin) the bacteria migrate through the enterocytes and access the lamina propria where they stimulate an inflammatory response. Both phagocytized and free *Salmonella* organisms travel via the lymphatics to regional lymph nodes where they persist in stimulating an inflammatory response. Salmonella can also reach circulation from efferent lymphatics. The neonate predisposition toward bacteremia and septicemia may be because of factors such as delayed gut closure at birth, immature cellular immune response and decreased complement activity. *Salmonella* enterotoxins, cytotoxins, and generalized inflammation within the bowel induces secretions of fluid from the intestinal epithelium.

Clinical Signs

Clinical signs of *Salmonellosis* are variable and can range from mild enteritis to severe septicemic shock. Diagnosis of *Salmonella* is demonstrated by a positive fecal or blood cultures. The author has seen foals present with fevers of unknown origin with no signs of diarrhea that have had positive blood and fecal cultures for *Salmonella.* Intermittent shedding *of Salmonella* is common and therefore a minimum of 3 to 5 consecutive 1-gram fecal cultures taken 24 hours apart are recommended.

Treatment

Treatment for salmonella is nonspecific and is aimed at maintaining hydration and electrolyte balance. Antibiotic therapy, even though it does not alter the clinical course of diarrhea or shedding of the organisms, should be initiated in foals to help prevent bacteremia. Polymyxin B (6000 IU/kg IV q8h) diluted in 1 L of fluids, flunixin meglumine (0.25 mg/kg q8h IV), and pentoxifylline (7.5 mg/kg PO q12h) all have been shown to reduce the effects of endotoxemia. Bismuth subsalicylate (1 to 3 mL/kg PO q4-8h) is also commonly used as a gastroprotectant secondary to its endotoxic and antiprostaglandin properties. J-5 plasma may also be given to aid in decreasing the systemic endotoxin level.

Prevention

Prevention of *Salmonella* consists of proper hygiene. Before the foal is able to nurse, the udder and perineal regions of the mare are to be thoroughly washed with dilute chlorohexidine or ivory soap and water. During an outbreak situation, foals should also be intubated with 6 to 8 oz of colostrum prior to contact with the mare.

An experimental inactivated bacterin (*Salmonella typhimurium and Newport*) vaccine has been developed by Hagyard Equine Medical Institute and Dr. John Timoney at the Gluck Research Center in Lexington, KY. This vaccine has been used on endemic farms since 2007.

7. *E. durans* (Group D Streptococcus)

E. durans is a gram-positive coccus in the alimentary tract that has been implicated as a cause of enteritis in foals, piglets, calves, and puppies. The author has documented *E. durans* as a cause of diarrhea in 5 of 7 foals that had developed diarrhea during the first 10 days of life.[38] In one study conducted in Australia, *E. durans* (isolated from a foal that had severe diarrhea) was experimentally infected in 7 foals (via stomach tube). All 7 foals developed profuse watery diarrhea within 24 hours of inoculation with varying degrees of depression, anorexia, abdominal tenderness, and dehydration.[39] The pathogenesis of diarrhea and enteric disease remains unknown. Diarrhea induced by *E. durans* is not associated with enterotoxin production or substantial mucosal injury. However, decreased activity of brush border digestive enzymes such as lactase and alkaline phosphatase suggest that there is a direct mechanical interference with digestion and absorption at the brush border.[39]

Treatment

Treatment for *E. durans* has not been adequately investigated but subjectively the β-lactams appear to help decrease the duration of the diarrhea (ampicillin or penicillin). The ideal treatment is to improve husbandry on the farm.

Formulating a Diagnostic Plan

The goal of the diagnostic plan for detecting pathogenic organisms is 3-fold.

1. Can we detect a pathogenic organism (qualitative testing)?
2. If a pathogenic organism is detected, then how much is present (quantification)?
3. If a pathogenic organism is detected, then identify it and if it is a bacterial organism, what is the antibiogram?

Methods utilized for pathogen detection for foal diarrhea may include microscopy, culture, immunological methods (ELISA), and molecular methods (PCR). The effectiveness of a proper diagnostic plan depends on the appropriate sample collection. Clinicians must be cognitive of safety precautions when collecting the fecal sample. The fecal samples should be at a minimum of 1 gram (size of an average adult's thumb nail) or 4 fecal swabs with adequate manure staining of the swabs. All sample collections should be collected while wearing gloves and placed in a leak-proof container to prevent environmental contamination during transport. Most pathogens resulting in foal diarrhea can cause a wide spectrum of overlapping clinical syndromes that make it difficult for the clinician to decide which organism(s) they test for in the feces. PCR is a molecular technique for the amplification of a DNA fragment via enzymatic replication. PCR has many advantages over conventional laboratory diagnostic techniques because it offers results that are quick, accurate, and affordable with high sensitivity and high specificity. Multiplex PCR is currently available that offers testing for a variety of enteric pathogens in just one fecal sample with a quick turnaround. The author prefers the use of a multiplex PCR over the use of single pathogen testing because a study has documented that the rate of coinfections as a cause for diarrhea in foals in central Kentucky is not uncommon.[12] If a veterinarian is in a situation where there are multiple cases of diarrhea occurring on a farm, they could pool the fecal samples in order to save money and perform a multiplex PCR for enteric pathogens. If a pathogen is detected then it can be assumed the pathogen that was detected is the causative agent. The author routinely performs fecal pooled testing for enteric pathogens and acknowledges that pooling fecal samples for equine enteric pathogens has been validated only for *Salmonella* enterica and not the other pathogens.[39]

8. Conclusion

Equine practitioners have always considered the availability of a correct etiologic diagnosis, particularly in contagious infections, to make early decisions on the patient's care and management, to address appropriate treatment, and to allow timely notification and discussion of management issues regarding prevention of disease spread a priority. Over the past years, both the understanding and characterization of existing and new equine infectious agents as well as the development of rapid, comprehensive, and affordable molecular diagnostic tools has experienced a rapid development. Recent advances in diagnostic technology have allowed for the development of various Equine Point of Care diagnostics (EPOCD). EPOCDs are able to achieve results in less than an hour and in some instances in less than a minute. Advantages of EPOCD for the equine practitioner would be to treat faster with test results while reducing the initial guess work and offering the patient optimal care with the end goal of better clinical outcomes. Several PCR Point of Care (POC) systems have recently entered the veterinary market. Companies such as Fluxergy LLC (Irvine, CA), Horiba's POCKIT Central PCR System (Japan) and Credo Biomedical's QubeMDx (Singapore) offer a variety of veterinary PCR assays. Credo's QubeMDx PCR does not offer any equine testing at this time but does offer canine and feline infectious disease testing. Fluxergy is unique in that they have been concentrating on primarily equine PCR POC technology. These advances will not only help practitioners make an accurate diagnosis but will be utilized to discover new pathogens affecting the foal's alimentary tract.

Acknowledgments

Declaration of Ethics

The Author has adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Author has no conflicts of interest.

References and Footnotes

1. Byars TD. Diarrhea in foals. In: Mair T, Divers T, Ducharme N, eds. *Manual of equine gastroenterology*. Philadelphia, PA: WB Saunders CO; 2002, 493–495.
2. Estes M, Cohen J. Rotavirus gene structure and function. *Microbiol Rev* 1989;53:410–449.
3. Wilson WD, East N, Rowe JD, et al. Use of biologics in the prevention of infectious diseases. In: *Large animal internal medicine*. St. Louis, MO: Mosby; 2009, 1586.
4. Udeni Balasuriya, Baton Rouge, LA, personal communication, 2020.
5. Powell DG, Dwyer RM, Traub-Dargatz JL, et al. Field study of the safety, immunogenicity, and efficacy of an inactivated equine rotavirus vaccine. *J Am Vet Med Assoc* 1997;211: 193–198.
6. Weese JS, Parsons DA, Staempfli H. Association of *Clostridium difficile* with enterocolitis and lactose intolerance in a foal. *J Am Vet Med Assoc* 1999;214:229–232.
7. Conner ME. Detection of rotavirus in horses with and without diarrhea with electron microscopy and rotazyme test. *Cornell Vet* 1983;73:280–287.
8. Conner ME, Darlington RW. Rotavirus infection in foals. *Am J Vet Res* 1980;41:1699–1703.
9. Darlington JW. Modified nano-bentonite anti-viral activity against the herpes simplex virus type1, rhinovirus type 37, and rotavirus. Presented at the 19th International Conference of Antiviral Research, San Juan, PR, May 7–11, 2006.
10. Guy, JS, Breslin JJ, Breuhaus B, et al. Characterization of a coronavirus isolated from a diarrheic foal. *J Clin Microbiol* 2000;38:4523–4526.
11. Bass EP, Sharpee RL. Coronavirus and gastroenteritis in foals. *Lancet* 1975;25:822.
12. Slovis NM, Elam J, Estrada M, et al. Comprehensive analysis of infectious agents associated with diarrhea in foals in central Kentucky, in *Proceedings*. Am Assoc Equine Pract 2010;56:262–266.
13. D'Armino Monforte A, Cozzi-Lepri A, Castagna A. Risk of developing specific AIDS-defining illnesses in patients coinfected with HIV and hepatitis C virus with or without liver cirrhosis. *Clin Infect Dis* 2009;15:612–622.
14. Brockmeier SL, Loving CL, Nicholson TL, et al. Coinfection of pigs with porcine respiratory coronavirus and *Bordetella bronchiseptica*. *Vet Microbiol* 2008;128:36–47.
15. Pakpinyo S, Ley DH, Barnes HJ, et al. Enhancement of enteropathogenic *Escherichia coli* pathogenicity in young turkeys by concurrent turkey coronavirus infection. *Avian Dis* 2003;47:396–405.
16. Larson HE, Price AB. Pseudomembranous colitis: Presence of clostridial toxin. *Lancet* 1977;310:1312–1314. doi: 10.1016/s0140-6736(77)90363-4.
17. Weese JS, Staempfli HR, Prescott JF. Isolation of environmental *Clostridium difficile* from a veterinary teaching hospital. *J Vet Diagn Invest* 2000;12:449–452.
18. Madewell BR, Tang YJ, Jang S, et al. Apparent outbreaks of *Clostridium difficile*–associated diarrhea in horses in a veterinary medical teaching hospital. *J Vet Diagn Invest* 1995; 7:343–346.
19. Kelly CP, Pothoulakis C, LaMont JT. *Clostridium difficile* colitis. *N Engl J Med* 1994;330:257–262.
20. Magdesian G, Hirsh D, Jang S, et al. *Clostridium difficile* and horses: A review. *Rev Med Microbiol* 1997;8:S46–S48.
21. Magdesian G, Hirsh D, Jang S, et al. Characterization of *Clostridium difficile* isolates from foals with diarrhea: 28 cases (1993–1997). *J Am Vet Med Assoc* 2002;220:67–73.
22. Baverud V, Franklin A, Gunnarsson A, et al. *Clostridium difficile* associated with acute colitis in mares when their foals are treated with erythromycin and rifampicin for *Rhodococcus equi* pneumonia. *Equine Vet J* 1998;30:482–488.
23. Medina-Torres CE, Weese JS, Staempfli HR. Validation of a commercial enzyme immunoassay for detection of *Clostridium difficile* toxins in feces of horses with acute diarrhea. *J Vet Intern Med* 2010;24:628–632.
24. Slovis, N, Justin E, Weese, N. Evaluation of *Clostridium difficile* antigen positive toxin ELISA negative results in foals. *J Vet Inter Med* 2019;33:2358.
25. Swain E. Pharmacokinetics of metronidazole in foals, in *Proceedings*. Am Assoc Equine Pract 2014;60:318.
26. Desrochers AM, Dolente BA, Roy MF, et al. Efficacy of *Saccharomyces boulardii* for treatment of horses with acute enterocolitis. *J Am Vet Med Assoc* 2005;227:954–959.
27. Weese JS, Cote NM, deGannes RVG. Evaluation of *in vitro* properties of di-tri-octahedral smectite on clostridial toxins and growth. *Equine Vet J* 2003;35:638–641.
28. Weese JS, Staempfli HR, Prescott JF. A prospective study of the roles of *Clostridium difficile* and enterotoxigenic *Clostridium perfringens* in equine diarrhoea. *Equine Vet J* 2001; 33:403–409.
29. Donaldson MT, Palmer JE. Prevalence of *Clostridium perfringens* enterotoxin and *Clostridium difficile* toxin A in feces of horses with diarrhea and colic. *J Am Vet Med Assoc* 1999;215:358–361.
30. Bueschel D, Walker R, Woods L, et al. Enterotoxigenic *Clostridium perfringens* type A necrotic enteritis in a foal. *J Am Vet Med Assoc* 1998;213:1305–1307, 1280.
31. Herholz C, Miserez R, Nicolet J, et al. Prevalence of beta2-toxigenic *Clostridium perfringens* in horses with intestinal disorders. *J Clin Microbiol* 1999;37:358–361.
32. Mehdizadeh G, Parreira VR, Timoney JF, et al. NetF-positive *Clostridium perfringens* in foal with necrotizing enteritis in Kentucky. *Vet Rec* 2016;178:216.
33. Traub-Dargatz JL, Jones RL. Clostridia-associated enterocolitis in adult horses and foals. *Vet Clin North Am Equine Pract* 1993;9:411–421.
34. Tillotson K, Traub-Dargatz JL, Dickinson CE, et al. Population-based study of fecal shedding of *Clostridium perfringens* in broodmares and foals. *J Am Vet Med Assoc* 2002; 220:342–348.
35. Lawler JB, Hassel DM, Magnuson RJ, et al. Adsorptive effects of di-tri-octahedral smectite on *Clostridium perfringens* alpha, beta, and beta-2 exotoxins and equine colostral antibodies. *Am J Vet Rec* 2008;69:233–239.
36. East LM, Dargatz DA, Traub-Dargatz JL, et al. Foaling-management practices associated with the occurrence of enterocolitis attributed to *Clostridium perfringens* infection in the equine neonate. *Prev Vet Med* 2000;46:61–74.
37. Madigan JE, Walker RL, Hird DW, et al. Equine neonatal salmonellosis: Clinical observations and control measures, in *Proceedings*. Am Assoc Equine Pract 1990;36:371–375.
38. Slovis N, Browne N, Giguere, et al. Identification of *Enterococcus durans* as a cause of neonatal diarrhea on a Thoroughbred breeding farm. *J Vet Inter Med* 2018;32:2127–2128.
39. Tzipori S, Hayes J, Withers M. *Streptococcus durans*: An unexpected enteropathogen of foals. *J Infect Dis* 1984;150: 589–593.

[a]Rotazyme, Abbott Laboratories, North Chicago, IL 60064; Wampole Laboratories, Cranberry, NJ 08512.

[b]LACTAID®, McNeil Consumer Healthcare, Fort Washington, PA 19034.

[c]Equine RotaVirus Vaccine, Zoetis Parsippany, NJ 07054.

[d]Releive™, Resolvet, Lexington, KY 40361.

[e]Lake Immunogenics *Clostridium diffcle* Toxin A and B Antibody Select HI Plasma, Ontario, NY 14519.

[f]Lake Immunogenics *Clostridium perfringens* Type A, C, & D Antibody Select HI Plasma, Ontario, NY 14519.

Autologous Bone Marrow Mononuclear Cells Modulate Joint Homeostasis in an *in vivo* Model of Synovitis

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Bone marrow mononuclear cells (BMNCs) resolve joint inflammation, preserving homeostatic mechanisms, and are an autologous point-of-care therapy. Authors' addresses: Gluck Equine Research Center, University of Kentucky, Lexington, KY 40546-0099 (Menarim); Virginia-Maryland College of Veterinary Medicine, Department of Large Animal Clinical Sciences, 205 Duck Pond Drive, Blacksburg, VA 24061 (Gillis, Oliver, Mason, Ngo, Werre, Barrett, Luo, Byron, Dahlgren); e-mail: bmenarim@gmail.com. *Corresponding and presenting author.

1. Introduction

Synovitis is a major feature of osteoarthritis, characterized by macrophage-driven inflammation. Synovial macrophages are essential for joint health; however, they become pro-inflammatory (M1) when their homeostatic (M2) functions are overwhelmed. Bone marrow mononuclear cells (BMNCs) are a rich source of macrophages used to treat chronic inflammation and produce essential molecules for cartilage metabolism. This study investigated the response of normal and inflamed joints to autologous BMNC injection.

2. Materials and Methods

Synovitis was induced (0.5 ng lipopolysaccharide [LPS]/joint) in both radiocarpal joints of six horses. After 8 h, one inflamed radiocarpal and one normal tarsocrural joint received a BMNC injection (20 million cells/joint). Contralateral joints received saline. Synovial fluid was collected at 1, 4, and 6 days for cytology, cytokine quantification, and flow cytometry. At 6 days, horses were euthanatized, joints evaluated, and synovium harvested. Data were analyzed using the General Estimating Equations. Significance was set at $P < 0.05$.

3. Results

Gross and analytical improvements in synovial fluid and membrane were observed in inflamed joints treated with BMNC compared to saline controls, which was associated with increasing synovial fluid concentrations of interleukin-10 (IL-10) and 10% higher counts of IL-10-expressing macrophages (M2) ($P = 0.0431$) (Fig. 1).

4. Discussion

BMNC-treated joints were ultimately comparable to healthy joints regarding histochemical patterns, which remained abnormally high in saline-treated controls, suggesting BMNCs provide

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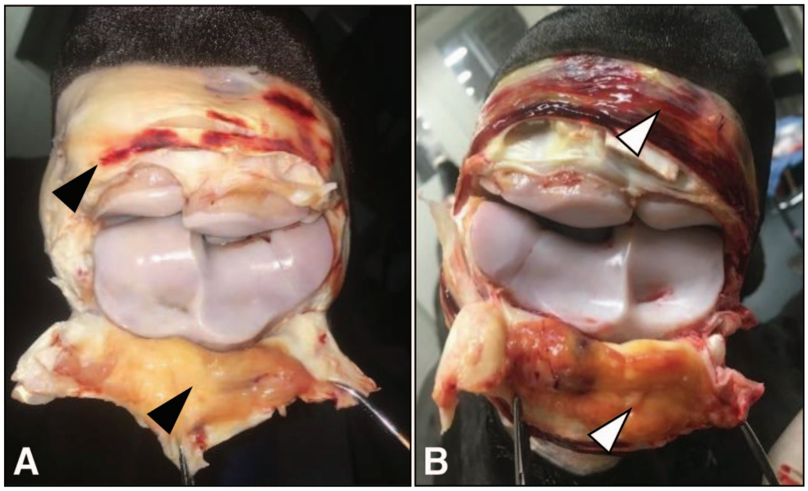

Fig. 1. Inflamed joints treated with BMNC showed gross improvement characterized by less swelling and peri- and intra-articular hemorrhage in joints treated with BMNC (A; black arrow heads) compared to PBS (B; white arrow heads).

macrophage-associated anti-inflammatory effects. BMNCs are autologous, a point-of-care treatment, and resolve synovial inflammation, preserving the production of molecules such as prostaglandin E_2 and IL-10, which are essential for joint homeostasis and negatively affected by corticosteroids.

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Declaration of Ethics

The Authors have adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Authors have no conflicts of interest.

Bone Marrow Mononuclear Cell Therapy for Equine Joint Disease

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Bone marrow mononuclear cell therapy is autologous, simple to process, and point-of-care and decreases lameness in horses with osteoarthritis. Authors' addresses: Department of Large Animal Clinical Sciences (Everett, Menarim, Byron, Pleasant, Bogers, Dahlgren); Laboratory for Study Design and Statistical Analysis (Werre); Department of Biomedical Sciences and Pathobiology (Barrett), Virginia-Maryland College of Veterinary Medicine, Virginia Tech, Blacksburg, VA 24061; e-mails: lad11@vt.edu; jamesbe1@vt.edu. *Corresponding author; †presenting author.

1. Introduction

Macrophage-driven synovitis is a major component of osteoarthritis (OA). In healthy joints, macrophages are central promoters of synovial health, but they become inflammatory (M1) when homeostatic functions (M2) become overwhelmed. Bone marrow mononuclear cells (BMNCs) are a rich source of macrophage progenitors that elicit an anti-inflammatory/pro-resolving response and promote the endogenous resolution of experimentally induced synovitis. The aim of this study was to evaluate the ability of intra-articular BMNC therapy to improve clinical signs of naturally occurring equine OA.

2. Materials and Methods

Horses presenting with clinical and radiographic evidence of moderate OA in a single joint were randomly assigned to 1 of 3 treatments: saline (negative control), triamcinolone (positive control), or BMNC (treatment group). Horses were evaluated for lameness (subjectively and objectively) and synovial fluid collected (cytology and cytokine/growth factor quantification) at 0, and 7, and 21 days post-injection. Data were analyzed using general estimating equations. Significance was set at $P < 0.05$.

3. Results

No adverse effects were observed. Lameness decreased in all groups over the study period but only significantly in the BMNC-treated group (between days 7 and 21) and not in the saline or triamcinolone groups.

4. Discussion

The BMNC injection was safe, with BMNC-treated horses being the only ones to show significant improvement during the study period. Moreover, BMNCs preserve the production of molecules essential for joint homeostasis, which are regularly inhibited by cortico-

Research Abstract—for more information, contact the corresponding author

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steroids. These results support a larger clinical trial using BMNCs in clinical cases of equine OA.

Acknowledgments

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Declaration of Ethics

The Authors have adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Authors have no conflicts of interest.

A Pooled Equine Platelet-Rich Plasma Lysate Biologic as a Novel Disease-Modifying Osteoarthritis Therapy

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BIO-PLY therapy could substantially change osteoarthritis (OA) treatment because of its ability to increase hyaluronic acid (HA) and cartilage matrix production while dampening inflammation. Authors' addresses: Department of Clinical Sciences, College of Veterinary Medicine, (Gilbertie, Schubert, Frink, Gagliardi, Schnabel), Comparative Medicine Institute (Gilbertie, Gagliardi, Schnabel), North Carolina State University, Raleigh, NC 27606; e-mail: lvschnab@ncsu.edu. *Corresponding and presenting author.

1. Introduction

Osteoarthritis (OA) remains the leading cause of poor performance in horses and novel therapies to treat it more effectively are needed. The objective of this study was to compare concentrated, fractionated pooled platelet-rich plasma lysate, termed BIO-PLY, to hyaluronic acid (HA) and steroid therapies in an *in vitro* OA model.

2. Materials and Methods

A co-culture system was utilized in which inflammation was induced with lipopolysaccharide 72 hours after joining of chondrocytes and synoviocytes. Treatments were instituted 24 hours post-lipopolysaccharide: no treatment control, exogenous HA,[a] steroid,[b] and BIO-PLY. Synoviocytes were examined for expression of HAS1, HAS2, HAS3, IL-1β, MMP-3, and MMP-13 24 hours post-treatment while chondrocytes were examined for expression of COL1A1 and COL2A1 72 hours post-treatment. Media HA concentration was examined 72 hours post-treatment by ELISA. Data were analyzed by ANCOVA with Tukey (significance $P < .05$).

3. Results

BIO-PLY significantly increased synoviocyte HAS2 and HAS1 expression as well as increased HA concentrations in media compared to other treatments and controls with no change in HAS3 expression. BIO-PLY also significantly decreased synoviocyte IL-1β, MMP-3, and MMP-13 expression compared to non-treated controls and equivalent to hyaluronate sodium or triamcinolone. Additionally, BIO-PLY significantly increased chondrocyte COL1A1 and COL2A1 expression compared to other treatments and controls without alteration of the COL2A2:COL1A1 ratio.

4. Discussion

BIO-PLY is able to restore homeostasis of HA synthesis and chondrocyte matrix production

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post-inflammation *in vitro*, warranting further investigation as a novel OA therapeutic.

Acknowledgments

Declaration of Ethics

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Conflict of Interest

The Authors have no conflicts of interest.

Footnotes

[a]Hyvisc®, Boehringer Ingelheim, Duluth, GA 30096.
[b]Kenalog®, Bristol-Myers Squibb Company, Princeton, NJ 08543.

Platelet-Rich Plasma Lysate Improves Bacterial Load and Outcomes of *Staphylococcus aureus* Infectious Arthritis in Horses

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Platelet-rich plasma lysate (PRP-L) shows great promise as a therapy against antimicrobial tolerant infections in synovial fluid (SynF) biofilms and has the potential to decrease morbidity and mortality associated with joint infections. Authors' addresses: Department of Clinical Sciences (Gilbertie, Schubert, Schnabel); Comparative Medicine Institute (Gilbertie, Jacob, Schnabel), Department of Molecular Biomedical Sciences (Seiler, Deddens), Department of Population Health and Pathobiology (Stowe, Jacob), College of Veterinary Medicine, North Carolina State University, Raleigh, NC 27607; Department of Clinical Studies (Schaer, Stefanovski); Department of Pathobiology (Engiles), New Bolton Center, School of Veterinary Medicine, University of Pennsylvania, Kennett Square, PA 19348; e-mail: lvschnab@ncsu.edu. *Corresponding and presenting author.

1. Introduction

Infectious arthritis can lead to euthanasia or to degenerative joint disease in patients that survive. The authors have recently shown that *Staphylococcus aureus* grown in equine synovial fluid (SynF) forms free-floating biofilms that are tolerant to antimicrobial therapy but sensitive to platelet-rich plasma lysate (PRP-L) *in vitro*.

2. Materials and Methods

Horses ($n = 12$) were inoculated with *S. aureus* in one tarsocrural joint and treated with intra-articular amikacin alone (control, $n = 6$) or in combination with PRP-L (treatment, $n = 6$) starting 24 hr post-infection and continuing daily for 7 days. All horses received systemic antimicrobials until day 10 and tapering phenylbutazone throughout the study. SynF and blood were evaluated at days 0–7, 14, and 21. Pain scoring and ultrasound examinations were also performed at these time points. At day 24 post-infection, horses were euthanized and synovium and cartilage were collected.

3. Results

Horses treated with PRP-L had lower pain scores ($P < 0.003$), lower levels of systemic inflammatory proteins

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($P < 0.0003$), and decreased SynF parameters of infection ($P < 0.02$) and inflammation ($p < 0.05$) than control horses. PRP-L-treated horses also had significantly lower bacterial loads in SynF ($P < 0.006$) and end-term synovium ($P < 0.01$) than control horses. Horses treated with PRP-L also had improved ultrasonographic and histological assessments.

4. Discussion

The results of this study strongly support the use of PRP-L in combination with antimicrobials to treat infectious arthritis.

Acknowledgments

Declaration of Ethics

The Authors have adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Authors have no conflicts of interest.

How to Manage Back Pain in Horses

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1. Introduction

The National Institutes of Health reports that up to 80% of humans experience lower back pain at some point during their adult life. In horses, the reported prevalence of back pain and/or dysfunction varies dramatically, from 0.9%[1] to 94%,[2] and seems to be more common in lame horses. A study of predominantly English performance horses found back pain in 32% of 805 lame horses compared with only 12% of 339 control horses.[3] In cutting horses, 70% of 140 horses that presented to a University Hospital for lameness or poor performance were found to have thoracolumbar back pain.[4] Considering the prevalence and increasing focus on back pain among the equine veterinary community,[5] it is important to explore ways to successfully treat, rehabilitate, and restore function to horses with back pain and/or dysfunction. Similar to treating humans with lower back pain, the principles of treating back pain and dysfunction in horses consists of first, breaking the pain cycle; and second, increasing and/or restoring muscle strength and function of the back. This paper will explore various methods and techniques to achieve these goals. It is important to state that while the focus of this paper is not on diagnosing back pain, that an accurate diagnosis is paramount to successful management of back pain cases.

2. Materials and Methods

Breaking the Pain Cycle

Breaking the pain cycle is arguably the most important feature of managing back pain (generically referring to pain and/or dysfunction of the thoracolumbar, lumbosacral, and/or sacroiliac [SI] regions), as it is the gateway that allows for building core strength and restoring proper function.

Anti-Inflammatory Medications

In humans, non-steroidal anti-inflammatory medications (NSAIDs) are considered an effective treatment for lower back pain.[6] However, in the author's opinion, NSAIDs rarely provide sufficient pain relief in horses with back pain and corticosteroids seem to be a more effective anti-inflammatory medication. While corticosteroids can of course be administered systemically (e.g., 1 mg/kg prednisolone PO q24h), conventional reasoning and common practice is to deliver the corticosteroids as close to the site of pathology as possible. Therefore, the delivery method for corticosteroid therapy depends on the underlying pathology.

Horses suffering from impinging or over-riding spinous processes ("kissing spines") often benefit from local infiltration of corticosteroids (~3 mg triamcinolone or 20–40 mg methylprednisolone), diluted in sterile saline to increase the injection volume as needed (~2 mL per site), around the

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affected spinous processes. One study found that corticosteroid infiltration resolved the pain in 89% of 38 horses with kissing spines, although 56% of those had recurrence of pain in < 1 year[7] and repeating this treatment once or twice a year is often necessary.[8] In cases of thoracolumbar osteoarthritis, corticosteroid injection of the articular facet joints can be performed using ultrasound guidance.[9] The author prefers triamcinolone (~3 mg/ joint, up to 18 mg total body dose) diluted to 2 mL volume with sterile saline or hyaluronic acid. A less specific alternative, and one that does not require ultrasound guidance yet is still clinically effective, is to perform an intramuscular corticosteroid injection (of the multifidus or longissimus muscle) in the region of the affected facet joints. The author has only performed this in a small proportion of horses using triamcinolone though others may use methylprednisolone or isoflupredone. While theoretically methylprednisolone could lead to mineralization of the soft tissues, the author has not appreciated this clinically. In humans, injection of methylprednisolone into the multifidus muscle was more effective in treating lower back pain than a 10-week physiotherapy program.[10]

Horses with clinical evidence of SI pain typically benefit greatly from corticosteroid injections of that region. Interestingly, response to treatment is not correlated with the presence or absence of pathologic changes of the SI joint identified with diagnostic imaging[a]. There are multiple published techniques for injecting the SI joints.[11,12] Regardless of technique, it should be noted that the SI joint contains a very small volume of synovial fluid (~1 mL)[13] and an SI "joint" injection is a bit of a misnomer as the injection is almost exclusively periarticular.[11] For SI region injections, the author prefers to inject a fairly large volume using the cranial ultrasound-guided approach (typically 100 mg methylprednisolone diluted to 15–20 mL in sterile saline per side); the cranial approach avoids the risk of penetrating the rectum as is possible using the caudal approach[12] and the higher volume ensures diffusion to the cranial and caudal aspects of the joint as well as the surrounding structures. In cases in which corticosteroid therapy is contraindicated, injection of autologous conditioned serum has yielded good clinical effects, anecdotally, in a handful of horses.

Generally speaking, adverse reactions are uncommon, but a minority of horses will have some increase in muscle pain and spasm following intra-articular facet joint injection or SI region injections at the site of needle placement. In these cases, the author prescribes hot packing (apply a warm compress, 20 minutes, q12h) and NSAIDs (1 mg/kg flunixin meglumine q24h) for 2–3 days following injection.

Methocarbamol

Methocarbamol is a centrally acting muscle relaxer used to decrease muscle spasms and excessive muscle tone (hypertonicity). One of the first reports of such use dates back to 1958 when a human physician reported "often prompt and striking" results in patients with acute orthopedic conditions, including herniated lumbar and cervical disks.[14] In a double blinded, placebo-controlled study, treatment with methocarbamol was effective in 70% of 98 people with acute lower back pain and spasm.[15] Like the 30% of people in the aforementioned study who were "non-responders," so too in horses there seems to be variable efficacy (from negligible to quite effective). In the majority of cases, the author appreciates a good clinical result from administration of 25 mg/kg q12h PO for 2 weeks followed by 25 mg/kg once daily for an additional 2 weeks. In cases with underlying back pathology, it is most effective when administered in conjunction with an initial corticosteroid treatment of the back and/or SI region. However, in more mild cases of thoracolumbar epaxial muscle pain, it can be used effectively in isolation, as a sole treatment. Methocarbamol is generally safe but rarely can cause drowsiness. It is important to note that the above dose is not legal under United State Equestrian Federation (USEF) drug regulations, which restricts its use to 5 mg/lb (11 mg/kg) every 24 hours for no more than 5 consecutive days.

Bisphosphonates

Despite the widespread clinical use of bisphosphonates to treat horses with osseous pathology of the thoracolumbar spine, the supporting research is extremely limited. A single study reports on the outcome of 29 horses with osteoarthritis of the thoracolumbar vertebrae, with or without concurrent osseous changes of the spinous processes.[16] The treatment group (consisting of 15 horses, each administered a single treatment of 1 mg/kg tiludronate in 1 L saline via slow IV infusion) had significantly better dorsal flexion of the back in canter compared with the control group 60 days following treatment. At 120 days, treated horses showed improvement over the control horses, but the difference between the groups was not statistically significant. Another clinical study demonstrated decreased lameness scores in horses with distal hock joint osteoarthritis 60 days after treatment with tiludronate (same dosing protocol as above).[17] These reports, in combination with the FDA-approved use for the treatment of navicular syndrome in adult horses, make the use of bisphosphonates for other osseous pathologic conditions a reasonable choice. Thus, in cases of osteoarthritis of the axial skeleton and/or kissing spine, judicious use of bisphosphonates could be considered.

Currently, treating thoracolumbar conditions with either FDA-approved bisphosphonate, clodronate, or tiludronate constitutes off-label use. Bisphosphonates are not approved for use in young (< 4 years old), pregnant, or lactating mares and can cause

Fig. 1. Photograph of the right side of a horse following mesotherapy treatment. Note the parallel rows of subdermal injections along the thoracolumbar epaxial musculature.

colic-like symptoms, although this seems to be more common with tiludronate than clodronate. Clodronate has infrequently been associated with acute renal failure and therefore should not be given in the face of abnormal serum blood urea nitrogen (BUN) or creatinine levels, nor should it be given in conjunction with NSAIDs. Clodronate appears to be the more widely used bisphosphonate in the United States, likely due to the ease of administration, the cost, and the infrequency of negative side effects. However, how the efficacy of clodronate compares to that of tiludronate, especially in the treatment of thoracolumbar conditions, is unknown.

Mesotherapy

Mesotherapy is a technique that began in human medicine in the 1950s that involves multiple, small-volume subdermal injections of analgesic and/or anti-inflammatory medications. One study in humans (n = 84) demonstrated that mesotherapy (consisting of lidocaine, ketoprofen, and methylprednisolone injected at days 1, 4, 7, 10, and 13) was, at less than half the dose, as effective as systemic administration of the same medications for treating lower back pain.[18] In horses with thoracolumbar pain, the injections are typically administered in three parallel rows, on either side of the spine (Fig. 1). There are a variety of "cocktails" used by practitioners; the author prefers a combination of mepivacaine, flumethasone, and traumeel diluted in saline. Injection of methylprednisolone in mesotherapy should be avoided due to anecdotal reports that the hair at the injection sites can turn white. Like many treatments for the lower back and pelvis, mesotherapy is often insufficient when used in isolation, but it can be very useful as an adjunct therapy, in combination with other treatments, and/or as a way to lengthen the time required between more aggressive therapies such as intra-articular injections. The author has not experienced any adverse effects with mesotherapy but is aware of one horse that developed diffuse, painful subcutaneous edema throughout the thoracolumbar epaxial region after being treated with mesotherapy once weekly for 3 weeks.

Extracorporeal Shockwave Therapy

Shockwave therapy is another very useful adjunct therapy that, until recently, was being used based on the positive effects reported anecdotally. A recent study reported the effects of shockwave therapy on a group (n = 12) of riding horses with thoracolumbar back pain.[19] Treatment consisted of 1500 pulses applied to the epaxial muscles from T12 through L5 with an 80-mm trode at an E4 energy setting, and was performed 3 times, spaced every 14 days. The authors found a significant and clinically relevant increase in mechanical nociceptive threshold (MNT), measured with pressure algometry along the thoracolumbar epaxial muscle, 7 days following the second and third treatments, but not after the first treatment. Interestingly, the increased MNT persisted for at least 1 month following the last treatment.

In contrast to the results of this study, in clinical practice, many practitioners report significantly decreased back pain following even a single treatment of shockwave therapy. It is a good option for treating muscle pain that may develop in the interim between corticosteroid injections, and should be strongly considered as an alternate treatment for horses that cannot receive corticosteroid injections (e.g., for metabolic reasons or due to competition drug regulations). Additionally, it is a safe and non-invasive treatment, with few to no reported side effects. It is also a good first-line treatment, but in the author's practice the cost of treatment is sometimes prohibitive. The author typically treats the thoracolumbar epaxial muscles as needed with a total of 1500 to 2000 pulses, half delivered with a 35-mm probe and half with an 80-mm probe, to try and target both superficial and deeper pain. Shockwave cannot be used within 5 days of Fédération Equestre Internationale (FEI) competition. Under USEF guidelines, shockwave of the back specifically (but not elsewhere on the body) is permitted >12 hours before competition.

Laser Therapy

In general, the scientific evidence for the efficacy of laser therapy in the treatment of musculoskeletal conditions is lacking. However, a recent study investigated the outcome of laser therapy in actively competing horses.[20] Sixty-one Quarter Horses with acute lower back pain were treated with low-level laser therapy (series of 3 treatments over 5 to 7 days), chiropractic, or a combination of both. Horses treated with laser alone had decreased epaxial muscle pain, trunk stiffness, and muscle hypertonicity lending support toward the use of laser to treat lower back pain. An advantage to this treatment is that it is non-invasive and, in the case of lower-level laser therapy, can be performed by owners.

Integrative Therapies

Acupuncture and chiropractic treatments can be effective adjunct therapies. Acupuncture mitigates pain through release of local neuropeptides that stimulate systemic release of endogenous opioids, serotonin, dopamine, and norepinephrine. A study of 15 horses with chronic lower back pain evaluated the effects of electroacupuncture (administered every 3 days for 5 treatments) compared with treatment with an oral NSAID (2.2 mg/kg phenylbutazone PO q12h) or to saline controls.[21] Thoracolumbar pain was not significantly altered in the phenylbutazone or control groups, but was significantly decreased following 3 electroacupuncture treatments and the analgesic effects lasted up to 2 weeks. Acupuncture is generally well tolerated though in cases with severe thoracolumbar pain, hypertonicity and/or wind-up, acupuncture may not be tolerated. In such cases, acupuncture can often be used in subsequent visits once the pain level has been dampened with use of other first-line treatments.

Chiropractic treatment can be used to restore normal spinal motion and functional mobility and can decrease muscle spasm, nerve dysfunction, and pain that can occur as a result of joint hypomobility.[22] In a study of horses without back pain (n = 38), a single chiropractic treatment increased the MNT by 27% for up to 7 days post-treatment whereas massage therapy and phenylbutazone treatment increased MNT by only 12% and 8%, respectively.[23]

Kinesiotape

Kinesiotape, or elastic athletic tape, has many purported mechanisms of action including stimulating proprioceptive pathways, increasing lymphatic flow, providing stability, and enhancing or inhibiting muscle function, but overall, there is limited evidence in the literature to support such claims. The human literature is conflicting regarding the efficacy of kinesiotape and a single study in horses (n = 8) did not show an alteration in thoracolumbar flexion-extension range of motion when kinesiotape was applied to the abdominal muscles.[24] Nonetheless, kinesiotape is widely used in both human and equine athletes. In the author's practice, kinesiotape, applied as pictured in Fig. 2A, can be helpful to alleviate mild to moderate muscle pain and tension of the thoracolumbar epaxial muscles; the pattern includes a base anchor strip along the thoracolumbar midline and multiple smaller strips crossing midline applied in such a way as to "lift" the skin and, in theory, reduce myofascial restriction. Alternatively, for focal areas of edema, as can sometimes occur with pressure points from tack, taping in a star pattern (Fig. 2A) can help reduce edema.

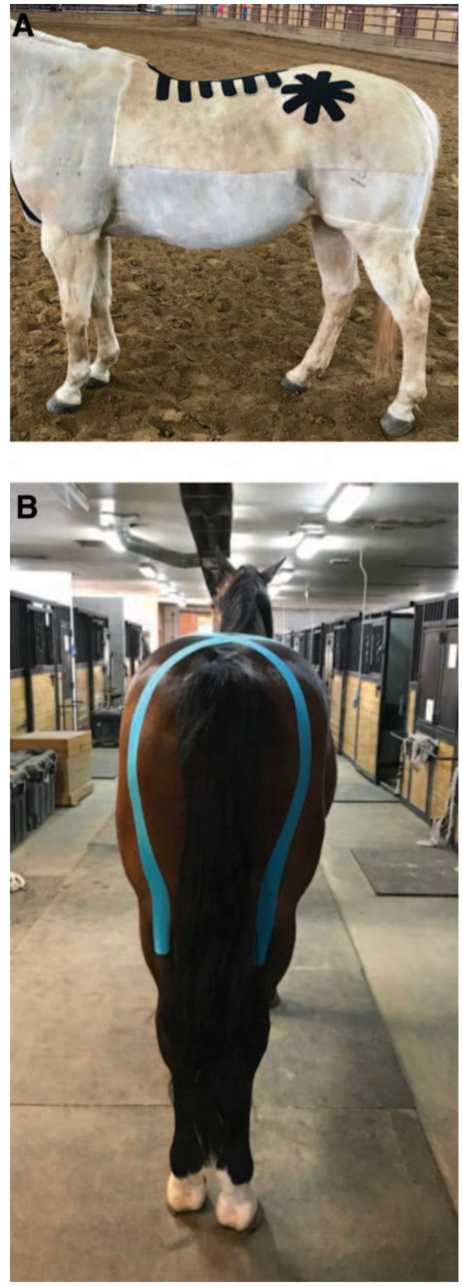

Fig. 2. A, This horse has kinesiotape applied in two different patterns. The pattern along the thoracolumbar midline entails an anchor strip on dorsal midline with multiple "cross hatch" strips running perpendicular to dorsal midline and crossing the thoracolumbar epaxial muscles. This pattern is commonly used to help alleviate thoracolumbar muscle pain. A "star" pattern, seen over the left tuber coxae, can be applied over an area of focal edema. B, Kinesiotape applied in a "stability pattern" from the tuber coxae to the opposite hamstring muscles. In this case, the tape is aimed to promote pelvic stability.

Finally, Fig. 2B demonstrates one version of a "stability" taping pattern that can be useful in horses with SI pain and/or in cases of mild pelvic instability.

Surgical Treatment

Surgical treatment of kissing spines is becoming increasingly common. Surgical resection of impinging or over-riding dorsal spinous processes was first described in 1968[25] and is still commonly performed. Results following ostectomy are quite good, with 72% (n = 209) to 100% (n = 9) of horses achieving normal function in the long term.[26–29] A newer procedure that is gaining favor is interspinous ligament desmotomy (ISLD), which can be performed standing. Outcomes of ISLD surgery are comparable (95% of 35 horses) to previously reported ostectomy outcomes.[7] The same study showed that while horses managed medically (with corticosteroid injections of the affected sites) and had good short-term outcomes (89% of 34 horses), recurrence of back pain was common (19 of 34). Horses treated with ISLD were 24 times more likely to have long-term resolution of symptoms compared to medically managed counterparts.

In the author's opinion, many cases of kissing spines can be successfully managed medically, especially when coupled with core strengthening and conditioning exercises. However, surgical treatment is a good option for horses that require repeated corticosteroid injections to maintain prolonged comfort. If the owner would like to pursue surgery as an initial treatment step, the author prefers to trial corticosteroid injections once, to ensure the horse has an adequate response to treatment, prior to pursuing a more invasive treatment option.

Increasing and/or Restoring Back Strength and Function

After breaking the pain cycle, building core strength and stability is essential for the long-term, successful management of back pain cases.

Dynamic Mobilization Exercises

The function of the multifidus muscle as a spine stabilizer, or a vertebral motion segment stabilizer, has been demonstrated in multiple species, including horses.[30,31] Atrophy and inhibition of the multifidus muscles is a common finding in humans with acute and subacute lower back pain[32] and can develop quickly (within 3 days) following induced back pain in an experimental animal model.[33] This creates instability of the vertebral motion segment, and perpetuates the underlying condition. Additionally, even once the underlying pain has been treated, the multifidus muscles do not spontaneously resume normal activity.[34] Exercises that target strengthening and mobilizing the multifidus muscles greatly reduce the recurrence of back pain in humans; with targeted exercise, recurrence decreased from 84% to 30% within 1 year and from 75% to 35% over 2 to 3 years.[35] Thus, increasing multifidus strength, symmetry and function is a major focus of managing back pain in horses.

Horses (n = 8 Arabians not in ridden work) that performed a series of core strengthening exercises (consisting of 5 sets of 3 cervical flexions, 1 cervical extension, and 3 lateral bending exercises to the left and right) 5 days per week for 3 months had increased cross-sectional area (CSA) and symmetry of the multifidus muscles at 6 different locations throughout thoracolumbar back.[30] Similar results were seen in Thoroughbreds in race training; those that underwent dynamic mobilization exercises (consisting of 10 repetitions of 3 cervical flexions, 1 cervical extension, 3 lateral bending exercises to the left and right, performed 5 days per week for 12 weeks) had significantly increased CSA of the multifidus muscles in as soon as 6 weeks.[36] Examples of some of these exercises can be seen in Fig. 3. Additionally, the book, *Activate Your Horse's Core*[37] is an excellent resource for these and other core strengthening exercises.

Elastic Resistance Bands

Exercises that encourage hindquarter engagement are very useful in rehabilitation of back pain and include resistance band training, hill work, and cavaletti exercises. A recent study of 7 general purpose riding horses showed that 4 weeks' training with elastic resistance bands increased dynamic stability of the back.[38] The exercise protocol started with familiarization to the bands in week 1 and then progressed to lounging and ridden work 10 minutes 5 times per week, to 20 minutes 4 times per week, to 30 minutes 3 times per week, in weeks 2, 3, and 4, respectively. It is proposed that the bands (Fig. 4) provide proprioceptive input that results in increased recruitment of the abdominal and hindquarters muscles during exercise.

Additional Core Strengthening Exercises

Gymnastic-type exercise, both in hand and on the lounge can increase core strength and therefore should be incorporated into the long-term management plan. As discussed above, dynamic mobilization exercises can increase the size of the multifidus muscle, but this effect can be furthered with the addition of gymnastics exercises. Horses that performed gymnastic exercises (including pelvis tilts, backing, turning small circles, and walking over a raised pole) 3 days per week for 3 months, in addition to dynamic mobilization exercises, had more increase in multifidus muscle CSA than horses that performed only dynamic mobilization exercises.[39]

Considerations for cavaletti work include varying pole placement and height. Placing elevated rails closer to one another will encourage more hindlimb flexion while placing rails on the ground spaced farther apart results in a longer stride, with more limb protraction. Changing the spacing and height of the rails can have the added benefit of challenging the proprioceptive system, as can having only one side of the rail elevated off the ground. Backing is an additional exercise that can be considered and seems to be particularly useful for horses with SI pain. Initially, backing is performed in hand on a

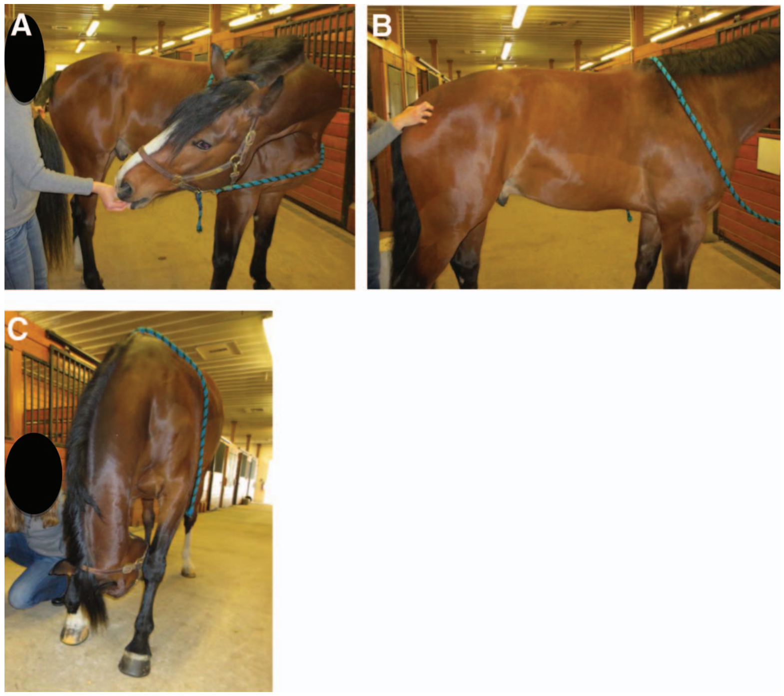

Fig. 3. Examples of various core strengthening exercises. A, A lateral tail pull combined with lateral bending to the right. B, A lumbosacral tuck. C, Ventral cervical flexion.

flat surface; the difficulty can be increased by backing up an incline as the horse gets stronger.

Another method to address core strength and balance are balance pads adapted from human physical therapy. While there are equine specific products, many human products work equally well. The horse is asked to stand on a dense foam block with both front, both hind, or all four limbs (Fig. 5). Firmer pads are more stable and thus less challenging than soft pads, yet many horses will have difficulty maintaining their center of balance on firm pads. Even 5 minutes a day on balance pads can result in noticeable improvement in core balance in

Fig. 4. Example of an elastic resistance band placed around the hindquarters. These systems can be used for a variety of reasons but in this case was prescribed to help increase core strength and encourage more hind-limb engagement.

Fig. 5. A horse standing on balance pads in order to increase core balance and stability. Here the horse stands on firmer (green) pads in front and softer (blue) pads behind to increase the level of difficulty of the exercise.

as little as 2 weeks, at which point the exercise can be made more difficult by decreasing the firmness of the pads. Softer pads require more fine motor control in order to limit postural sway.

Whole-body vibration (WBV) therapy is a relatively common modality, largely due to consumer-direct marketing, that may be useful in increasing core strength. A non-blinded study of 9 horses examined the effects of WBV on the multifidus muscle and found that, following 2 months of WBV performed 30 minutes twice daily 5 days a week, there was a statistically significant increase in multifidus symmetry and CSA.[40] The study utilized a commercially available, vertical vibrating platform with a frequency of 40 Hz, amplitude of 0.8 mm, and an acceleration of 4.9 m/s^2 (0.5 g). The authors proposed that WBV could be an alternative to dynamic mobilization exercises. It is this author's opinion that core strengthening exercises are superior to WBV in management of back pain and that the place for WBV is not yet well understood.

3. Results and Discussion

The treatment and rehabilitation strategies presented here are a culmination of experiences gained from managing more than 200 cases of back pain. In the most typical case, if there is osseous pathology such as kissing spine and/or facet joint osteoarthritis, the author would start by breaking the pain cycle with corticosteroid injections or shockwave of the affected area(s) and prescribe a course of methocarbamol. Additionally, basic core strengthening exercises consisting of lumbosacral tucks, ventral flexions, and lateral bending exercises are prescribed. At the 2-week recheck, the clinical signs (e.g., pain to palpation of the thoracolumbar epaxial muscles, willingness/ability to perform basic functional tests) are often markedly improved but, if there is residual pain and/or the horse displays aversion behaviors under saddle that are consistent with back pain, additional therapies such as shockwave, mesotherapy, acupuncture, and chiropractic treatment are considered. Once the initial pain is adequately managed, a long-term plan is implemented that usually entails gradually increasing the difficulty of the core strengthening exercises, adding balance pads, and incorporating elastic resistance bands and gymnastic exercises to the training program.

In cases in which corticosteroids are contraindicated, the author often begins treatment with shockwave of the affected area and a course of methocarbamol, as well as acupuncture (if not already being performed) and/or kinesiotape application. Mesotherapy can also be performed without corticosteroids. For horses with indication of SI joint pain/dysfunction, the author has been very pleased with the results obtained from injection of autologous conditioned serum (~5 mL administered per side, from a cranial, ultrasound-guided approach) in the handful of horses in which it has been performed.

If the initial pain cycle is managed and the horse is kept in a good strength and conditioning program, many times back pain will not recur until there is an inciting cause, such as becoming cast or enduring a long trailer ride. Additionally, as managing back pain relies heavily on maintaining core strength, it is common for back pain to recur when the horse requires lay-up for another injury. In the majority of instances, adequate core strength can be maintained with daily dynamic mobilization exercises and/or hand-walking (if able) with elastic resistance bands. Adjunct therapies such as acupuncture, laser therapy, and kinesiotaope can also be beneficial in mitigating back pain during periods of decreased training.

In summary, successful management of cases of back pain and dysfunction requires first breaking the pain cycle and second, maximizing core strength and condition. Treatment of pain can be accomplished with various medical therapies and in certain cases, surgical treatment may be warranted. Rehabilitation is critical and while there is no "one-size-fits-all" protocol, it entails various core strengthening and dynamic exercises.

Acknowledgments

Declaration of Ethics

The Author has adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Author has no conflicts of interest.

References and Footnote

1. Jeffcott L. Disorders of the thoracolumbar spine of the horse—A survey of 443 cases. *Equine Vet J* 1980;12:197–210.
2. Haussler K. Chiropractic evaluation and management. *Vet Clin N Am Equine Pract* 1999;15:195–208.
3. Landman M, de Blaauw J, Hofland L, et al. Field study of the prevalence of lameness in horses with back problems. *Vet Record* 2004;155:165–168.
4. Swor T, Dabareiner R, Honnas C, et al. Musculoskeletal problems associated with lameness and poor performance in cutting horses: 200 cases (2007–2015). *J Am Vet Med Assoc* 2019;254:619–625.
5. Riccio B, Fraschetto C, Villanueva J, et al. Two multicenter surveys on equine back-pain 10 years apart. *Frontiers Vet Sci* 2018;5:195.
6. Kuritzky L, Samria G. Nonsteroidal anti-inflammatory drugs in the treatment of low back pain. *J Pain Res* 2012; 5:579–590.
7. Coomer R, McKane S, Smith N, et al. A controlled study evaluating a novel surgical treatment for kissing spines in standing sedated horses. *Vet Surg* 2012;41:890–897.
8. Cousty M, Firidolfi C, Geffroy O, et al. Comparison of medial and lateral ultrasound-guided approaches for periarticular injection of the thoracolumbar intervertebral facet joints in horses. *Vet Surg* 2011;40:494–499.
9. Garcia Lopez J. Surgical management of impinging or overriding dorsal spinous processes. 2019. Available from: https://news.vet.tufts.edu/2019/09/surgical-management-of-impinging-or-overriding-dorsal-spinous-processes.

10. Kader D, Wardlaw D, Smith F. Evaluation of perifacet injections and specific lumbar multifidus retraining program in treatment of lower back pain (A prospective randomized controlled trial). *Ortho Proc* 2018:94-B.
11. Engeli E, Haussler K, Erb N. Development and validation of a periarticular injection technique of the sacroiliac joint in horses. *Equine Vet J* 2004;36:324–330.
12. Denoix JM, Jacquet S. Ultrasound-guided injections of the sacroiliac area in horses. *Equine Vet Educ* 2010;20:203–207.
13. Haussler K. Diagnosis and management of sacroiliac joint injuries, in Dyson S, Ross M, eds. *Diagnosis and management of lameness in the horse*. St. Louis, MO: Elsevier Saunders; 2011, 583–592.
14. Forsyth F. Methocarbamol (Robaxin) in orthopedic conditions: preliminary report of one hundred cases. *J American Med Assoc* 1958;167:163–168.
15. Emrich O, Milachowski K, Strohmeier M. Methocarbamol in acute low back pain. A randomized double-blind controlled study. *Fortschritte der Medizin* 2015;157:9–16.
16. Coudry V, Thibaud D, Riccio B, et al. Efficacy of tiludronate in the treatment of horses with signs of pain associated with osteoarthritic lesions of the thoracolumbar vertebral column. *Am J Vet Res* 2007;68:329–337.
17. Gough M, Thibaud D, Smith R. Tiludronate infusion in the treatment of bone spavin: a double blind placebo-controlled trial. *Equine Vet J* 2010;42:381–387.
18. Costantino C, Marangio E, Coruzzi G. Mesotherapy versus systemic therapy in the treatment of acute low back pain: A randomized trial. *Evid Based Complement Alt Med* 2011; 2011:317183.
19. Trager L, Funk R, Clapp K, et al. Extracorporeal shockwave therapy raises mechanical nociceptive threshold in horses with thoracolumbar pain. *Equine Vet J* 2020;52:250–257.
20. Haussler J, Manchon P, Donnell J, et al. Effects of low-level laser therapy and chiropractic care on back pain in Quarter Horses. *J Equine Vet Sci* 2019: doi: 10.1016/j.jevs.2019.102891.
21. Xie H, Colahan P, Ott E. Evaluation of electroacupuncture treatment of horses with signs of chronic thoracolumbar pain. *J Am Vet Med Assoc* 2005;227:281–286.
22. Haq A, Hussain S, Beigh S, et al. A mini review on chiropractic medicine and its application in veterinay medicine. *Pharma Innovation* 2017;6:471–473.
23. Sullivan K, Hill A, Haussler K. The effects of chiropractic, massage and phenylbutazone on spinal mechanical nociceptive thresholds in horses without clinical signs. *Equine Vet J* 2008;40:14–20.
24. Ericson C, Stenfeldt P, Hardeman A, et al. The effect of kinesiotape on flexion-extension of the thoracolumbar back in horses at trot. *Animals* 2020;10:301.
25. Roberts EJ. Resection of thoracolumbar spinous processes for the relief of pain responsible for lameness and some other locomotor disorders or horses, in *Proceedings*. Am Assoc Equine Pract 1968;14:13–30.
26. Jeffcott L, Hickman J. The treatment of horses with chronic back pain by resecting the summits of the impinging dorsal spinous processes. *Equine Vet J* 1975;7:115–119.
27. Walmsley J, Pettersson H, Winberg F, et al. Impingement of the dorsal spinous processes in two hundred and fifteen horses: Case selection, surgical technique and results. *Equine Vet J* 2002;34:23–28.
28. Perkins JD, Schumacher J, Kelly G, et al. Subtotal ostectomy of dorsal spinous processes performed in nine standing horses. *Vet Surg* 2005;34:625–629.
29. Steckel R, Kraus-Hansen A, Fackelman G, et al. Clinical aspects of thoraco-lumbar spinal disease in horses: A review of 50 cases, in *Proceedings*. Am Assoc Equine Pract 1991; 36:583.
30. Garcia Lineiro J, Graziotti G, Rodrıguez Menendez J, et al. Structural and functional characteristics of the thoracolumbar multifidus muscle in horses. *J Anatomy* 2017;230:398–406.
31. Stubbs NC, Kaiser LJ, Hauptman J, et al. Dynamic mobilization exercises increase cross sectional area of musculus multifidus. *Equine Vet J* 2011;43:522–529.
32. Hides J, Stokes M, Jull G, et al. Evidence of lumbar multifidus wasting ipsilateral to symptoms in patients with acute/subacute low back pain. *Spine* 1994;19:165–172.
33. Hodges P, Holm A, Hansson T, et al. Rapid atrophy of the lumbar multifidus follows experimental disc or nerve root injury. *Spine* 2006;31:2926–2933.
34. Hides J, Richardson C, Jull G. Multifidus muscle recovery is not automatic after resolution of acute, first episode low back pain. *Spine* 1996;21:2763–2769.
35. Hides J, Jull G, Richardson C. Long-term effects of specific stabilizing exercises for first-episode low back pain. *Spine* 2001;26:E243–E248.
36. Tabor G. The effect of dynamic mobilisation exercises on the equine multifidus muscle and thoracic profile. 2015. Available from: https://pearl.plymouth.ac.uk.
37. Stubbs N, Clayton H. Activate your horses core: Unmounted exercises for dynamic mobility, strength and balance. Mason, MI: Sport Horse Publications; 2008.
38. Pfau T, Simons V, Romback N, et al. Effect of a 4-week elastic resistance band training regimen on back kinematics in horses trotting in-hand and on the lunge. *Equine Vet J* 2017;49:829–835.
39. de Oliveira K, Soutello R, da Fonseca R, et al. Gymnastic training and dynamic mobilization exercises improve stride quality and increase epaxial muscle size in therapy horses. *J Equine Vet Sci* 2015;35:888–893.
40. Halsberghe B, Gordon-Ross P, Peterson R. Whole body vibration affects the cross-sectional area and symmetry of the m. multifidus of the thoracolumbar spine in the horse. *Equine Vet Educ* 2017;29:493–499.

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Identification of Genomic Loci Associated with Performance-Limiting Kissing Spines in Quarter Horses and Warmbloods

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Kissing spines in the thoracolumbar vertebrae is a condition known to cause back pain and poor performance in horses. Authors' addresses: Brazos Valley Equine Hospital, 6999 Hwy 6, Navasota, TX 77868 (Whitaker, C. Buchanan, B. Buchanan); Department of Animal Science, UF Genetics Institute, University of Florida, Gainesville, FL 32608 (Brooks); Virginia Equine Imaging Center, 2716 Landmark School Road, The Plains, VA 20198 (Allen); East-West Equine Sports, PO Box 13503, Lexington, KY 40583 (Peters); Midwest Equine, 2615 Eastgate Drive, Boone, IA 50036 (McClure); Pinkham Equine Veterinary Services, Home Farm Offices, Salisbury SP2 8PJ, UK (Pinkham); Texas Equine Hospital, 13688 Texas 6 Frontage Road, Bryan, TX 77807 (Honnas, McClure); Etalon, Inc., 401 El Camino Real, Menlo Park, CA 94025 (T. Lafayette, Martin, Vierra, Davies, Carpenter, C. Lafayette); e-mail: beauwhitaker@gmail.com. *Corresponding author; †presenting authors.

1. Introduction

The radiographic presence of kissing spines (KS) does not always cause clinical symptoms; however, horses with KS are three times more likely to have back pain. KS are more likely to appear in referral clinics when found in Thoroughbreds, dressage horses, horses five years of age or less, and horses with five or more vertebrae involved.

2. Materials and Methods

For this study, a diagnosis of KS was determined radiographically in horses presenting with poor performance and/or back pain. Lateral radiographs of the spinous processes of the thoracolumbar vertebrae were used to confirm the KS condition. Hair or blood samples were submitted for DNA extraction and genotyped with the Illumina Equine SNP70 array. In the present preliminary investigation, the authors compared these 50 cases from the American Quarter Horses, Warmbloods, and Thoroughbred breeds to 50 genetically matched controls of unknown phenotype.

3. Results and Discussion

Genome-wide association analysis revealed a single significant locus on chromosome 14 (raw, $P = 3.76 \times 10^{-07}$; bonf. Threshold, 9.07×10^{-07}). Ongoing work will expand the sampling of cases, identifying

Research Abstract—for more information, contact the corresponding author

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breed and sex-matched controls phenotyped for healthy spines. These newly identified loci will improve understanding of this challenging condition and are promising targets for novel diagnostic and preventative treatment strategies.

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Declaration of Ethics

The Authors have adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

All Authors other than C. Honnas are advisors to or employees of Etalon, Inc.

Relationship Between Postural Stability and Paraspinal Muscle Adaptation in Lame Horses Undergoing Rehabilitation

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There is a positive correlation between musculus multifidus cross-sectional area (CSA) and postural stability in lame horses undergoing a rehabilitation program. Authors' address: Colorado State University, 300 West Drake Road, Fort Collins, CO 80523; e-mail: klotellis@gmail.com. *Corresponding and presenting author.

1. Introduction

Postural stability maintains balance, protects the spinal column, and allows accurate responses to destabilizing forces. The m. multifidus is the major postural muscle located adjacent to the vertebrae along the length of the spinal column. Increased cross-sectional area (CSA) of the m. multifidus has been demonstrated in horses following rehabilitation strengthening exercises; however, correlation with functional postural stability has not been shown. The current study aimed to evaluate the relationship of the thoracolumbar m. multifidus CSA and measures of postural sway performance in lame horses undergoing rehabilitation exercises.

2. Materials and Methods

Seven horses admitted to a rehabilitation facility were included in the study. M. multifidus CSA was measured via ultrasonography at the start of a rehabilitation program (initial evaluation) and after 12 weeks of rehabilitation exercises (final evaluation). Postural sway data was also measured at these time points.

3. Results

A significant increase in m. multifidus CSA was seen from initial to final evaluation. A moderate to strong correlation was present between m. multifidus CSA and postural sway variables.

4. Discussion

These results suggest that there is an association between postural stability and m. multifidus hypertrophy in lame horses undergoing individualized rehabilitation programs. This suggests that postural stability can be improved by performing rehabilitation exercises that promote increased m. multifidus size.

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Declaration of Ethics

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Conflict of Interest

The Authors have no conflicts of interest.

Research Abstract—for more information, contact the corresponding author

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Review: Management of Pain Associated with Laminitis in the Horse—Evidence for Therapies

Katherine L. Ellis, DVM*; Melissa R. King, DVM, PhD, DACVSMR; and Khursheed R. Mama, DVM, DACVAA

Pain management of the laminitic horse can be extremely challenging. Given the various types of pain these horses experience, a multimodal approach to pain management of the laminitic horse is necessary. While evidence for pharmaceutical and nonpharmaceutical approaches in the laminitic horse is somewhat limited, multiple treatment options are available. Authors' addresses: Gail Holmes Equine Orthopaedic Research Center, (Ellis, King); College of Veterinary Medicine and Biomedical Sciences, Department of Clinical Sciences (Ellis, King, Mama), Colorado State University, Fort Collins, CO 80523; e-mail: klottellis@gmail.com. *Corresponding and presenting author.

1. Introduction

Horses with laminitis can experience significant pain, which can make their management extremely challenging, and in fact a large proportion of horses with laminitis are euthanized because of severe, unmanageable pain.[1,2] Sources of pain in the laminitic horse include inflammation within the laminae, increased pressure within the rigid hoof capsule, tearing and contusion of the soft tissues within the foot, tissue ischemia, and altered/excessive contact between the sole and distal phalanx.[3,4] In addition, horses with chronic laminitis can develop a neuropathic component to their pain, which may occur following neural injury. Repetitive neuropathic and nociceptive stimulation can lead to central sensitization, contributing to maladaptive pain.[5–8] Allodynia (pain with a normally non-noxious stimuli) and hyperalgesia (exaggerated response to a noxious stimuli) are features of central sensitization and can result in plasticity of the central pain pathways, further impacting the well-being of the horse.[9,10] Thus, horses with chronic laminitis can experience nociceptive and neuropathic pain which in the absence of treatment can lead to central sensitization and maladaptive pain that has no value to the animal.

Because of the complex and multifaceted pathophysiology of pain in laminitic horses, many treatment options have been suggested with none being universally effective. Previous reviews have listed the pain management options that are available for the laminitic horse, but evidence for their use in treating this complex condition has not been described. This review will describe the evidence behind pharmaceutical and nonpharmaceutical-based pain management options in the horse with laminitis.

2. Pharmaceutical Treatment Options

Since studies specific to laminitis are limited, broad-based evidence for included drugs and therapeutic modalities is also presented where available, allowing the reader to consider the sum total of literature

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Table 1. Acute Versus Chronic Analgesic Options for the Laminitic Horse

Acute Treatment Options		Chronic Treatment Options	
Drug Name	Evidence in the Laminitic Horse	Drug Name	Evidence in the Laminitic Horse
NSAIDs	Yes: Clinical cases, anecdotal	NSAIDs	Yes: Clinical cases, anecdotal
Opioids	Yes: Clinical cases, anecdotal	Opioids	Yes: Clinical cases, anecdotal
Alpha-2 agonists	Yes: Anecdotal	Alpha-2 agonists	Yes: Anecdotal
Local anesthetics	Yes: Clinical cases, anecdotal	Local anesthetics	Yes: Clinical cases, anecdotal
Epidurals	Yes: Anecdotal	Ketamine	Yes: Clinical cases, anecdotal
Vasodilators	Yes: Anecdotal	Gabapentin	Yes: Clinical cases, anecdotal
Cytochrome P450 epoxygenases	Yes: Clinical cases	Vasodilator	Yes: Anecdotal
Acetaminophen	No	Biologics	Yes: Clinical cases, anecdotal
Amitriptyline	No	Cytochrome P450 epoxygenases	Yes: Clinical cases
Grapiprant	No	Resveratrol	No
Digital hypothermia	Yes: Controlled studies	Acetaminophen	No
Acupuncture	Yes: Clinical cases, anecdotal	Amitriptyline	No
Manual therapies	No	Grapiprant	No
TENS	No	Acupuncture	Yes: Clinical cases, anecdotal
Therapeutic trimming/shoeing	Yes: Clinical cases, anecdotal	Manual therapies	No
		TENS	No
		Therapeutic trimming/shoeing	Yes: Clinical cases, anecdotal

NSAIDs, non-steroidal anti-inflammatory drugs; TENS, transcutaneous electrical nerve stimulation.
Not all treatments listed above may be appropriate for all patients. Please see precautions for each medication in Table 2.

when developing a therapeutic plan. To help guide this, treatment options for horses with acute versus chronic laminitis are listed in Table 1. Case examples as to how these treatment options can be applied are included in the text and reported drug dosages are listed in Table 2.

Non-Steroidal Anti-Inflammatory Drugs

Mechanism of action: Non-steroidal anti-inflammatory drugs (NSAIDs) mediate analgesia by blocking the generation of proinflammatory and pro-algesic lipids from oxidative metabolism of arachidonic acid.[11] In addition, NSAIDs can help decrease peripheral sensitization caused by products of arachidonic acid metabolism (prostaglandins and leukotrienes).[12] There is also evidence that NSAIDs may help with pain due to inhibition of central sensory neurons.[13]

Phenylbutazone

Phenylbutazone is considered by clinicians to be the most efficacious and consistent NSAID in relieving pain in the laminitic horse.[13] Phenylbutazone, which inhibits both COX-1 and -2, has been shown to be more effective than selective COX-2 inhibitors (e.g., firocoxib) in the laminitic horse.[13] Phenylbutazone is also effective in treating other musculoskeletal disorders. In treatment of joint pain, its analgesic effects are likely the result of suppression of synovial membrane PGE_2, and an *in vitro* study of equine synovial explants challenged with lipopolysaccharide showed no detrimental effects on synovial membrane viability and function after treatment with phenylbutazone.[14] In human patients, phenylbutazone has also been shown to reach higher concentrations in inflamed versus non-inflamed joints due to differences in pH.[15] Given the inflammation associated with laminitis, it is possible that phenylbutazone concentration will be higher in the affected digit of the laminitic horse. While the concentration of phenylbutazone within the equine digit has not been evaluated, a study of induced subcutaneous inflammation in ponies showed that a single dose of phenylbutazone (4.4 mg/kg) given intravenously (IV) or orally (PO) significantly reduced exudate concentrations of PGE_2 and PGF_1 and reduced skin temperature.[15]

A dose-effect relationship has also been shown with phenylbutazone. In a study of induced carpal osteoarthritis in horses, no analgesic effect was seen with a single dose at 1.1 mg/kg while maximum analgesic effect was seen at 2.2 mg/kg. Further increasing the dose did not change the analgesic effect but increased the duration of effect (8 hours with 2 mg/kg dose; 24 hours with 8 mg/kg dose).[16] In a separate study of horses with naturally occurring chronic forelimb lameness, no difference was seen in force platform analysis between 4.4 and 8.8 mg/kg phenylbutazone IV given daily for 4 days.[17] Because of increasing risk of toxicity with increasing dosage,[15] the lowest effective dose should be used.

While there is evidence for efficacy of phenylbutazone, and some report it as having superior analgesic effects when compared to other NSAIDs,[3] several studies contradict this. For example, in a group of horses evaluated for pain using response to thermal thresholds, phenylbutazone was indistinguishable from saline controls.[15] Similarly, minimal differences were seen between phenylbutazone and placebo treatment in a group of horses undergoing arthroscopic surgery,[18] suggesting that the origin and type of pain may have an influence on efficacy of phenylbutazone.

In addition, one study suggests that combining phenylbutazone with other NSAIDs may be more

Table 2. Analgesic Options for the Laminitic Horse

Drug Name	Dosage/Route of Administration	Precautions/Notes	References
Phenylbutazone	2.2–4.4 mg/kg IV or PO q12h	Possible renal, GI	2
Flunixin	0.5–1.1 mg/kg IV or PO q8–12h	Possible renal, GI	2
Ketoprofen	2.2–3.6 mg/kg IV q6–12h	Possible renal, GI	2, 11, 21
Firocoxib	0.1 mg/kg PO q24h	0.3 mg/kg often given on first day	21, 23
Diclofenac ointment	Topical q12–24h	Skin irritation can occur; must clip hair	29
Pentoxifylline	4.4 mg/kg PO q8h	No known direct analgesic effect	94
Lidocaine	1.3 mg/kg IV loading dose, 0.05 mg/kg/min CRI	Neurologic side effects can occur	2
Bupivacaine	3 mL of 0.5% solution perineurally q12–24h	Can consider placing percutaneous catheter	38
Detomidine	10–40 μg/kg IM or IV q2–4h	Consider coadministration with opioid	21
	Bolus 5–10 μg/kg IV, 24–36 μg/kg/hr CRI		
Morphine	0.1–0.2 mg/kg IV/IM q4–6h	GI, behavioral side effects can occur;	21
	0.1 mg/kg qs to 50 mL with saline via IVRP	Consider coadministration with alpha-2	
Butorphanol	0.01–0.4 mg/kg IV/IM q2–4h	GI, behavioral side effects can occur	21
		Consider coadministration with alpha-2	
Buprenorphine	5–20 μg/kg IV/IM q8h	GI, behavioral side effects can occur	21
	6 μg/kg sublingual q12h	Consider coadministration with alpha-2	
Methadone	0.1–0.2 mg/kg IV/IM q4–6h	Consider combining with detomidine at 0.1 mg/kg	21, 51
Fentanyl	2–3 10 mg (100 μg/hr) patches changed q2–3d	IV fentanyl ineffective	20, 47
Tramadol	5 mg/kg PO q12h Combine with ketamine CRI at 0.6 mg/kg/hr for first 3 days	Increased risk GI side effects at 10 mg/kg PO q12h	48, 49, 50
Ketamine	100–150 μg/kg bolus, 60–120 ug/kg/hr CRI	Consider combining with tramadol	19, 21, 50
Epidurals	Morphine 0.1–0.2 mg/kg, xylazine 0.17 mg/kg OR detomidine 20–30 μg/kg) ± bupivacaine (0.125–0.25%), bolus 15–30 mL or infuse at 0.5–3.0 mL/hr		21
	Morphine 0.2 mg/kg, xylazine 0.2 mg/kg diluted with 0.9% NaCl to 0.2 ml/kg		3
	Morphine 0.2 mg/kg, detomidine 30 μg/kg		43, 82
Gabapentin	5–20 mg/kg PO q8–12h	Must wean off slowly when discontinuing	3
Acepromazine	0.06 mg/kg IV q12h	No known direct analgesic effect	2
Isoxsuprine	1.2 mg/kg PO q12h	No known direct analgesic effect	94
Resveratrol	2000 mg resveratrol + 200 mg sodium hyaluronic acid q24h for minimum 28 days		129
Acetaminophen		No controlled studies have been performed	131
TENS	Acute pain settings: Frequency >100 Hz, pulse duration 50 μs		
	Chronic pain settings: Frequency <20 Hz, pulse duration 200 μs		

CRI, constant rate infusion; GI, gastrointestinal; IM, intramuscular; IV, intravenous; IVRP, intravenous regional limb perfusion; TENS, transcutaneous electrical nerve stimulation.

effective. Horses with naturally occurring forelimb or hindlimb lameness were exercised on a treadmill. Horses were given either phenylbutazone (2.2 mg/kg PO q12h) or phenylbutazone plus flunixin (1.1 mg/kg IV q12h) for 5 days. No significant clinical improvement was seen with phenylbutazone alone; however, greater effect was seen with stacking of the NSAIDs at 12 and 24 hours.[19] Gastrointestinal and renal side effects must be taken into consideration if multiple NSAIDs are administered.

Flunixin Meglumine (Flunixin)

While anecdotally phenylbutazone has been considered superior to other NSAIDs for musculoskeletal pain, flunixin may also be effective. While not specifically evaluated in the laminitic horse, analgesic effects of flunixin (1.1mg/kg IV) and phenylbutazone (4.4 mg/kg IV) were comparable in horses with naturally occurring navicular syndrome evaluated using both objective (force platforms) and subjective lameness methods.[20]

Ketoprofen

One study evaluating horses with bilateral chronic laminitis demonstrated that when administered at an equivalent dose, ketoprofen was more effective than phenylbutazone for controlling pain in horses with naturally occurring chronic laminitis.[21] A dose of 3.63 mg/kg (equimolar to 4.4 mg/kg phenylbutazone dose) was more effective than the 2.2 mg/kg ketoprofen or the 4.4 mg/kg phenylbutazone doses at reducing lameness and hoof pain.[21]

Firocoxib

Firocoxib has not been specifically evaluated in the laminitic horse; however, firocoxib has been effective at reducing lameness in horses with other musculoskeletal conditions. In horses with naturally occurring osteoarthritis, firocoxib at 0.1 mg/kg PO q24h was as effective as phenylbutazone at 4.4 mg/kg PO q24h in improving lameness.[22] Firocoxib was also shown to improve signs of lameness in 80% of a group of 390 horses with naturally occurring osteoarthritis.[23] Therefore, firocoxib administration can be considered in the laminitic horse, particularly if gastrointestinal or renal side effects are of concern.

Diclofenac

The topical anti-inflammatory, diclofenac, has been shown to be effective for certain conditions. In horses with experimentally-induced carpal osteoarthritis, significant improvements in lameness and histologic cartilage scores were seen with topical diclofenac (7.3 g applied twice daily) versus controls.[24] Diclofenac also has the ability to readily cross into joints and subcutaneous tissues. In one study, topical treatment over the joint resulted in higher concentrations in synovial fluid than the minimal anti-inflammatory levels needed to control local inflammation.[25] In a rodent study of subcutaneous inflammation induced with carrageenan, topical administration of a single dose of diclofenac significantly reduced local PGE_2 levels.[26] Based on these limited studies, it may be reasonable to apply diclofenac to the coronary band of a horse with laminitis when inflammation is suspected as a component of the clinical picture. In addition, due to limited systemic absorption,[24] topical diclofenac may be an option for horses in whom systemic NSAIDs are contraindicated or in horses that need additional local anti-inflammatories.

Opioids

<u>Mechanism of action:</u> Opioids mediate analgesia by stimulating μ, κ, or δ opioid receptors.[27] Opioids are classified as pure μ-agonists (morphine, fentanyl), partial μ-agonists/κ-antagonists (buprenorphine), or partial μ-antagonists/κ-agonists (butorphanol).[3] Methadone, a synthetic μ-opioid agonist/NMDA antagonist has also been used in the horse.[3,28] Tramadol is a weak opioid receptor agonist but also functions as a neuronal serotonin and norepinephrine reuptake inhibitor.[11] Since work in horses with laminitis is limited for this class of drugs, the following information is largely based on studies of their use in unrelated orthopedic and gastrointestinal conditions. It is worthwhile noting that moderate to high doses of opioids when given alone in the horse can have significant gastrointestinal, hemodynamic, and behavioral side effects.[1] It is also worth mentioning that drugs in this class are scheduled (II–IV) by the drug enforcement agency and have potential for human abuse.

Morphine

While morphine can have negative side effects if given IV, other routes of administration have proven effective. Morphine given at 0.1 mg/kg intramuscularly (IM) to horses hospitalized for a variety of conditions was shown to be at detectable levels in the plasma for 3 hours after administration with minimal side effects; however, heart rate and respiratory rate were the only clinical parameters assessed[29]; the level of analgesia this dose provides is unknown. In an equine study using a lipopolysaccharide-induced synovitis model, intra-articular administration (0.05 mg/kg) significantly reduced inflammation (decreased joint circumference, synovial total protein, serum amyloid A) as compared to IV administration.[30] Measurable concentrations of morphine (0.1 mg/kg) were reported in the middle carpal joint between 20 minutes and for 5 hours after administration by intravenous regional limb perfusion (IVRP).[31] In addition, morphine administered to people subcutaneously prior to intradermal capsaicin injection attenuated mechanical hypersensitivity and markedly reduced the area of mechanical hypersensitivity.[32] Therefore, local administration of morphine in the laminitic horse may provide pain relief and has anecdotally been used perineurally.

Butorphanol

In a study of 203 horses undergoing surgery (the majority were elective orthopedic surgeries), horses received either IV phenylbutazone, flunixin, or carprofen intraoperatively. Sixty-eight of the horses received 0.1 mg/kg butorphanol IV intraoperatively in addition to the NSAID. Significantly fewer horses that received butorphanol during surgery required additional analgesics postoperatively compared to those that received NSAIDs alone.[33]

The duration of analgesia in response to superficial and visceral stimulation after IM administration has been reported to be 15 to 90 minutes with 0.4 mg/kg dosage providing the most intense and longest-lasting analgesia.[34] However, other studies have shown that the systemic availability after IM injection is low (37%) with a dosage of 0.08 mg/kg IM q3h necessary to maintain plasma concentrations.[35] In addition, horses assessed for pain following castration showed no difference between butorphanol (0.05 mg/kg IM prior to surgery then q4h for 24 hours) and phenylbutazone (4.4 mg/kg IV prior to surgery then 2.2 mg/kg PO q12h for 3 days). Combining the drugs was not superior to each drug administered alone.[36]

In a different study evaluating administration of butorphanol constant rate infusion (CRI), delayed gastrointestinal transit time was seen without substantially affecting somatic nociception; 4/8 horses showed signs of colic when butorphanol was included in the CRI.[37]

Fentanyl

Transdermal fentanyl (patch) may also be a viable option for managing pain in the laminitic horse. In a study of healthy research horses with 2×10-mg fentanyl patches applied to either the antebrachium or gaskin, mean serum fentanyl concentrations were consistent with those reported to be analgesic in other species (1 ng/mL) by 1 hour of application. This level was maintained until 32 hours after patch application with no hematologic or clinical side effects.[38]

Another study looked at fentanyl patches administered to client-owned horses suffering from a variety of soft tissue or orthopedic conditions (including laminitis). All horses were thought to be refractory to NSAIDs (phenylbutazone or flunixin). Serum fentanyl concentrations of 1 mg/mL were measured 14 hours after patch application on the antebrachium and stayed at this level for 18 hours post-application. However, while pain scores were improved in the horses, lameness scores were not significantly improved.[39] In another report of subjective pain assessment in a group of hospitalized horses, only slight improvement in horses with laminitic pain was noted as opposed to significant improvement in horses with visceral pain.[40]

It is worth noting that when given intravenously, fentanyl has been shown to provide ineffective analgesia with undesirable behavioral effects in adult horses.[41,42] A study of conscious, standing horses tested visceral and somatic pain using duodenal/colorectal distention and thermal thresholds, respectively. Fentanyl was administered as a CRI at four doses (8, 16, 32, 64 ng/kg/min). Control horses received either xylazine (positive control) or saline (negative control). None of the fentanyl groups showed a significant increase in visceral pain threshold following administration, while horses receiving xylazine showed a significant increase. A trend toward increased somatic threshold was seen 15 minutes after fentanyl CRI was initiated, but only in the highest fentanyl group.[42] Based on these data, it appears that there is more benefit to treating pain in the laminitic horse with transdermal as opposed to IV administration.

Methadone

Methadone administration has not been evaluated in the laminitic horse. As with other opioids, the dosage of methadone must be chosen carefully—side effects including spontaneous locomotion (0.2 mg/kg), ataxia (0.5 mg/kg), and muscle tremors (0.5 mg/kg) have been seen.[43,44] In a study of healthy horses, methadone administered at 0.2 mg/kg IV alone showed no significant analgesic effects, as determined by thermal and electrical nociceptive thresholds. However, when combined with detomidine (0.1 mg/kg IV), a synergistic effect was seen with significant increases in thermal and electrical nociceptive thresholds. This improvement in analgesia was also greater with both methadone and detomidine than with detomidine alone.[43] Therefore, administration of methadone could be considered in combination with detomidine for treatment of acute pain.

Tramadol

Tramadol has been shown to have poor oral bioavailability and rapid elimination in horses.[45] It has, however, been shown to dose-dependently improve pain in horses with chronic laminitis. Analgesia was reported at a dose of 10 mg/kg (not seen at 5 mg/kg) q12h.[11] However, signs of colic have been reported in horses at the 10 mg/kg dosage.[46,47] Interestingly, when tramadol was administered in conjunction with a ketamine CRI, oral tramadol was more effective at a lower dose in a laminitis model. Dose administration included ketamine at 0.6 mg/kg/hr for 6 hours/day for 3 days and oral tramadol at 5 mg/kg q12h for 7 days. Significant improvement in comfort level was reported.[48]

α-2 Agonists

<u>Mechanism of action:</u> α-2 adrenergic or adrenoreceptor agonists mediate analgesia by decreasing afferent activity and activating descending inhibitory neurons.[11] α-2 receptors are found on primary afferent terminals in peripheral and spinal nerve endings, the dorsal horn of the spinal cord, centrally in the brainstem, and peripherally in the joint—their activation can produce central and peripheral analgesia.[10,49] α-2 agonists also have a synergistic effect with opioids in both horses and humans, allowing an opioid-sparing effect.[50–54] While effective analgesics when given systemically, α-2 adrenergic agonists cause sedation, cardiopulmonary depression, and may influence gastrointestinal function that may impact duration of their use.[55] Alternate routes (e.g., epidural, intra-articular) are therefore sometimes suggested as alternatives.

Detomidine

Antinociceptive effects of α-2 agonists in the horse have been well demonstrated,[56,57] but controlled studies in the laminitic horse are lacking. For other forms of musculoskeletal pain, detomidine has been shown to be an effective analgesic. In one study of induced hoof lameness, detomidine given at 10, 20, or 40 μg/kg IV effectively raised the mechanical hoof pain threshold and lowered the intensity of hoof withdrawal response. This analgesic effect lasted for 55 minutes (mechanical hoof pain threshold) and 120 minutes (hoof withdrawal response). Lameness, as assessed by the modified Obel scale, was also significantly reduced at 20- and 40-μg/kg doses.[58] In a study of horses with naturally occurring forelimb or hindlimb lameness, horses that received 0.007 mg/kg detomidine IV alone or in combination with butorphanol (0.007 mg/kg IV) showed significant increases in mechanical nociceptive thresholds proximal to the coronary band up to 30 minutes after administration. Small, but significant improvements in lameness, as measured by an inertial sensor system, were also seen.[59]

Xylazine

Local administration of xylazine may be an option for managing pain in horses. In people, intra-articular administration of α-2 agonists has been shown to mediate analgesia.[49] Similarly, an equine study by Scicluna[60] showed that xylazine offers analgesic benefits for horses when administered intra-articularly. However, an *in vitro* study evaluating xylazine administration at various concentrations to equine cartilage explants showed dose-dependent chondrotoxicity.[61] In people, perineural administration of α-2 agonists with local anesthetics has also been shown to increase analgesia compared to anesthetics alone.[62] Therefore, perineural administration in the laminitic horse could be considered; however, intra-articular use in the horse should be performed with caution.

Local Anesthetics

Mechanism of action: Local anesthetics inhibit pain by blocking sodium channels, thereby interrupting neurotransmission near the site of injury.[11] Local anesthetics prevent initiation and conduction of electrical impulses in C and A-delta sensory nerve fibers.[63] They have also been shown to reduce post-synaptic depolarization mediated by NMDA receptors at the spinal cord in laboratory animals.[64,65] This drug class has a long history of diagnostic and therapeutic use in the horse.

Lidocaine

The antinociceptive effects of systemic lidocaine have been evaluated in horses. In a study of conscious, healthy research horses, CRI of lidocaine (2 mg/kg bolus followed by 50 μg/kg/min CRI for 2 hours) significantly increased somatic pain (thermal threshold) and visceral pain thresholds.[66] Clinical reports have also shown effective analgesia with the use of lidocaine CRI in horses with chronic laminitis.[67] While not studied in the horse, IV lidocaine has also been established as having analgesic effects in human patients with neuropathic pain.[67]

In addition to blocking neurotransmission or afferent signals, perineural administration of local anesthetics have also been reported to cause a decrease in gene expression of inflammatory proteins.[68] A suppression of inflammation with perineural anesthesia has been suggested in humans and in laboratory animals,[69] but has not been demonstrated in the horse. There is some controversy as to whether lidocaine has any anti-inflammatory effects in the horse.[9]

Transdermal administration of local anesthetics are thought to have some local benefit over the site of injury,[70] and it has been suggested that lidocaine patches could be applied over the digital nerves of laminitic horses for pain relief.[11] A study of healthy, adult horses showed an increase in both thermal and superficial mechanical nociceptive thresholds after application of a 5% lidocaine patch to the withers and saddle region. Analgesic effects were seen after product application and at 1 hour after the patch was removed.[70] Percutaneous catheter placement over the palmar nerves has also been described in the horse to provide continuous nerve blockade. This allows treatment with lidocaine, mepivacaine, or bupivacaine.[71]

Liposomal Bupivacaine

Liposomal bupivacaine was developed and approved for use in humans to help prolong the analgesic effects of the local anesthetic bupivacaine.[72,73] This formulation allows the slow release of bupivacaine over time and is approved for infiltrative use in the dog and cat following specific procedures. It is estimated to provide up to 72 hours of pain relief.[74]

To date, two equine studies have been performed. The first evaluated use of liposomal bupivacaine in the joint of healthy horses to assess possible chondrotoxic effects. Minimal effect on markers of chondrodestruction were found, suggesting that this medication can be administered in the joint safely.[75] The second study looked at use of liposomal bupivacaine compared to standard bupivacaine administered perineurally (abaxial nerve block). Forelimb lameness was induced by inserting a screw into the sole. Objective lameness (inertial sensor system) and mechanical nociceptive thresholds were evaluated. Liposomal bupivacaine significantly improved objective lameness and mechanical nociceptive thresholds up to 24 hours after administration. The time of analgesia was greater for liposomal bupivacaine compared to standard bupivacaine (analgesia for 1 hour only post-injection).[76] This formulation of bupivacaine would be beneficial to provide the laminitic patient with longer-lasting analgesia; however, a liposomal bupivacaine formulation is not currently labeled for use in the horse.

Ketamine

Mechanism of action: Ketamine is an NMDA antagonist and is used to help mitigate central sensitization that can occur with chronic pain.[11] Ketamine has been shown to have a short duration of action; therefore, administration via CRI is strongly suggested.[77]

As mentioned previously, ketamine in combination with tramadol provided analgesia in horses with naturally occurring chronic laminitis.[48] Authors report that the addition of ketamine resulted in significantly reduced limb off-loading frequency for the entire treatment period of 7 days. Significant reductions in TNF-α and TXB2 (a stable metabolite of the vasoconstrictor prostanoid, TXA2) were also seen in the ketamine-tramadol group, which was not seen with oral tramadol alone.[48]

However, CRI of ketamine alone may not be beneficial. One study looked at ketamine given to horses treated for a variety of conditions, including osteomyelitis, joint sepsis, burns, and colic.[13] Ketamine CRI was given at 400 and 800 μg/kg/hr for 5 days. Horses showed variable response with some horses showing no signs of comfort while others showed markedly increased comfort. However, pain was evaluated using only heart rate and a subjective comfort evaluation.[13]

Gabapentin

Mechanism of action: Gabapentin is used predominantly for human and veterinary patients with chronic and neuropathic pain.[78] Gabapentin mediates analgesia by binding to the α-2-δ-1 subunit of voltage-gated calcium channels in the spinal cord and brain. It can then change the release of the neurotransmitters glutamate, GABA, and norepinephrine.[79]

Multiple case reports are available detailing success with use of gabapentin in horses with neuropathic pain,[78] including chronic laminitis,[80,81] headshaking,[82] and femoral neuropathy.[78] However, the reported bioavailability of gabapentin is low (16.2%).[83] Therefore, high oral doses (5 to 20 mg/kg PO 2 to 3 times daily) are recommended.[3] A recent study suggests even higher doses could be used in the horse. A single dose of gabapentin was administered to a group of 9 healthy horses at 10, 20, 40, 60, 80, 120, and 160 mg/kg in a randomized cross-over design. Plasma samples were taken up to 64 hours after administration. Horses were also evaluated for signs of sedation and ataxia. While plasma concentrations increased across the dose level, the increase was not in a proportional manner—the authors concluded that a dose higher than 120 mg/kg would not provide any noticeable differences in pharmacological effect. Only one horse showed signs of moderate sedation at the higher dosages (120 mg/kg and 160 mg/kg). However, evaluation of hepatic and renal values was not performed and the authors comment that the safety of repeated dose administration higher than 20 mg/kg needs to be evaluated further.[84]

Gabapentin has been reported to be ineffective at reducing the degree of chronic lameness in the horse. In one study, horses with naturally occurring osteoarthritis in a variety of joints were given gabapentin orally at 5 mg/kg and 10 mg/kg q8h for 14 days. No significant improvement in lameness was seen for either group.[80] In another report, no improvement was seen when gabapentin (20 mg/kg q12h PO) was added to treatment with phenylbutazone (4 mg/kg q12h PO) in a horse with severe laminitis. Authors also showed that the plasma concentrations were well below that reported to provide analgesia in humans and treatment duration was limited to 2 days.[81] It is likely that both an increased dose and duration of treatment are needed if gabapentin is to have efficacy in treating laminitic horses.

Epidurals

Mechanism of action: Epidurals allow administration of analgesics at lower doses than those required for systemic administration.

Morphine given alone (0.2 mg/kg) and when combined with detomidine (30 μg/kg) for experimentally-induced hindlimb lameness showed significantly reduced lameness for up to 6 hours after administration.[85] In addition, horses that received this same drug combination via epidural before stifle arthroscopy had significantly reduced lameness and heart rates compared to controls.[86] Hence it is possible that epidural morphine (alone or in combination with detomidine) might have a benefit for hind-limb laminitis. Efficacy of epidurals for horses with forelimb disease including laminitis remains a topic of debate. However, several studies suggest that there may be a benefit. For example, in a study of carpal synovitis induced with lipopolysaccharide in ponies, either a morphine (0.1 mg/kg diluted to 0.15 mL/kg with saline) or buprenorphine epidural (5 μg/kg diluted to 0.15 mL/kg with saline) was administered. A significant reduction in lameness was seen at 30 minutes with the morphine group and at 6 hours with the buprenorphine group, suggesting that morphine epidural was an effective analgesic for pain in the thoracic limbs.[87]

Vasodilators

Mechanism of action: Chronic laminitis is marked by aberrant vascular patterns and hemodynamic disturbances of lamellar tissues.[88,89] Endothelin-1, a potent vasoconstrictor has been shown to have significantly increased expression in connective tissues during chronic laminitis as opposed to acute laminitis.[90] While vasodilators have been used in the laminitic horse in an attempt to offset this disruption, it is unknown if changes in blood flow consistently occur and help with healing or alleviate pain.

Pentoxifylline

Pentoxifylline is a rheologic agent[4] that is thought to increase blood flow in compromised vasculature by increasing the malleability of blood cells.[91] Vasodilatory effects are mediated through increases in production of intracellular cyclic adenomonophosphate and nitric oxide.[92,93] Pentoxifylline has been shown to have extremely variable absorption in the horse after oral administration.[94,95] Bioavailability is also somewhat variable. In one study, healthy horses received 10 mg/kg pentoxifylline PO q12h for 8 days—bioavailability after the first dose was 68% and decreased to 44% after the last dose. Pentoxifylline has been shown to produce endothelium-dependent and endothelium-independent relaxation of the equine digital veins. Pentoxifylline also mediates improvements in systemic microvascular flow and tissue oxygen delivery.[92] Relaxation of the equine digital veins was shown *in vitro*[92]; however, use of pentoxifylline (4.4 mg/kg PO q8h for

10 days) was not found to increase blood flow in the digit of normal horses in an in vivo study.[91] Use of pentoxifylline has not been evaluated in laminitic horses.

Isoxsuprine

Isoxsuprine is a peripheral vasodilating agent that has been described as a beta receptor agonist and an alpha adrenergic receptor antagonist.[91,96] Isoxsuprine is also thought to decrease blood viscosity by increasing blood flow or by increasing flexibility of red blood cells.[91] In a study of horses with navicular syndrome, improvements in clinical assessments (lameness evaluation, hoof testers, flexion tests) were seen after oral administration (0.6 mg/kg, 1.2 mg/kg, or 1.8 mg/kg q12h for 21 days)[97] with no differences between dosages.[98]

However, in a study evaluating isoxsuprine administration to a group of healthy horses (1.2 mg/kg q12h orally for 10 days), no significant increase in blood flow to the digit or dorsal laminae was seen.[91] Evaluation of use in the laminitic horse has not been performed. Additionally, reports indicate that the vasodilatory effects of isoxsuprine occur only at doses that induce neurologic side effects in the horse.[9,91] A somewhat novel suggestion is that isoxsuprine may have some local anesthetic properties, but again analgesia following administration has not been evaluated in the horse.[97]

Acepromazine

Acepromazine is a phenothiazine tranquilizer with no direct analgesic effects. Acepromazine has been suggested for use in laminitic horses for its peripheral vasodilatory effects and potential to restore digital blood flow.[91] Acepromazine has been reported to increase arterial diameter and blood flow in the dorsal metatarsal artery in horses.[99] In addition, IV administration at 0.06 mg/kg has been shown to increase digital arterial and laminar blood flow in multiple studies using normal horses.[100,101] While these studies have shown an increase in digital blood flow in the normal horse, it is unknown if increased blood flow occurs in the laminitic horse. This dose is also on the higher side of what is commonly used for tranquilization so other side effects (e.g., tranquilization, hypotension) could occur.

Biologics

Mechanism of action: Biologic therapies including platelet-rich plasma (PRP) and stem cells have been evaluated for use in the laminitic horse. These biologic therapies are thought to help alleviate pain mainly through their anti-inflammatory activity. Biologics may be particularly useful for cases of chronic laminitis by antagonizing the self-perpetuating catabolic and proinflammatory mechanisms that lead to local ischemia and neuropathic pain.[88] In addition to anti-inflammatory effects, stem cells also have immunomodulatory and anti-oxidative effects that may be protective against hypoxia/reperfusion injury.[102–104]

A study evaluated return to use in a group of nine horses with chronic laminitis treated with stem cells. Horses received IVRP with adipose-derived stem cells suspended in PRP. Horses received between 3 and 6 treatments at 1-month intervals. All horses were back in use 6 months after treatment. One year after treatment, 7/9 horses were still in work.[105]

An additional study looked at treating a group of 15 horses with mesenchymal stem cells via IVRP or intra-arterial stem cells. Intra-arterial stem cells were shown to have a better distribution within the foot than IVRP; however, no significant difference in success by treatment route was appreciated. There was a significant relationship between timing of treatment and success following treatment with stem cells. For horses treated sooner than 71.5 days after onset of laminitis, 87% were successful. For horses treated after 71.5 days, only 53% were successful. Treatment was also more successful in younger horses (82% for horses <11 years of age) versus older horses (50% for horses >11 years of age); however, there was no significant difference between age groups. While this study shows promise, “success” of treatment was never defined.[106] There are also reports of several horses with chronic laminitis treated with PRP injected into the coronary band. These horses showed decreased lameness and improved comfort level; however, no controlled studies have been performed.[88]

Potential Treatment Options

Cytochrome P450 Epoxygenases

Mechanism of action: Oxidative metabolism of polyunsaturated fatty acids (arachidonic acid, docosahexaenoic acid, eicosapentaenoic acid) result in production of potent inflammatory mediators. Cytochrome P450 mediates another pathway of polyunsaturated fatty acid metabolism, which includes transformation into epoxides.[81] Epoxides have multiple biological activities, including modulation of inflammation and nociceptive signaling.[107] The biological activity of epoxides is limited by the enzyme soluble epoxide hydrolase (sEH inhibitor).[81]

An equine study evaluated the use of an sEH inhibitor in 10 horses with naturally occurring acute and chronic laminitis affecting 2 to 4 feet. Eight of the 10 horses showed significant improvements in comfort level, as evaluated by visual analog scale and reduced number of forelimb lifts observed (limb shifting). Histopathology of the laminae was performed on three horses who were not treated with the sEH inhibitor. Evaluation showed increased levels of sEH activity in the laminae of laminitic horses compared to nonlaminitic controls.[108]

An additional equine study by the same author looked at use of an sEH inhibitor in an induced model of synovitis. Horses were treated with the sEH inhibitor intravenously after induction of synovitis in one radiocarpal joint with lipopolysaccharide. A dose of 1 mg/kg of the sEH inhibitor produced significant antinociceptive effects, as evaluated by visual analog scale and subjective lameness scores. No significant anti-inflammatory activity was present as evaluated by cell numbers, joint effusion, and protein concentration.[109]

Similar findings were seen in laboratory rodent models. An sEH inhibitor showed significantly improved pain in a model of inflammatory and neuropathic pain in rodents.[110,111] In addition, stronger anti-inflammatory and analgesic effects have been seen in rodents when compared to coxibs or NSAIDs.[111,112] Unfortunately, to the author's knowledge there currently is no product that is commercially available. In the equine studies, the drug was synthesized by one of the authors.[108,109]

Resveratrol

Mechanism of action: Resveratrol is found in the skins of certain red grapes, peanuts, blueberries, and the roots/stalks of Japanese knotwood.[113] Reported benefits of resveratrol include anti-inflammatory, anticancer, antimicrobial, and antioxidant.[114] The antioxidative effects are thought to be due to activity as a free radical scavenger.[115]

Resveratrol has been shown to be as effective as COX inhibitors in decreasing production of IFN-γ and TNF-α by peripheral blood mononuclear cells.[11] In an equine study, resveratrol administration to a group of 20 older horses for 4 weeks was shown to significantly decrease serum inflammatory cytokine production.[116]

Another study evaluated horses fed 2000 mg resveratrol daily for 28 days. These horses had significantly increased superoxide dismutase activity (provides vascular protective effect and protection against oxidative stress) following supplementation. However, the resveratrol product given also contained 200 mg sodium hyaluronic acid, so it is unknown which compound was of most benefit.[116] An additional equine study evaluated supplementation to horses with hindlimb lameness localized to the distal hock joints. Client-owned horses had the distal hock joints treated with corticosteroids and then received 1000 mg resveratrol twice daily or a placebo supplement for 4 months. Horses that received resveratrol showed significant improvements in performance compared to the placebo group according to client questionnaire. The resveratrol group on objective lameness evaluations demonstrated significant improvements in the amplitude of pelvic displacement. However, there was no difference in subjective lameness scores or objective maximum/minimum pelvic height difference using inertial sensor assessment.[117]

Acetaminophen

Mechanism of action: While the mechanism for pain modulation is not completely understood, acetaminophen is thought to inhibit COX-3, which is involved in central pain perception.[3] Other reports have suggested that acetaminophen acts on serotonergic and cannabinoid pain pathways in the central nervous system (CNS).[77] Acetaminophen also has activity as a vasodilator.[100,118]

Acetaminophen was reported as an effective adjunctive treatment in a pony with laminitis[119] and has excellent oral bioavailability.[3,77] A recent study was performed evaluating the oral administration of acetaminophen in healthy, adult horses at a dose of 20 mg/kg for 14 days. Gastroscopy was performed at the start of the study and at the end of the 14-day course; no significant changes in gastroscopy scores were seen. Liver biopsies were also performed, which showed mild evidence of portal inflammation in all horses; however, horses showed no signs of hepatic dysfunction. A mild increase in total bilirubin was also found on serum chemical analysis.[120]

Amitriptyline

Mechanism of action: Amitriptyline is a tricyclic antidepressant and is thought to have analgesic effects by its action on α-2 adrenoreceptors and its ability to block sodium channels.[77,121] Amitriptyline also has anticholinergic and antihistamine properties[122] and has also been shown to be a serotonin reuptake inhibitor, which then enhances the action of serotonin at the spinal terminals of the opioid-mediated intrinsic analgesic system.[49]

In a rat study, addition of amitriptyline significantly improved analgesia as measured by the tail-flick test when compared to administration of morphine alone.[123] While there are reports of use in the horse,[3,77] to date no controlled studies have been performed.

Grapiprant

Mechanism of action: Grapiprant is a prostaglandin receptor antagonist with specific and potent activity against the PGE_2 EP4 receptor with anti-inflammatory and analgesic effects.[124]

Multiple canine studies have shown effective pain relief in dogs with osteoarthritis[124] with no significant side effects with long-term use.[125] A study in 12 healthy, adult horses evaluated the safety and pharmacokinetics following a single dose of grapiprant at 2 mg/kg by mouth. No adverse effects were noted. Grapriprant was able to be measured within the serum for 72 hours post-administration.[126] To date, no studies evaluating the analgesic effects in the horse have been performed.

3. Non-Pharmaceutical Treatment Options

Digital Hypothermia

Mechanism of action: Digital hypothermia (icing) of the distal limb of the horse can decrease pain by decreasing inflammation within the foot.[9] In addition, digital hypothermia may have a protective effect on the tissues due to a reduction in energy metabolism, mitochondrial dysfunction, and free-radical production.[127] The recommended hoof wall therapeutic surface temperature is 5° to 10°C sustained for 48 to 72 hours.[128] A comparative study evaluating various methods of icing the digit showed that ice and water immersion methods that included both the foot and the distal limb were effective at reaching this temperature. Commercially available dry icing units did not reach the targeted tissue temperature.[128]

In multiple experimental studies of induced laminitis, digital hypothermia performed just below the carpus for 72 hours at the induction of laminitis significantly reduced lamellar injury[129–131] compared to controls. Horses also showed significantly improved clinical signs of laminitic pain for 7 days following 72 hours of continuous digital hypothermia.[132]

There is conflicting information about the efficacy of initiating digital hypothermia after lameness associated with laminitis is present. One study demonstrated that a protective effect was still present with significantly reduced lamellar injury observed.[130] However, another study showed no reduction in the lamellar concentration of molecules associated with inflammatory signaling when digital hypothermia was initiated after signs of laminitis versus initiation at the time of laminitis induction.[68]

While no studies have shown a detrimental effect of digital hypothermia in the laminitic horse, there is thought that therapy must be performed continuously rather than intermittently. Otherwise, vasodilation and rebound hyperemia could occur once the feet are removed from the ice water.[2]

Acupuncture

Mechanism of action: Acupuncture can mediate analgesia by modulating nociceptive input at the level of the dorsal horn of the spinal cord[133]and by endogenous opioid release after stimulation of receptor sites in the dorsal horn of the spinal cord.[134] Acupuncture stimulates descending inhibitory pathways, leading to norepinephrine and serotonin release in addition to endogenous opioids. Electroacupuncture uses stimulation of the acupuncture needles with a mild electrical current, and may provide more analgesia than dry-needle acupuncture.[135]

Several laboratory animal studies have shown positive effects of electroacupuncture. In one rodent study, rats with induced osteoarthritis received either no treatment, treatment with electroacupuncture, or electroacupuncture with an opioid antagonist, serotonin antagonist, or dopamine antagonist given via intraperitoneal injection before electroacupuncture was performed. Significantly more weight bearing was noted in the electroacupuncture group versus the control and antagonist groups, demonstrating that the mechanism of action of electroacupuncture is similar to stimulation of opioid, serotonin, and dopamine receptors.[135] Other rodent studies showed that electroacupuncture is effective at modulating chronic inflammatory pain.[136,137]

Benefit has also been shown in horses. In one equine study, dry-needle acupuncture and electroacupuncture significantly increased the cutaneous pain thresholds in the lumbar region with thermal and electrical stimulation. In addition, β-endorphin cerebrospinal fluid concentrations were significantly increased at 30 and 120 minutes following electroacupuncture.[134] An additional equine study showed alleviation of pain in 6/7 horses with chronic laminitis following acupuncture treatment. In addition, these horses had a reduced need for analgesic medications; however, only subjective evaluation of pain was used for assessment and the duration of the analgesic effect was not described.[98]

Manual Therapies

Mechanism of action: Horses with chronic laminitis can experience significant comorbidities throughout the axial skeleton as they compensate for pain originating from their feet. Manual therapies, including spinal manipulation, massage, and physiotherapy can be of benefit to help treat this secondary pain. Manual therapies can induce relaxation and are thought to increase pain thresholds by stimulating release of endorphins and serotonin. Spinal manipulation alleviates pain by means of gate-control theory by inducing stretch of spinal mechanoreceptors that then decrease central sensitization. Massage is thought to modulate local blood flow and oxygenation of tissues.[138]

No studies have been performed in the laminitic horse; however, massage and soft-tissue mobilization are thought to increase blood flow, decrease muscle hypertonicity, and speed return to normal function; however, few controlled studies have been performed.[138] A study of horses with back pain showed that following massage, mechanical nociceptive thresholds were increased in the thoracolumbar region.[139] Other studies have also demonstrated an increase in mechanical nociceptive thresholds following chiropractic treatments.[139–141] An additional equine study showed that passive stretching helps significantly increase stride length, increase joint range of motion, and improves overall comfort.[138]

Transcutaneous Electrical Nerve Stimulation

Mechanism of action: transcutaneous electrical nerve stimulation (TENS) uses electrical current applied via surface electrodes to preferentially stimulate peripheral nerves and is used primarily for pain modulation.[142,143] Similar to acupuncture, there are two proposed mechanisms for the antinociceptive effects of TENS: 1) Gate control theory: reduction of pain input at the dorsal horn of the spinal cord secondary to stimulation of peripheral mechanoreceptors, and 2) opiate-mediated pain control: TENS stimulates release of endorphins and their precursors into the cerebrospinal fluid.[134]

To date, there are no studies evaluating use of TENS in horses. However, human studies suggest that TENS may be a viable option for pain control. TENS has been shown to alleviate procedural pain in humans during dental procedures (minor tooth extractions, cavity preparations, intraoral injections) and to reduce post-operative pain, analgesic consumption, nausea/vomiting, and speed of recovery.[143] TENS was shown to be effective for reducing acute post-operative pain in people if electrodes were placed close to the incision and a strong, definite, subnoxious (maximal tolerable) sensation was achieved.[142] TENS is commonly recommended for use in humans with chronic pain in addition to medication. Benefits have been reported in 60% of patients during the first few months of use. However, this effect is noted to diminish over time.[142]

Not all human studies show support for use of TENS. In a randomized human study evaluating use of TENS for chronic lower-back pain, there was no significant improvement in pain even when patients were educated on how to correctly use the TENS unit.[144] In addition, variable efficacy is present when evaluating pain modulation for people with rotator cuff tears, sciatica, and fibromyalgia.[142]

Therapeutic Shoeing/Trimming

Therapeutic shoeing and trimming can provide tremendous pain relief in the laminitic horse and is a critical component for long-term management of these cases. Because this topic has been covered extensively elsewhere by experts in the field,[4,106,145] it will not be covered in this review.

4. Case Examples

The case examples below show a potential multimodal approach to treating acute and chronic laminitis. Many treatment options are available, based on clinician experience and preference.

Acute Laminitis

Treatment in the Field

A 14-year-old Quarter Horse gelding unlocks the door to the feed room and consumes half a bag of sweet feed. Within 24 hours the gelding is acutely grade 4/5 forelimb lame with moderately increased digital pulses in both front feet and the horse has adopted the classic laminitic stance.

Pain Management Strategies

- NSAIDs: Administration of phenylbutazone at 4.4 mg/kg PO twice daily for 3 to 5 days, then tapered to 2.2 mg/kg PO twice daily. The dose is further reduced to 2.2 mg/kg once daily as the horse's pain level will allow. If phenylbutazone alone is not sufficient, administration of 2.2 mg/kg phenylbutazone PO twice daily plus 1.1 mg/kg flunixin PO twice daily for 2 to 3 days can be considered.
- Digital hypothermia: Ice and water are placed in an ice boot that includes the foot and distal limb and secured to the horse's front feet. This is changed as frequently as possible by the owner. At times when the digital hypothermia is not possible, the horse is kept in cushioned boots that provide frog and sole support. If unable to ice, the horse is placed in a cushioned boot at all times.
- Acupuncture: Perform both dry-needle and electroacupuncture, choosing points aimed at targeting the front feet. Treatment is performed 1 to 2 times weekly.
- TENS: A region of hair is clipped over the cranial thoracic region, just off dorsal midline. The TENS pads are applied after wetting the area and applying a small amount of coupling gel. The TENS unit itself is secured to the mane. Chronic pain settings are used despite the acute nature of the laminitis and the unit is applied to 30 minutes twice daily. This is to stimulate endogenous opioid release—this will allow pain relief that lasts beyond the time the TENS unit is removed.
- Topical diclofenac: The hair above the coronary band is clipped. When not icing, topical diclofenac ointment is applied over the coronary band, 1 to 2 times daily.

Treatment in the Hospital

A 12-year-old Warmblood mare is presented to an equine referral hospital for acute colitis and endotoxemia. While being treated for this condition, the mare develops acute bilateral forelimb laminitis.

Pain management strategies to target the laminitis are below (other treatments are also being performed to treat the colitis and endotoxemia):

- NSAIDs: Administer phenylbutazone at 4.4 mg/kg IV twice daily for the first 3 to 5 days. This dose is then tapered, as dictated by the horse's comfort level. Because of the endotoxemia present, flunixin at 1.1 mg/kg IV q12h is also a reasonable choice. If phenylbutazone alone is not sufficient, administration of 2.2 mg/kg phenylbutazone IV twice daily plus 1.1 mg/kg flunixin IV twice daily for 2 to 3 days can be considered.
- Digital hypothermia: Ice and water are placed in an ice boot that includes the foot and distal limb and secured to the horse's front feet. The boots are regularly refilled with ice, such that icing is continuous for at least 72 hours.
- Acupuncture: Perform both dry-needle and electroacupuncture, choosing points aimed at targeting the front feet. Treatment is performed 1 to 2 times weekly.
- TENS: A region of hair is clipped over the cranial thoracic region, just off dorsal midline. The TENS pads are applied after wetting the

area and applying a small amount of coupling gel. The TENS unit itself is secured to the mane. Chronic pain settings are used despite the acute nature of the laminitis and the unit is applied to 30 minutes twice daily. This is to stimulate endogenous opioid release—this will allow pain relief that lasts beyond the time the TENS unit is removed.

- Fentanyl patch: 2 × 10-mg fentanyl patches are applied over the antebrachium after clipping the hair. They are covered with elasticon to keep them in place. The patches are changed every 36 to 48 hours.
- Perineural analgesia: 3 mL of 0.5% bupivacaine is injected over the medial and lateral palmar nerves at the level of the fetlock (abaxial nerve block) every 12 to 24 hours.
- Morphine: 0.1 mg/kg morphine is given IM as needed, not to exceed a frequency q3h administration.

Chronic Laminitis

Treatment in the Field

A 25-year-old Paint gelding previously diagnosed with pituitary pars intermedia dysfunction (PPID) has a history of multiple episodes of laminitis affecting the front feet. While previous episodes have improved after a few days of phenylbutazone, this episode has already lasted 14 days with no signs of improving. The horse has been on 2 g phenylbutazone by mouth twice daily for the last 14 days. His appetite has decreased, and he has mildly loose stool. Radiographs show 3° to 5° rotation of the coffin bone in both front feet and chronic remodeling of the distal aspect of P3. On palpation, marked muscle hypertonicity and sensitivity is present through the brachiocephalicus bilaterally, as well as over the thoracolumbar epaxial musculature. The horse appears to be hypersensitive to light touch over the back and neck, and wind-up pain is suspected.

Pain Management Strategies

NSAIDs: Because of the reduced appetite and loose stool, place the horse on firocoxib, 3 × 57-mg tablets are given on the first day, followed by 1 × 57 mg tablet once daily by mouth.

Supportive, therapeutic trimming/shoeing: Recommend placing the horse in a therapeutic boot that provides support over the frog/sole as well as cushioning. Then consult with the horse's farrier to have therapeutic trimming/shoeing performed.

Gabapentin: Gabapentin is prescribed at 20 mg/kg q12h PO. This dose is slowly tapered over 3 to 4 weeks once the wind-up pain has resolved. Tapering of the dose (reducing total dose by ½ every week) has been advised to prevent rebound pain.

Acupuncture: Perform both dry-needle and electroacupuncture; acupuncture points are chosen that target the front feet. Treatment is performed once weekly for 3 to 4 weeks, then once every 2 to 4 weeks, depending on the horse's response to treatment. Local points are also chosen over the neck and back to help with secondary muscle pain, as tolerated by the patient. This treatment may not be tolerated by the horse until the wind-up pain is addressed.

TENS: TENS is applied for 30 minutes 2 to 3 times per day in the same manner as for acute laminitis.

Manual therapy: Advise the owner to purchase a massager to gently massage over the back and neck, as tolerated by the patient. Gentle physiotherapy exercises, such as back wiggles, are also prescribed. It may not be possible to perform this treatment until the wind-up pain is addressed.

Topical diclofenac: The hair above the coronary band is clipped. Topical diclofenac ointment is applied over the coronary band, twice daily.

Lidocaine patches: After clipping the hair in the pastern region, 5% lidocaine patches are placed over the palmar digital nerves and secured with elasticon. The duration of effect of the patches is not known, so it is elected to change the pads every 8 to 12 hours.

Biologics: IVRP with mesenchymal stem cells is performed at 1-month intervals for 3 to 6 treatments. After placing a tourniquet above the fetlock, 20 to 30 million stem cells suspended in lactated ringer's solution are infused in the palmar digital vein. Intra-arterial administration via the palmar digital or medial artery could also be considered. No tourniquet is used if intra-arterial injection is to be performed.

Treatment in the Hospital

A 5-year-old Thoroughbred gelding has been hospitalized for the past 3 weeks following fracture repair of the left hindlimb (LH) proximal phalanx. The horse has been only intermittently weight-bearing on the LH limb and has laminitis in the right hindlimb (RH) foot. The horse also has marked sensitivity to palpation of the gluteal and lumbar epaxial musculature, and central sensitization is suspected.

Pain Management Strategies

- NSAIDs: The horse is maintained on 2.2 mg/kg phenylbutazone IV twice daily, carefully monitoring the horse's kidney values, albumin, appetite, and stool. If phenylbutazone alone is not sufficient, administration of 4.4 mg/kg phenylbutazone IV twice daily or 2.2 mg/kg phenylbutazone IV twice daily plus 1.1 mg/kg flunixin IV twice daily for 2 to 3 days can be considered.
- Supportive or therapeutic boot: A cushioned boot is applied to the RH foot.
- Acupuncture: Perform both dry-needle and electroacupuncture; acupuncture points are

chosen that target the hind feet. Treatment is performed once weekly for 3 to 4 weeks, then once every 2 to 4 weeks, depending on the horse's response to treatment. Local points are also chosen over lumbar and gluteal region to help with secondary muscle pain, as tolerated by the patient. This treatment may not be tolerated by the horse until the wind-up pain is addressed.

- TENS: TENS is applied for 30 minutes 2 to 3 times per day in the same manner as for acute laminitis.
- Manual therapy: A massager is applied over the thoracolumbar and gluteal musculature daily, as tolerated by the patient. This treatment may not be tolerated by the horse until the wind-up pain is addressed.
- Epidural: An epidural consisting of morphine at 0.2 mg/kg and detomidine at 30 μg/kg is administered via epidural catheter every 12 hours.
- Gabapentin: Gabapentin is prescribed at 20 mg/kg q12h PO. This dose is slowly tapered over 3 to 4 weeks once the wind-up pain has resolved. Tapering of the dose (reducing total dose by ½ every week) has been advised to prevent rebound pain.
- Biologics: IVRP with mesenchymal stem cells is performed at 1-month intervals for 3 to 6 treatments. After placing a tourniquet above the fetlock, 20 to 30 million stem cells suspended in lactated ringer's solution are infused in the palmar digital vein. Intra-arterial administration via the palmar digital or medial artery could also be considered. No tourniquet is used if intra-arterial injection is to be performed.

5. Summary

Pain management of the laminitic horse can be extremely challenging. Given the various types of pain these horses experience, a multimodal approach to pain management of the laminitic horse is necessary. While evidence for pharmaceutical and non-pharmaceutical approaches in the laminitic horse is somewhat limited, multiple treatment options are available.

Acknowledgments

Declaration of Ethics

The Authors have adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Authors have no conflicts of interest.

References

1. Collins SN, Pollitt C, Wylie CE, et al. Laminitic pain: Parallels with pain states in humans and other species. *Vet Clin North Am Equine Pract* 2010;26:643–671.
2. Eades SC, Holm AMS, Moore RM. A review of the pathophysiology and treatment of acute laminitis: Pathophysiologic and therapeutic implications of endothelin-1, in *Proceedings*. Am Assoc Equine Pract 2002;48:353–361.
3. Hopster K, van Eps AW. Pain management for laminitis in the horse. *Equine Vet Educ* 2019;31:384–392.
4. Parks A, O'Grady SE. Chronic laminitis: Current treatment strategies. *Vet Clin North Am Equine Pract* 2003;19: 393–416.
5. Junger H, Sorkin LS. Nociceptive and inflammatory effects of subcutaneous TNFα. *Pain* 2000;85:145–151,.
6. Kawasaki Y, Zhang L, Cheng JK, et al. Cytokine mechanisms of central sensitization: Distinct and overlapping role of interleukin-1β, interleukin-6, and tumor necrosis factor-α in regulating synaptic and neuronal activity in the superficial spinal cord. *J Neurosci* 2008;28:5189–5194.
7. Schäfers M, Svensson CI, Sommer C, et al. Tumor necrosis factor-α induces mechanical allodynia after spinal nerve ligation by activation of p38 MAPK in primary sensory neurons. *J Neurosci* 2003;23:2517–2521.
8. Schäfers M, Lee DH, Brors D, et al. Increased sensitivity of injured and adjacent uninjured rat primary sensory neurons to exogenous tumor necrosis factor-α after spinal nerve ligation. *J Neurosci* 2003;23:3028–3038.
9. Belknap JK. The pharmacologic basis for the treatment of developmental and acute laminitis. *Vet Clin North Am Equine Pract* 2010;26:115–124.
10. Daglish J, Mama KR. Pain. Its diagnosis and management in the rehabilitation of horses. *Vet Clin North Am Equine Pract* 2016;32:13–29.
11. Guedes A. Pain management in horses. *Vet Clin North Am Equine Pract* 2017;33:181–211.
12. Muir WW. Preface: pain in horses: Physiology, pathophysiology, and therapeutic implications. *Vet Clin North Am Equine Pract* 2010;26(3):xi-xii.
13. Driessen B, Bauquier SH, Zarucco L. Neuropathic pain management in chronic laminitis. *Vet Clin North Am Equine Pract* 2010;26:315–337.
14. Moses VS, Hardy J, Bertone AL, et al. Effects of anti-inflammatory drugs on lipopolysaccharide-challenged and -unchallenged equine synovial explants. *Am J Vet Res* 2001;62:54–60.
15. Soma LR, Uboh CE, Maylin GM. The use of phenylbutazone in the horse. *J Vet Pharmacol Ther* 2012;35:1–12.
16. Toutain PL, Autefage A, Legrand C, et al. Plasma concentrations and therapeutic efficacy of phenylbutazone and flunixin meglumine in the horse: Pharmacokinetic/pharmacodynamic modelling. *J Vet Pharmacol Ther* 1994;17:459–469.
17. Hu HH, MacAllister CG, Payton ME, et al. Evaluation of the analgesic effects of phenylbutazone administered at a high or low dosage in horses with chronic lameness. *J Am Vet Med Assoc* 2005;226:414–417.
18. Raekallio M, Taylor PM, Bennett RC. Preliminary investigations of pain and analgesia assessment in horses administered phenylbutazone or placebo after arthroscopic surgery. *Vet Surg* 1997;26:150–155.
19. Keegan KG, Messer NT, Reed SK, et al. Effectiveness of administration of phenylbutazone alone or concurrent administration of phenylbutazone and flunixin meglumine to alleviate lameness in horses. *Am J Vet Res* 2008;69:167–173.
20. Erkert RS, MacAllister CG, Payton ME, et al. Use of force plate analysis to compare the analgesic effects of intravenous administration of phenylbutazone and flunixin meglumine in horses with navicular syndrome. *Am J Vet Res* 2005;66:284–288.
21. Owens JG, Kamerling SG, Stanton SR, et al. Effects of ketoprofen and phenylbutazone on chronic hoof pain and lameness in the horse. *Equine Vet J* 1995;27:296–300.
22. Doucet MY, Bertone AL, Hendrickson D, et al. Comparison of efficacy and safety of paste formulations of firocoxib and phenylbutazone in horses with naturally occurring osteoarthritis. *J Am Vet Med Assoc* 2008;232:91–97.

23. Orsini JA, Ryan WG, Carithers DS, et al. Evaluation of oral administration of firocoxib for the management of musculoskeletal pain and lameness associated with osteoarthritis in horses. *Am J Vet Res* 2012;73:664–671.
24. Frisbie DD, McIlwraith CW, Kawcak CE, et al. Evaluation of topically administered diclofenac liposomal cream for treatment of horses with experimentally induced osteoarthritis. *Am J Vet Res* 2009;70:210–215.
25. Azevedo MS, De La Côrte FD, Brass KE, et al. Bioavailability and tolerability of topical and oral diclofenac sodium administration in healthy ponies. *J Equine Vet Sci* 2013; 33:22–26.
26. Caldwell FJ, Mueller POE, Lynn RC, et al. Effect of topical application of diclofenac liposomal suspension on experimentally induced subcutaneous inflammation in horses. *Am J Vet Res* 2004;65:271–276.
27. Hector RC, Mama KR. Recognizing and Treating Pain in Horses. In: Reed SM, Bayly WM, Sellon DC, eds. *Equine internal medicine.* 4th ed. St. Louis, MO: Elsevier Saunders; 2017, 138–157.
28. Dutton DW, Lashnits KJ, Wegner K. Managing severe hoof pain in a horse using multimodal analgesia and a modified composite pain score. *Equine Vet Educ* 2009;21: 37–43.
29. Devine E, KuKanich B, Beard WL. Pharmacokinetics of intramuscularly administered morphine in horses. *J Am Vet Med Assoc* 2013;243:105–112.
30. Lindegaard C, Gleerup KB, Thomsen MH, et al. Anti-inflammatory effects of intra-articular administration of morphine in horses with experimentally induced synovitis. *Am J Vet Res* 2010;71:69–75.
31. Hunter BG, Parker JE, Wehrman R, et al. Morphine synovial fluid concentrations after intravenous regional limb perfusion in Standing Horses. *Vet Surg* 2015;44:679–686.
32. Kinnman E, Nygards EB, Hansson P. Peripherally administrated morphine attenuates capsaicin-induced mechanical hypersensitivity in humans. *Anesth Analg* 1997;84:595–599.
33. Johnson C, Taylor PM, Young SS, et al. Post-operative analgesia using phenylbutazone, flunixin or carprofen in horses. *Vet Rec Open* 1993;133:336–338.
34. Bennett RC, Steffey EP. Use of opioids for pain and anesthetic management in horses. *Vet Clin North Am Equine Pract* 2002;18:47–60.
35. Sellon DC, Papich MG, Palmer L, et al. Pharmacokinetics of butorphanol in horses after intramuscular injection. *J Vet Pharmacol Ther* 2009;32:62–65.
36. Sanz M, Sellon DC, Julie A, et al. Analgesic effects of butorphanol tartrate and phenylbutazone administered alone and in combination in young horses undergoing routine castration. *J Am Vet Med Assoc* 2009;235:1194–1203.
37. Elfenbein JR, Robertson SA, MacKay RJ, et al. Systemic and anti-nociceptive effects of prolonged lidocaine, ketamine, and butorphanol infusions alone and in combination in healthy horses. *BMC Vet Res* 2014;10:4–11.
38. Maxwell LK, Thomasy SM, Slovis N, et al. Pharmacokinetics of fentanyl following intravenous and transdermal administration in horses. *Equine Vet J* 2010;35:484–490.
39. Thomasy SM, Slovis N, Maxwell LK, et al. Transdermal fentanyl combined with nonsteroidal anti-inflammatory drugs for analgesia in horses. *J Vet Intern Med* 2004;18: 550–554.
40. Wegner K, Franklin R. How to use fentanyl transdermal patches for analgesia in horses. *Am Assoc Equine Pract* 2002;48:291–294.
41. Ohta M, Wakuno A, Okada J, et al. Effects of intravenous fentanyl administration on end-tidal sevoflurane concentrations in Thoroughbred racehorses undergoing orthopedic surgery. *J Vet Med Sci* 2010;72:1107–1111.
42. Sanchez LC, Robertson SA, Maxwell LK, et al. Effect of fentanyl on visceral and somatic nociception in conscious horses. *J Vet Intern Med* 2007;21:1067–1075.
43. De Oliveira FA, Pignaton W, Teixeira-Neto FJ, et al. Antinociceptive and behavioral effects of methadone alone or in combination with detomidine in conscious horses. *J Equine Vet Sci* 2014;34:380–386.
44. Combie J, Dougherty J, Nugent E, et al. The pharmacology of narcotic analgesics in the horse: IV dose and time response relationships for behavioral responses to morphine, meperidine, pentazocine, anileridine, MET, and hydromorphone. *J Equine Med Surg* 1979;3:377–385.
45. Dhanjal JK, Wilson DV, Robinson E, et al. Intravenous tramadol: Effects, nociceptive properties, and pharmacokinetics in horses. *Vet Anaesth Analg* 2009;36:581–590.
46. Guedes AGP, Knych HK, Soares JHN, et al. Pharmacokinetics and physiological effects of repeated oral administrations of tramadol in horses. *J Vet Pharmacol Ther* 2014; 37:269–278.
47. Bennett GJ. Update on the neurophysiology of pain transmission and modulation: focus on the NMDA-receptor. *J Pain Symptom Manage* 2000;19:2–6.
48. Guedes AGP, Matthews NS, Hood DM. Effect of ketamine hydrochloride on the analgesic effects of tramadol hydrochloride in horses with signs of chronic laminitis associated pain. *Am J Vet Res* 2012;73:610–619.
49. Valverde A. Alpha-2 agonists as pain therapy in horses. *Vet Clin North Am Equine Pract* 2010;26:515–532.
50. Robertson JT, Muir WW. A new analgesic drug combination in the horse. *Am J Vet Res* 1983;44:1667–1669.
51. Sellon DC, Roberts MC, Blikslager AT, et al. Effects of continuous rate intravenous infusion of butorphanol on physiologic and outcome variables in horses after celiotomy. *J Vet Intern Med* 2004;18:555–563.
52. Fairbanks CA, Stone LS, Kitto KF, et al. α2C-Adrenergic receptors mediate spinal analgesia and adrenergic-opioid synergy. *J Pharmacol Exp Ther* 2002;300:282–290.
53. Stone LS, MacMillan LB, Kitto KF, et al. The α(2a) adrenergic receptor subtype mediates spinal analgesia evoked by α2 agonists and is necessary for spinal adrenergic-opioid synergy. *J Neurosci* 1997;17:7157–7165.
54. Dirikolu L, McFadden ET, Ely KJ, et al. Clonidine in horses: Identification, detection, and clinical pharmacology. *Vet Ther* 2006;7:141–155.
55. Mama KR, Hector RC. Therapeutic developments in equine pain management. *Vet J* 2019;247:50–56.
56. Moens Y, Lanz F, Doherr MG, et al. A comparison of the antinociceptive effects of xylazine, detomidine and romifidine on experimental pain in horses. *Vet Anaesth Analg* 2003;30:183–190.
57. Muir WW, Robertson J. Visceral analgesia: effects of xylazine, butorphanol, meperidine, and pentazocine in horses. *Am J Vet Res* 1985;46:2081–2084.
58. Owens JG, Kamerling SG, Stanton SR, et al. Evaluation of detomidine-induced analgesia in horses with chronic hoof pain. *J Pharmacol Exp Ther* 1996;278:179–184.
59. Moorman VJ, Bass L, King MR. Evaluation of the effects of commonly used α2-adrenergic receptor agonists alone and in combination with butorphanol tartrate on objective measurements of lameness in horses. *Am J Vet Res* 2019;80: 868–877.
60. Scicluna C. The use of xylazine for joint analgesia during equine arthroscopy, in *Proceedings*. Int Congr Vet Anesth September 1997;6:131.
61. Ullmer JJ, Mama KR, Lee CM, et al. The effects of xylazine on normal and interleukin-1 conditioned equine articular cartilage explants *in Proceedings*. Am Coll of Vet Anaesth and Analg. 2014;41(1).
62. Abdallah FW, Brull R. Facilitatory effects of perineural dexmedetomidine on neuraxial and peripheral nerve block: A systematic review and meta-analysis. *Br J Anaesth* 2013;110:915–925.
63. Muir WW. Pain: mechanisms and management in horses. *Vet Clin North Am Equine Pract* 2010;26:467–480.
64. Sugimoto M, Uchida I, Mashimo T. Local anaesthetics have different mechanisms and sites of action at the recombinant N-methyl-D-aspartate (NMDA) receptors. *Br J Pharmacol* 2003;138:876–882.

65. Nagy I, Woolf CJ. Lignocaine selectively reduces C fibre–evoked neuronal activity in rat spinal cord in dtro by decreasing N-methyl-D-aspartate and neurokinin. *Pain* 1996;64:59–70.
66. Robertson SA, Sanchez LC, Merritt AM, et al. Effect of systemic lidocaine on visceral and somatic nociception in conscious horses. *Equine Vet J* 2010;37:122–127.
67. Doherty TJ, Seddighi MR. Local anesthetics as pain therapy in horses. *Vet Clin North Am Equine Pract* 2010;26:533–549.
68. Dern K, Watts M, Werle B, et al. Effect of delayed digital hypothermia on lamellar inflammatory signaling in the oligofructose laminitis model. *J Vet Intern Med* 2017;31:575–581.
69. Hollmann MW, Durieux ME, Fisher DM. Local anesthetics and the inflammatory response: a new therapeutic indication? *Anesthesiology* 2000;93:858–875.
70. Söbbeler FJ, Kästner SB. Effects of transdermal lidocaine or lidocaine with prilocaine or tetracaine on mechanical superficial sensation and nociceptive thermal thresholds in horses. *Vet Anaesth Analg* 2018;45:227–233.
71. Zarucco L, Driessen B, Scandella M, et al. Continuous perineural block of the palmar nerves: A new technique for pain relief in the distal equine forelimb. *Clin Tech Equine Pract* 2007;6:154–164.
72. Broome CB, Burnikel B. Novel strategies to improve early outcomes following total knee arthroplasty: A case control study of intra articular injection versus femoral nerve block. *Int Orthop* 2014;38:2087–2089.
73. Rice D, Heil JW, Biernat L. Pharmacokinetic profile and tolerability of liposomal bupivacaine following a repeated dose via local subcutaneous infiltration in healthy volunteers. *Clin Drug Investig* 2017;37:249–257.
74. Lascelles BDX, Rausch-Derra LC, Wofford JA, et al. Pilot, randomized, placebo-controlled clinical field study to evaluate the effectiveness of bupivacaine liposome injectable suspension for the provision of post-surgical analgesia in dogs undergoing stifle surgery. *BMC Vet Res* 2016;12:1–10.
75. Knych HK, Mama KR, Moore CE, et al. Plasma and synovial fluid concentrations and cartilage toxicity of bupivacaine following intra-articular administration of a liposomal formulation to horses. *Equine Vet J* 2019;51:408–414.
76. Griffenhagen G, Pezzanite L, Hendrickson D, et al. Liposomal encapsulated bupivacaine provides longer duration analgesia than bupivacaine HCl when administered as an abaxial sesamoid block in horses. *Vet Anaesth Analg* 2019;46:831.e6–831.e7.
77. Taylor PM, Senior M. Update in advances in pain management for the equine practitioner. *Equine Vet Educ* 2019;31:340–342.
78. Davis JL, Posner LP, Elce Y. Gabapentin for the treatment of neuropathic pain in a pregnant horse. *J Am Vet Med Assoc* 2007;231:755–758.
79. Taylor CP. The biology and pharmacology of calcium channel alpha2-delta proteins. *Drug Rev* 2004;10:183–188.
80. Caldwell FJ, Taintor J, Waguespack RW, et al. Effect of PO administered gabapentin on chronic lameness in horses. *J Equine Vet Sci* 2015;35:536–540.
81. Guedes AGP, Morisseau C, Sole A, et al. Use of a soluble epoxide hydrolase inhibitor as an adjunct analgesic in a horse with laminitis. *Vet Anaesth Analg* 2013;40:440–448.
82. Readford PK, Lester GD, Secombe CJ. Temporohyoid osteoarthropathy in two young horses. *Aust Vet J* 2013;91:209–212.
83. Terry R, McDonnell SM, van Eps AW, et al. Pharmacokinetic profile and behavioral effects of gabapentin in the horse. *J Vet Pharmacol Ther* 2010;33:485–494.
84. Gold JR, Grubb TL, Green S, et al. Plasma disposition of gabapentin after the intragastric administration of escalating doses to adult horses. *J Vet Intern Med* 2020;34:933–940.
85. Sysel AM, Pleasant RS, Jacobson JD, et al. Efficacy of an epidural combination of morphine and detomidine in alleviating experimentally induced hindlimb lameness in horses. *Vet Surg* 1996;25:511–518.
86. Goodrich LR, Nixon AJ, Fubini SL, et al. Epidural morphine and detomidine decreases postoperative hindlimb lameness in horses after bilateral stifle arthroscopy. *Vet Surg* 2002;31:232–239.
87. Freitas GC, Carregaro AB, Gehrcke MI, et al. Epidural analgesia with morphine or buprenorphine in ponies with lipopolysaccharide (LPS)-induced carpal synovitis. *Can J Vet Res* 2011;75:141–146.
88. Carmona JU, Gómez WA, López C. Could platelet-rich plasma be a clinical treatment for horses with laminitis? *J Equine Vet Sci* 2018;61:46–57.
89. Keen JA, Hillier C, McGorum BC, et al. Endothelin-mediated contraction of equine laminar veins. *Equine Vet J* 2008;40:488–492.
90. Katwa LC, Johnson PJ, Ganjam VK, et al. Expression of endothelin in equine laminitis. *Equine Vet J* 1999;31:243–247.
91. Ingle-Fehr JE, Baxter GM. The effect of oral isoxsuprine and pentoxifylline on digital and laminar blood flow in healthy horses. *Vet Surg* 1999;28:154–160.
92. Kabbesh N, Gogny M, Chatagnon G, et al. Vasodilatory effect of pentoxifylline in isolated equine digital veins. *Vet J* 2012;192:368–373.
93. Kaye AD, Ibrahim IN, Kadowitz PJ, et al. Analysis of response to pentoxifylline in the pulmonary vascular bed of the cat. *Crit Care Med* 1996;24:263–267.
94. Crisman MV, Wilcke JR, Correll LS, et al. Pharmacokinetic disposition of intravenous and oral pentoxifylline in horses. *J Vet Pharmacol Ther* 1993;16:23–31.
95. Liska DA, Akucewich LH, Marsella R, et al. Pharmacokinetics of pentoxifylline and its 5-hydroxyhexyl metabolite after oral and intravenous administration of pentoxifylline to healthy adult horses. *Am J Vet Res* 2006;67:1621–1627.
96. Harkins JD, Mundy GD, Stanley S, et al. Character and duration of pharmacological effects of intravenous isoxsuprine. *Equine Vet J* 1996;28:320–326.
97. Lopez HS, Hoyos Sepulveda ML, Brumbaugh G. Pharmacologic and alternative therapies for the horse with chronic laminitis. *Vet Clin North Am Equine Pract* 1999;15:495–516.
98. Turner AS, Tucker CM. The evaluation of isoxsuprine hydrochloride for the treatment of navicular disease: A double blind study. *Equine Vet J* 1989;21:338–341.
99. Walker M, Geiser DR. Effects of acepromazine on the hemodynamics of the equine metatarsal artery, as determined by two-dimensional real-time and pulsed doppler ultrasonography. *Am J Vet Res* 1986;47:1075–1078.
100. Hunt RJ, Brandon CI, McCann ME. Effects of acetylpromazine, xylazine, and vertical load on digital arterial blood flow in horses. *Am J Vet Res* 1994;55:375–378.
101. Adair HS, Goble DO, Shires GMH. Evaluation of laser doppler flowmetry for measuring coronary band and laminar microcirculatory blood flow in clinically normal horses. *Am J Vet Res* 1994;55:445–449.
102. Inan M, Bakar E, Cerkezkayabekir A, et al. Mesenchymal stem cells increase antioxidant capacity in intestinal ischemia/reperfusion damage. *J Pediatr Surg* 2017;52:1196-
103. Gu W, Hong X, Potter C, et al. Mesenchymal stem cells and vascular regeneration. *Microcirculation* 2017;24:1–15.
104. Prockop DJ, Oh JY. Mesenchymal stem/stromal cells (MSCs): Role as guardians of inflammation. *Mol Ther* 2012;20:14–20.
105. Angelone M, Conti V, Biacca C, et al. The contribution of adipose tissue-derived mesenchymal stem cells and platelet-rich plasma to the treatment of chronic equine laminitis: A proof of concept. *Int J Mol Sci* 2017;18:1–17.
106. Morrison S. Chronic laminitis: Foot management. *Vet Clin North Am Equine Pract* 2010;26:425–446.
107. Murakami M. Lipid mediators in life science. *Exp Anim* 2011;60:7–20.

108. Guedes A, Galuppo L, Hood D, et al. Soluble epoxide hydrolase activity and pharmacologic inhibition in horses with chronic severe laminitis. *Equine Vet J* 2017;49:345–351.
109. Guedes AGP, Aristizabal F, Sole A, et al. Pharmacokinetics and antinociceptive effects of the soluble epoxide hydrolase inhibitor t-TUCB in horses with experimentally induced radiocarpal synovitis. *J Vet Pharmacol Ther* 2018; 41:230–238.
110. Inceoglu B, Jinks SL, Schmelzer KR, et al. Inhibition of soluble epoxide hydrolase reduces LPS-induced thermal hyperalgesia and mechanical allodynia in a rat model of inflammatory pain. *Life Sci* 2006;79:2311–2319.
111. Inceoglu B, Schmelzer KR, Morisseau C, et al. Soluble epoxide hydrolase inhibition reveals novel biological functions of epoxyeicosatrienoic acids (EETs). *Prostaglandins Other Lipid Mediat* 2007;82:42–49.
112. Wagner K, Inceoglu B, Hammock BD. Soluble epoxide hydrolase inhibition, epoxygenated fatty acids and nociception. *Prostaglandins Other Lipid Mediat* 2011;96(1–4):76–83.
113. Pervaiz S. Resveratrol: From grapevines to mammalian biology. *FASEB J* 2003;17(14):1975–1985.
114. Harikumar KB, Aggarwal BB. Resveratrol: a multitargeted agent for age-associated chronic diseases. *Cell Cycle* 2008;7:1020–1037.
115. Xia EQ, Deng GF, Guo YJ, et al. Biological activities of polyphenols from grapes. *Int J Mol Sci* 2010;11:622–646.
116. Ememe MU, Mshelia WP, Ayo JO. Ameliorative effects of resveratrol on oxidative stress biomarkers in horses. *J Equine Vet Sci* 2015;35:518–523.
117. Watts AE, Dabareiner R, Marsh C, et al. A randomized, controlled trial of the effects of resveratrol administration in performance horses with lameness localized to the distal tarsal joints. *J Am Vet Med Assoc* 2016;249:650–659.
118. Leise BS, Fugler LA, Stokes AM, et al. Effects of intramuscular administration of acepromazine on palmar digital blood flow, palmar digital arterial pressure, transverse facial arterial pressure, and packed cell volume in clinically healthy, conscious horses. *Vet Surg* 2007;36:717–723.
119. West E, Bardell D, Morgan R, et al. Use of acetaminophen (paracetamol) as a short-term adjunctive analgesic in a laminitic pony. *Vet Anaesth Analg* 2011;38:521–522.
120. Mercer MA, McKenzie HC, Davis JL, et al. Pharmacokinetics and safety of repeated oral dosing of acetaminophen in adult horses. *Equine Vet J* 2020;52:120–125.
121. Song JH, Ham SS, Shin YK, et al. Amitriptyline modulation of Na+ channels in rat dorsal root ganglion neurons. *Eur J Pharmacol* 2000;401:297–305.
122. Kruger JM, Conway TS, Kaneene JB, et al. Randomized controlled trial of the efficacy of short-term amitriptyline administration for treatment of acute, nonobstructive, idiopathic lower urinary tract disease in cats. *J Am Vet Med Assoc* 2003;222:749–758.
123. Botney M, Fields HL. Amitriptyline potentiates morphine analgesia by a direct action on the central nervous system. *Ann Neurol* 1983;13:160–164.
124. Rausch-Derra L, Huebner M, Wofford J, et al. A prospective, randomized, masked, placebo-controlled multisite clinical study of grapiprant, an EP4 prostaglandin receptor antagonist (PRA), in dogs with osteoarthritis. *J Vet Intern Med* 2016;30:756–763.
125. Rausch-Derra LC, Huebner M, Rhodes L. Evaluation of the safety of long-term, daily oral administration of grapiprant, a novel drug for treatment of osteoarthritic pain and inflammation, in healthy dogs. *Am J Vet Res* 2015;76:853–859.
126. Knych HK, Seminoff K, McKemie DS. Detection and pharmacokinetics of grapiprant following oral administration to exercised Thoroughbred horses. *Drug Test Anal* 2018;10: 1237–1243.
127. Schmitt KRL, Tong G, Berger F. Mechanisms of hypothermia-induced cell protection in the brain. *Mol Cell Pediatr* 2014;1:4–8.
128. van Eps AW, Orsini JA. A comparison of seven methods for continuous therapeutic cooling of the equine digit. *Equine Vet J* 2016;48:120–124.
129. Stokes SM, Belknap JK, Engiles JB, et al. Continuous digital hypothermia prevents lamellar failure in the euglycaemic hyperinsulinaemic clamp model of equine laminitis. *Equine Vet J* 2019;51:658–664.
130. van Eps AW, Pollitt CC, Underwood C, et al. Continuous digital hypothermia initiated after the onset of lameness prevents lamellar failure in the oligofructose laminitis model. *Equine Vet J* 2014;46:625–630.
131. Eps AW, Pollitt CC. Equine laminitis: cryotherapy reduces the severity of the acute lesion. *Equine Vet J* 2010;36:255–260.
132. van Eps AW, Pollitt CC. Equine laminitis model: Cryotherapy reduces the severity of lesions evaluated seven days after induction with oligofructose. *Equine Vet J* 2009;41: 741–746.
133. Tobaldini G, Aisengart B, Lima MMS, et al. Ascending nociceptive control contributes to the antinociceptive effect of acupuncture in a rat model of acute pain. *J Pain* 2014; 15:422–434.
134. Skarda RT, Tejwani GA, Muir WW. Cutaneous analgesia, hemodynamic and respiratory effects, and β-endorphin concentration in spinal fluid and plasma of horses after acupuncture and electroacupuncture. *Am J Vet Res* 2002;63: 1435–1442.
135. Yoo YC, Oh JH, Kwon TD, et al. Analgesic mechanism of electroacupuncture in an arthritic pain model of rats: A neurotransmitter study. *Yonsei Med J* 2011;52:1016–1021.
136. Huang C, Hu ZP, Long H, et al. Attenuation of mechanical but not thermal hyperalgesia by electroacupuncture with the involvement of opioids in rat model of chronic inflammatory pain. *Brain Res Bull* 2004;63:99–103.
137. Koo ST, Lim KS, Chung K, et al. Electroacupuncture-induced analgesia in a rat model of ankle sprain pain is mediated by spinal α-adrenoceptors. *Pain* 135:11–19, 2008.
138. Haussler KK. The role of manual therapies in equine pain management. *Vet Clin North Am Equine Pract* 2010;26: 579–601.
139. Sullivan KA, Hill AE, Haussler KK. The effects of chiropractic, massage and phenylbutazone on spinal mechanical nociceptive thresholds in horses without clinical signs. *Equine Vet J* 2008;40:14–20.
140. Gómez Álvarez CB, L'Ami JJ, Moffatt D, et al. Effect of chiropractic manipulations on the kinematics of back and limbs in horses with clinically diagnosed back problems. *Equine Vet J* 2008;40:153–159.
141. Langstone J, Ellis J, Cunliffe C. A preliminary study of the effect of manual chiropractic treatment on the splenius muscle in horses when measured by surface electromyography. *Equine Vet J* 2015;47:18.
142. Coutaux A. Non-pharmacological treatments for pain relief: TENS and acupuncture. *Jt Bone Spine* 2017;84:657–661.
143. Johnson MI. Transcutaneous electrical nerve stimulation (TENS) as an adjunct for pain management in perioperative settings: A critical review. *Expert Rev Neurother* 2017;17: 1013–1027.
144. Garaud T, Gervais C, Szekely B, et al. Randomized study of the impact of a therapeutic education program on patients suffering from chronic low-back pain who are treated with transcutaneous electrical nerve stimulation. *Medicine (Baltimore)* 2018;97:e13782.
145. Rendle D. Equine laminitis 1. Management in the acute stage. *In Pract* 2006;28:434–443.

Effects of Horseshoe Characteristics and Surface Composition on Shear Forces on the Equine Digit

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Optimizing shear force with manageable surface factors and horseshoe characteristics may have the potential to enhance limb biomechanics for injury prevention. The addition of fiber to a sand surface resulted in differences in shear properties and horseshoe traction characteristics altered the shear force most notably on the synthetic surface. Authors' address: J.D. Wheat Veterinary Orthopedic Research Laboratory, Department of Surgical and Radiological Sciences, School of Veterinary Medicine, University of California–Davis, Davis, CA 95616; e-mail: tdoherty@ucdavis.edu. *Corresponding and presenting author.

1. Introduction

Horseshoe characteristics and ground surface properties affect limb kinematics and incidence of injury. This project compared the effects of arena surface material and horseshoe traction characteristics on shear forces on the equine digit.

2. Materials and Methods

Shear properties and vertical displacement were studied with eight paired equine cadaver hooves on dirt (sand) and synthetic (sand with fiber) surfaces at increasing normal loads (50, 100, 150, 200, and 225 lb). Hooves were shod with positive, neutral, and negative traction characteristics; and unshod hooves served as a control. Shear data were used to calculate angle of internal friction and cohesion. A repeated-measures ANOVA assessed the effects of horseshoe characteristics, surface material, and their interaction on shear properties ($P < .05$).

3. Results and Discussion

Surface material had a greater effect than horseshoe traction characteristics on shear properties. This may indicate that the addition of fiber alone to surface material can significantly alter the shear forces. The synthetic surface experienced greater forces that resist horizontal movement evidenced by larger values of normalized maximum shear force ($P < .05$) and angle of internal friction ($P < .05$). Surface-specific differences among horseshoe traction characteristics were more pronounced on the synthetic surface.

Acknowledgments

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Declaration of Ethics

The Authors have adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Authors have no conflicts of interest.

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Association of mRNA Biomarkers with Catastrophic Racing Injuries in Thoroughbreds

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Results suggest that analysis of messenger RNA expression using select genes could be an economical, effective, and non-invasive means by which individual racehorses at risk for catastrophic injury can be identified. Authors' addresses: University of Kentucky Maxwell H. Gluck Equine Research Center, Lexington, KY 40546 (Page, Adam, Barker, Partridge, Horohov); School of Veterinary Medicine, University of California-Davis, Davis, CA 95616 (Arthur); California Horse Racing Board, 1010 Hurley Way, Suite 300, Sacramento, CA 95825 (Franklin, Grande, Vale); Washington Horse Racing Commission, 6326 Martin Way, Suite 209, Olympia, WA 98516 (Friedman); Indiana Grand Racing and Casino, 4300 N Michigan Road, Shelbyville, IN 46176 (Hardy); Kentucky Horse Racing Commission, 4063 Iron Works Pkwy, Lexington, KY 40511 (Howard); 401 W Main Street, Suite 222, Lexington, KY 40507 (Scollay); 312 Lucille Drive, Lexington, KY 40511 (Stewart); e-mail: a.page@uky.edu. *Corresponding and presenting author.

1. Introduction

It has been established that many catastrophic injuries (CIs) occur in limbs with underlying or preexisting pathology. While the detection of protein biomarkers for equine injuries has been explored as a means of early injury detection in racehorses, the measurement of messenger RNA (mRNA) has not. The objective of this study was to determine whether those horses with a CI during racing demonstrate increased inflammatory mRNA expression at the time of their injury when compared to non-injured control horses.

2. Materials and Methods

Prospective study in which peripheral blood samples were collected into Tempus tubes either pre-race or post-race from non-injured horses (n = 545) or immediately post-CI (n = 100). Sample collection took place from September 2017 to January 2020 and included 5 different racing jurisdictions from across the United States. RNA was isolated from Tempus tubes and subjected to RT-qPCR for 20 different genes. Relative quantities of expression were calculated and analyzed for each gene using analysis of variance and receiver operating characteristic curve analysis.

3. Results

Twelve genes were excluded from data analysis due to post-race, exercise-related effects. Of the 8 remaining genes, *ALOX5AP*, *IGF1*, *IL-6*, and *MMP2* were significantly different in injured horses com-

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pared to non-injured horses, and calculated sensitivities/specificities for identifying injured horses were 63%, 72%, 63%, and 78%, respectively. Additionally, there were significant differences between specific injury types (e.g., proximal sesamoid bone fractures) and non-injured controls. The largest number of CIs in this study involved horses in claiming races (50%) and horses that were 3 to 4 years old at the time of their injury (66%), while proximal sesamoid bone fractures (uniaxial or biaxial) were noted to have the highest frequency in injured horses (38%).

4. Discussion

Although *ALOX5AP* and *IL-6* had relatively low sensitivities/specificities with respect to identifying injured horses, increased *IGF1* and *MMP2* expression was such that they could play a role as a predictor for impending CI. This is further supported by significantly increased expression in certain fracture types as well as the important role these two biomarkers are known to play in bone development and fracture repair. While these findings should be confirmed through a large-scale study utilizing pre-race/pre-training samples only, the data provided by this study suggests that mRNA expression analysis may provide an economical, effective, and non-invasive means by which most horses at risk for CIs can be identified.

Acknowledgments

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Declaration of Ethics

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The Authors have no conflicts of interest.

What Practitioners Should Know About Corporate Practices: Buying and Selling

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1. Introduction

The landscape of veterinary practice is definitely changing, with corporate buyers investing heavily—and this isn't a brand-new trend. In fact, DVM 360 offers up these examples from 2007:

- Summit Partners, a private equity and venture capital firm, invested $128 million in National Veterinary Associates (NVA); at that point, NVA owned the most freestanding veterinary hospitals in the United States: 99 of them in 29 states.
- VCA Antech, Inc. bought Healthy Pet Corp. and its 44 hospitals for $152.9 million, bringing their holdings to 450+ clinics in the country.

By 2016, approximately 10% of practices are corporately owned.

Some people, upon hearing these stories, have rung the death knell for single-doctor practices. DVM 360, in the 2007 article, begged to differ, pointing out that VCA Antech—after more than 20 years of being in business—still only owned approximately 450 hospitals out of the country's 31,000-plus practices.

So, is it possible to continue to maintain a practice, and even compete with the corporate giants? Definitely. Although the percentage of corporately owned practices has increased, in 2016 there are still 90% that are NOT owned by corporations.

But what if a private practice owner *wants* to sell a practice? Does it make sense to consider a corporate buyer?

To help answer that question, here are insights into why a veterinary practice can be seen as an attractive investment by corporate buyers; the pros and cons of selling to one; maximizing the sales price; tax and legal implications and more—along with information about how a private practice can buy another one when going up against a corporate buyer.

2. Behind-the-Scenes of Corporate Decisions

Reasons that investors like veterinary practices are listed below:

- Veterinarians get paid at time of service, unlike human medicine, where doctors need to wait for insurance reimbursement.
- Malpractice insurance costs are significantly lower than in human medicine and emotional damage payments are still much lower.
- The veterinary industry has grown steadily for more than 40 years, even during 5 recessions.

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Lest this seems like a slam dunk for corporate buyouts, consider this: investors need to buy approximately 50 hospitals before they benefit from consolidated infrastructure. So, even if they were to buy one hospital a month, it would still take more than 4 years to reach that tipping point.

3. Selling a Practice to a Corporate Buyer

Some practice owners willingly sell to corporate buyers. Advantages of selling include the following:

- Being offered a good price: if a veterinarian sees an excellent way to maximize profit—and corporate investors often offer top dollar—then it may make sense to sell.
- Speed of transaction: whereas an associate buy-in can take several years, corporate investors can close a deal much more quickly.
- Reducing the challenges of management: if a veterinarian just wants to practice medicine and dislikes business aspects, selling can make good sense.
- Having necessary capital to upgrade facilities and equipment.
- Receiving the benefits of collective wisdom.

Other potential reasons for selling range from the increasing numbers of baby boomers who are ready to retire without an associate ready to buy to young veterinarians with plenty of student loan debt who don't want to go even further in debt by buying a practice.

Disadvantages to selling a practice to a corporate buyer can include the following:

- Impact to the clients: If clients have chosen a practice because of the one-on-one relationships formed with practice doctors and staff, they may not be satisfied with a corporate practice environment, perhaps seeking out a new veterinarian even before giving the new corporate buyer a chance.
- Impact on the staff, including other doctors: Employees are a practice's most valuable asset and, if a sale causes them to have concerns about their future employment (perhaps assuming that a corporate buyer will ease in its own team or that the work culture will change too drastically), then key employees may decide to seek a job with another practice.
- Corporate requirements: A corporate buyer will likely ask for continuing owner/veterinarian employment for a period of time after the sale, along with a large non-compete geography and non-compete agreements with practice associates.

4. Managing Staff and Client Expectations and Fears

If a sale to a corporate buyer is going to take place, it can make sense for current practice owners to work in tandem with the corporate buyer to share information about the sale/transition as transparently as possible with both the practice team and clients.

When a family- or founder-run practice is being sold, it can be hard for employees and clients to separate the people who have cared for their pet companions from the business itself. They may have concerns about how the practice will now be run differently and how the care may change. To calm the waters, it can help to acknowledge that this will be a change, but that quality of care and concerns for employees' wellbeing will remain paramount. If the practice team has largely agreed to stay, it can help to share that with the clients.

5. Selling Versus Leasing

When selling a practice, there are two main components: selling the practice itself and selling the real estate. Typically, the corporate buyer will want to purchase both—and may not consider the deal under a leasing agreement. So, if a practice/real estate owner is otherwise happy with the sale parameters, the only choice may be to sell the real estate—or to start all over with another buyer.

If leasing the real estate is a consideration on the table, here are a few pros and cons to consider. First, here are some pros of leasing:

- This will create a stream of rental income.
- If the real estate appreciates, a higher sale price can be secured in the future.
- Taxes that would be owed on the real estate portion of the sale will be deferred.

Now, here are some cons:

- Some owners may not want the responsibilities of being a landlord/property manager.
- Real estate values can go down or stagnate.
- If the corporate buyer ultimately moves the practice to another location, perhaps one they build, this can lead to complications when seeking another renter or buyer.

Also consider current leasing agreements of equipment and how that may affect the sale. In most cases, leases must be paid off at the close of a sale, not being transferable to a new owner. How much will that cost and who will pay them? Plus, even when leases are assignable, the corporate buyer may not want to accept the transfer and associated obligations. So, during the negotiations with the buyer, it's important to go through leases on equipment with a fine-toothed comb and discuss them until a resolution can be found.

6. Maximizing the Price

An appraisal will be necessary as part of the negotiations process. To maximize the sales price, it can make sense for a practice owner to get one as soon as it seems likely that the practice will be sold within the next few years. Recommendations will be made on the appraisal that the practice owners can implement in ways to maximize the property's value.

7. Tax and Other Legal Implications

The seller must be clear on how the sales price will be taxed and, for optimal tax planning, the legal structure of the practice may need to be changed—something that may not happen as quickly as either party may prefer. Plus, the buyer may not agree with the legal structure preferred by the seller.

The owner should obtain legal advice on any liabilities that should be addressed before a sale takes place and to deal with any personal guarantees that have been given to the practice. Are there any third-party claims to consider? The seller should also address any tax or legal issues that are unique to the practice or situation with the attorney.

8. Continuing Employment

This is a key issue to address with a corporate buyer. The buyer may want, for continuity's sake, for the owner to stay at the practice for a pre-determined amount of time—perhaps 2 or 3 years. If so, what salary arrangements will be made?

Continuing employment may be a sticking point for some sellers, especially ones who want to sell because they're ready for retirement; have health issues; or who are not interested in becoming an employee again, especially under operational systems that may be quite different from how the practice has been run.

9. Wanting to Buy?

Finally, look at the other side of the equation. How is it possible to compete against corporate competition if wanting to *buy* a private practice? Well, chances of success are clearly higher if the seller likes the idea of his or her practice staying in private ownership. In that case, it can be important to share with the seller how the practice would continue providing the quality personal attention and service that his or her clients are used to receiving.

As far as financing, it's possible that the seller will allow the practice to make payments for a predetermined amount of time to eliminate the need for immediate bank financing. This is similar to a land contract arrangement that some home buyers and sellers create. If this arrangement can be made, this will facilitate the building up of equity in the practice, which will help when the practice ultimately needs finance; this equity may count as the down payment, at least in part.

Having equity in the practice may also help to convince a bank to agree to a longer-term loan when financing does occur, which will reduce monthly payments. It's possible that the Small Business Administration can provide financing, especially with a practice in a rural area.

Also consider going in with multiple associates to buy a practice together. This will facilitate the ability to offer the seller a better price, reduce the amount of personal financial investment, and otherwise spread the risk and workload.

Acknowledgments

Declaration of Ethics

The Author has adhered to the Principles of Veterinary Medical Ethics of the AVMA.

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The Author has no conflicts of interest.

Issues to Negotiate in Contracts Seen in Practice

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1. Introduction

When offered a job at a veterinary practice, it's important to get as much information as possible about the specifics. Typically, a certain wage will be offered, often along with benefits such as health insurance, retirement benefits, vacation time, etc. However, the offer may not mention workplace flexibility and other perks that can have a significant impact on the job—and so it's crucial to negotiate all of the key elements of the offer.

Many people feel uncomfortable when negotiating a work package, but gaining the ability to negotiate will help one be more successful and work long after beginning a particular job. As a part of a veterinary practice team, negotiation with vendors and challenging clients will be necessary—and almost certainly there will be times the employee needs to negotiate with the employer about a raise, a revised benefits package, and evolving workplace perks and policies.

Negotiating fair compensation can make the employee more committed to the practice, which translates into better care for the practice's clients and their pets. As an employer, negotiating fairly with employees helps to build loyalty that will stabilize and strengthen the practice.

2. What Negotiations Are and Why They're Needed

A negotiation is a process in which two or more parties attempt to resolve differing needs and interests through a series of communications. An employer, for example, may want to offer someone higher wages, but needs to consider the overall profitability of a practice. Meanwhile, an employee may understand and support the need for a thriving practice, but also needs to earn a certain wage to support his or her family.

Employers and employees negotiate because they each have what the other one needs, and they believe they can obtain a better outcome through the process than if they simply accept what the other party is offering. Sometimes, negotiations occur because the status quo is no longer acceptable for one or both parties.

Negotiations take finesse because, besides dealing with specific tangible points (wages, insurance benefits and workplace perks, as just 3 examples), emotions play a part and ongoing relationships are involved. The parties are choosing to try to resolve their different positions through discussions, rather than arguing, ending the relationship, having one person dominate the relationship, or taking the dispute to another party with more authority.

3. Negotiation Terminology

Using the example of wages, employers and employee alike have a *target point*, which are the wages they would like the other party to agree to. The difference between what an employee wants to be paid and the employer wants to pay is the *bargain-*

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ing range. Meanwhile, the *resistance point* is where a party would walk away from negotiations; if too low of a wage or raise is proposed, an employee may begin job searching or a job candidate may decline an offer; the employer also has a point at which he or she will reject a wage request and end negotiations.

When the buyer (employer) has a resistance point that's above the seller's (employee), this situation has a *positive bargaining range*. The employer, in this case, is willing to pay more than the employee's minimum requirements, so this situation has a good chance of being satisfactorily resolved. With a *negative bargaining range*, though, one or both of the parties must change their resistance point(s) for there to be a possibility of resolution.

In a wage-negotiation scenario, either the employer will offer a starting wage or raise, or an employee or job candidate will request a certain dollar amount; the first person to name a dollar amount is making the *opening offer*. If at least one of the parties has a *BATNA—best alternative to negotiation agreements*—then he or she will probably approach the discussions with more confidence, having another alternative. So, if an employer offers someone a job, but has another excellent candidate waiting in the wings, the employer has another alternative and can set a higher and/or firmer resistance point. Conversely, if an employee or job candidate has a unique set of skills that are needed in today's practices, that person probably has more options in the job market—perhaps even other pending offers. The quality of a negotiator's alternatives drives his or her value by providing the power to walk away and/or set a higher and/or firmer resistance point.

4. Bargaining Styles

There is more than one type of bargaining style. One way to differentiate them is to divide them into distributive bargaining and integrative bargaining.

In distributive bargaining, parties' needs and desires are in direct conflict with one another's, with each party wanting a bigger piece of a fixed tangible such as money or time, so these negotiations are typically competitive. Parties are not concerned with a future relationship with the other person. A slang term for this type of negotiation is "playing hardball" or "one upping" someone. Strategies often include making extreme offers, such as an employer offering a very low wage or a job candidate asking for an exceptionally high one. Tactics include trying to persuade the other party to reconsider his or her resistance point because of the value being offered—in this example, the job candidate might say that a high salary was required because of his or her abilities or an employer could say that lower wages would be compensated by a great work environment.

With integrative bargaining, although, the goal is win-win collaborations that will provide a good opportunity for both parties. The employer would acknowledge the employee's value and need for a decent wage, and negotiate accordingly, while the employee or job candidate would recognize the value of working at a particular practice as well as the fact that the employer has numerous other financial commitments to fulfill. Each must recognize that they need one another to maximize their respective opportunities and negotiate from a place of trust and integrity, with a positive outlook that recognizes and validates the other party's interest in the transaction.

Here's an interesting psychological truth: Negotiators are more satisfied with final outcomes if there is a series of concessions rather than if their first offer is accepted, because they feel they could have done better.

5. Negotiation Styles

To successfully negotiate, it's crucial to clearly define the issues involved, and to prepare for the negotiations. Each party should be clear about his or her target point, opening offer, resistance point, and BATNAs.

Multiple negotiation styles exist, each on the spectrum of assertiveness and cooperativeness. Below are summaries of common styles:

- Competing (high in assertiveness, low in cooperativeness): these negotiators are self-confident and assertive, focusing on results and the bottom line; they tend to impose their views on others.
- Avoiding (low in assertiveness and cooperativeness): these negotiators are passive and avoid conflict whenever possible; they try to remove themselves from negotiations or pass the responsibility to someone else without an honest attempt to resolve the situation.
- Collaborating (high in assertiveness and cooperativeness): these negotiators use open and honest communication, searching for creative solutions that work well for both parties, even if the solution is new; this negotiator often offers multiple recommendations for the other party to consider.
- Accommodating (low in assertiveness, high in cooperativeness): these negotiators focus on downplaying conflicts and smoothing over differences to maintain relationships; they are most concerned with satisfying the other party.
- Compromising (moderate in assertiveness and cooperativeness): these negotiators search for common ground and are willing to meet the other party in the middle; they are usually willing to give and take and find moderate satisfaction acceptable.

As long as both parties are committed to the business relationship and believe there is value in coming to an agreement, negotiations can typically proceed. If one or both parties, though, are unreasonable, uninformed, or stubborn—or listening to advisors with those characteristics—negotiations can fall through. Other challenges exist when one party doesn't necessarily need the deal, isn't in a hurry, or knows that the other party is without other options and/or in a time crunch.

6. Negotiation Fears

Many people dread negotiation. Common reasons for this include the following:

- The employee's position has not yet been solidified: in this case, more preparation is clearly needed.
- Fear of looking stupid. Nobody likes looking foolish, so some people will avoid negotiations altogether rather than take the risk of not negotiating well.

Liking people and wanting to make them happy (but perhaps not being able to give them what they want!)/not wanting to affect someone else in a negative way: when interviewing for a promotion at a practice, and the employee really like the practice manager, they may worry that negotiations will upset the manager or put them in a difficult position.

- Fear of failure. Some people would prefer to not negotiate at all, rather than make an unsuccessful attempt.
- Feeling uncomfortable with money. Some people were taught that it wasn't polite to talk about money!

Still, other people have an aversion to conflict, overall, and so they avoid the potential by not negotiating. Yet others feel vulnerable when negotiating.

Women in particular are reluctant to negotiate, with only 7% doing so.[1] They suffer the costs associated with not negotiating because they tend to have lower expectations, fear being considered difficult, and can be penalized for negotiating. As a solution, women can consider framing their wants into the value that they will bring to the other party, and share how they can solve the underlying problem of the other party.

Areas where negotiating may not feel as intimidating include the following:

- Negotiations for resources, whether it's asking for more equipment or for a practice to hire more people.
- Negotiations about how to use resources; with a common purpose, solutions can be reverse engineered fairly easily.
- Negotiations where the employee has expertise.
- Negotiations with big companies where nothing is personal.
- Negotiations where the employee has evidence to support their position, including facts, data, and logical reasoning.

7. Salary and Benefits Negotiation Tips

Even though the examples given so far have focused on monetary compensation, when negotiating, don't focus solely on wage or salary. Also discuss benefits offered and workplace perks—meaning the entire package. This can include, but is not limited to, health care coverage, life insurance, retirement programs, vacation time, and flextime. When job hunting, investigate what companies are offering. Where does the interviewing company/practice fall on that spectrum? What is the minimum pay level that is acceptable? What is the preferred wage? What benefits are important?

If someone wants to work at a particular practice, but the pay rate isn't ideal, they could request a salary review in 6 months. This doesn't mean accepting a salary that is clearly sub-par, nor does it mean putting more pressure on a potential employer who is already offering a good deal. It is simply something to consider in relevant circumstances.

What workplace perks might be desired? Would a company cell phone help? Better equipment or software? If so, consider accepting somewhat lower pay if more tools are offered to help get the job done.

Although telecommuting is seldom an option for veterinary staff, outside of perhaps financial or other purely administrative functions, a potential employee could negotiate coming in half an hour later to accommodate children's school drop off or pick up. If the employee brings crucial skills to the negotiating table, it is more likely they will receive these concessions than an employee in an entry-level position.

If relevant, ask about practice policy regarding pregnancy. How acceptable is the policy? How important of a negotiating point is this? What about injury in the workplace? Be educated on workplace rights before negotiations occur, as well as company policy. If the employee is valuable to the practice, perhaps some additional flexibility can be negotiated.

Who should be the first to make an offer? Some experts believe that, if the other party provides a starting dollar figure, then their hand has been shown. But, research indicates that final figures tend to be closer to the original number stated than what the other party had originally hoped.

8. What NOT to Do

Beware of "between"! It probably feels reasonable to ask for a certain salary range—or range for a raise. But if done with a current or prospective employer, the employee has basically tipped their hand as far as how low they would go. Using the word "between" is actually a concession!

Another risky term: "I think we're close." A savvy negotiator will recognize "deal fatigue" on the employee's end and perhaps stall in the hopes for a concession, just to complete the deal.

9. Negotiating with Brokers

If buying or selling a veterinary practice, then negotiating skills will likely come in handy. For example, let's say an owner is selling a practice. In the listing agreement contract, it is typical to agree on a period of time wherein the broker has exclusive rights to sell, perhaps 6 months or a year. If not satisfied, can the owner terminate the agreement? It depends! It depends upon how well the original contract was negotiated with the agent. For example, negotiate a clause stating that the listing can be terminated immediately for good cause or with a short period of prior notification if the termination is without cause. In exchange for that clause being included, perhaps agree to reimburse expenses incurred by the agent during the listing period and/or pay commission if the buyer is one that the agent initially identified.

10. Negotiating Lab Contracts

Contracts with labs that provide diagnostic services for the practice will also need to be negotiated. Work on a pay-as-you-go arrangement, sending work to different labs, as needed. The flaw is that financial incentives may not be offered to practices who sign contracts. By signing a contract, lower fees or better rate schedules can be negotiated. When paying less in lab fees, lower rates could be offered to customers, which will probably make more of them agree to pay for diagnostic testing in the first place. Signing a multi-year contract with a lab may also allow the owner to lease in-house lab equipment as part of the deal.

Know what's most important, run the figures, and negotiate!

11. For Best Results

People tend to feel more confident during negotiations when it focuses on an area of their expertise and/or where solid evidence exists to back up the negotiations. Overall, success is achieved when:

- Determining the interests of the other party.
- Embracing compromise.
- Observing the Golden Rule, treating others fairly and reasonably, without defensiveness.
- Be prepared, both in factual information and in strategy.
- Good luck!

Acknowledgments

Declaration of Ethics

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The Author has no conflicts of interest.

Reference

1. Babcock L, Laschever S, Gelfand M, Small D. Nice Girls Don't Ask. October 2003. Available from: https://hbr.org/2003/10/nice-girls-dont-ask

Employee Performance Coaching and Setting Goals

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1. Introduction

A performance management program (PMP) strives to ensure the right people with the right competencies are in the right jobs at the right time. An effective PMP will also look to achieve the following objectives:

- Shape the culture and reinforce the core values of the practice—Assessment of performance includes behavior, specifically behaviors that fall under core values. An example of a core value would be honesty. Has the employee behaved in a way that demonstrates honesty?
- Facilitate communications between supervisors and subordinates—Performance reviews allow the subordinate and supervisor to discuss any gaps between their individual assessments of performance. For example, if an employee, Elaine, thinks she is excellent at a blood draw, but the supervisor has had 4 complaints about her blood draws this week, it opens the door to discuss those items in a constructive way.
- Motivate and reward superior performance—Creating a PMP template will help the employer see across the board how staff are performing by comparing apples to apples. If everyone is reviewed based on a certain set of criteria, it will create a performance standard. If one of the criteria is teamwork, and Elaine is always helping out her coworkers, this would provide an opportunity to give positive feedback and possible rewards.
- Effectively manage unsatisfactory performance—As stated above, this will also identify those employees who are performing below the hospital standard and allow managers to focus on the items those employees need to improve.
- Identify opportunities for personal growth and development—Using the previous example of Elaine, if an employee is rated poorly in blood draw, then an opportunity can be created for them to take a course. Or perhaps a mentor day could be scheduled where one of the doctors practices blood draws with the employee. This results in a better employee and benefits the practice as well.
- Link pay to performance—When setting goals for the employee, tie financial rewards to achievements. Either next year's raise or end of year bonuses.
- Stimulate individual and collective productivity—If Elaine and the other teammates were not meeting expectations, it lets the supervi-

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sors know this is an area where work is needed as a whole. The staff can be incentivized by making this a team goal and focusing for the year.

2. Why PMP's Fail

While PMPs have been utilized for many years, they are not universally considered an effective management tool. In some cases, performance management is more about checking a box than about aligning employee performance and development. Instead of viewing the performance review as a valuable communication and recognition tool, many practices think of it as a necessary evil; a paperwork exercise that managers love to hate. Exacerbating this feeling of disdain is the fact that supervisors often spend a majority of their time focusing on the small minority of employees who do not meet expectations and not enough time giving appropriate praise, recognition, and appreciation to those who do. Even the best workers can be better, but if they are not given the guidance they deserve, then their full potential will never be reached. Some of the more common shortcomings of a PMP include the following:

- Individual goals are not tied to the strategic direction of the practice—i.e., the goal does not help the practice's vision. For example, a goal to create a protocol for remote working, when the practice does not allow a remote work environment.
- Senior management is not fully committed or invested in the process—When PMP's are not made a priority, and not done in a timely manner, oftentimes employees feel devalued and not important. This can kill practice productivity.
- Performance objectives are only looked at every 6 or 12 months and not on a continuing basis—Evaluations should be all year long. For example, Elaine was late to work 34 times over the summer (June to August), and called out sick every Friday. It's now November and Elaine is due for her performance review. The last 30 days she's been on time and seemingly doing fine. If only recent attendance was taken into account, and not what has happened over the last year, then there is a skewed vision of performance.
- Performance appraisals are not included as part of a larger employee development initiative—Supervisors want teams to grow. When a team continues to evolve and grow, the practice is more efficient and productive which can lead to increased revenue and client satisfaction.
- Little or nothing is done with the actual appraisal results—Evaluations can take a lot of time and effort on both the employee and the supervisor. When next steps aren't taken to reward positive behavior, create goals, and growth opportunities for the employee, they can feel discouraged and disengaged.
- Management fails to develop and administer a coaching and improvement plan for any employee not meeting expectations—If an employee is not meeting expectations, but nothing is done, the employee will keep doing the same things over and over leading the supervisor to likely repeat the conversation the following year.
- There is a lack of clarity in the link between pay and performance. If goals, or the criteria that an employee will be reviewed against are not set, it often leads to a disparity between what the employee thinks their performance can be vs what the supervisor believes performance is.

3. Developing a Performance Management Program

A PMP can be a valuable resource for a supervisor to help employees identify and develop needed skills, knowledge, and abilities. However, if used inappropriately, a PMP can demoralize employees, frustrate managers, and expose a practice to potential legal risks. Therefore, several questions must be addressed when developing a PMP: Who will be involved in the performance review process? Will the review be horizontal, vertical, or a 360°? How much time can each contributing party commit to the PMP? Will the review focus on objective results and/or subjective perceptions? How often should the reviews be performed? Who will oversee the PMP to ensure it is being used properly? Who will provide training to the reviewers? What will be done with the results of the reviews? And, most importantly, how will the success of the PMP be measured?

4. Conducting the Performance Evaluation Review

Prior to meeting with an employee to conduct the performance evaluation review, it is advisable to have them complete a self-evaluation form. Give the employee approximately 1 week to complete the performance evaluation form and return it to his/her supervisor 1 week in advance of the performance evaluation review date. Only after the supervisor has completed the performance evaluation form for the employee, should the supervisor review the employee's self-evaluation form and rating. Following this process will help ensure the supervisor performs an independent performance evaluation that is not biased by the employee's perceptions of how he/she performed. Other important points to consider when preparing for and conducting a performance evaluation review include the following:

- Be sure to deliver the performance evaluation review at the designated time. Giving the review after the date can leave an employee feeling slighted, anxious, and devalued. It also sends the unintended message that the performance evaluation review cannot be that important to the practice.

- Be mindful of overrating an employee. Rating an employee higher than is warranted may be an easier message to deliver, but it can create other problems. For one thing, it may give failing employees a false sense of security and make it difficult to administer needed discipline.
- When discussing a performance issue with an employee, be sure verbal and written comments support the rating and always use specific examples that clearly demonstrate the level of performance.
- Be sure to rate the entire performance evaluation review period. Supervisors often fall into the trap of rating only the most recent activities and actions. If an employee is being evaluated annually, the performance evaluation review should consider everything, good or bad, that has occurred during the past twelve months vis-à-vis the employee's performance. In this case, it is helpful to review notes of conversations that have taken place with the employee throughout the year prior to meeting with them. For example, if an employee is late and has been reprimanded, a note should be placed in that employee's file. Also, if the employee receives a compliment from a client, this should be included in the file as well.
- Ask for feedback. There may be mitigating factors and circumstances that affected the employee's performance during the review period. It is critically important to provide an employee the opportunity to discuss and present an explanation of any factors and influences that may have contributed to his/her performance. Encouraging this two-way dialogue ensures "everything" is considered when developing the performance rating.

5. Developing Performance Goals

Another key piece of a PMP involves developing performance goals and expectations. Goals are written statements that clearly describe certain actions or tasks with a measurable end result. Goals should be well defined, detailed declarations of specific actions to be taken during the upcoming review period for which measurable outcomes are expected. Each goal should be specific enough to let the employee know what is expected to be accomplished, why it is to be done, and the target date for accomplishing it. The following acronym is often used to assist supervisors in developing goals for their employees:

S: Specific—Answers what, why, and when actions or activities should be accomplished.

M: Measurable—Clarifies how to determine whether the goal has been achieved.

A: Agreed Upon—Both the employee/supervisor should agree on what is expected to successfully complete the goal.

A: Aligned—Supports the practice's mission and overall objectives.

R: Realistic—Ensures goals are doable but with a stretch challenge.

T: Time Specific—Establishes a deadline for completion.

An example of a smart goal would look like this: The practice has identified a goal to improve communications with administrative staff by implementing an internal departmental newsletter. Elaine will complete a business writing course by January 2021 and will publish the first monthly newsletter by March 2021. Elaine will gather input and/or articles from others in the department and draft the newsletter for the supervisor to review, and when approved, distribute the newsletter to staff by the 15th of each month.

6. Summary

In order to determine the effectiveness of a PMP, it must first and foremost support achievement of the practice's mission and goals. It should help employees understand what is expected of them and against what measurement criteria their performance will be assessed. If the program is utilized properly, a welcomed byproduct of the PMP is improved communications between supervisors and subordinates. As the PMP evolves, a practice should begin to notice a stronger link between pay and performance. Rather than giving arbitrary increases to all employees, the PMP will provide justification for differences in salary increases and rewards. Finally, documented differences in performance should help identify employees able to assume additional responsibilities as well as those individuals requiring additional development and/or discipline.

Acknowledgments

Declaration of Ethics

The Author has adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Author has no conflicts of interest.

Cannabis in the Patient and Legal Conundrums

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1. Introduction

Cannabis products in the veterinary industry have become a hot topic in the media lately and little is known about the products on the market, including their safety or efficacy. The goal of this paper is to explore how cannabis products have gained popularity, and to share any scientific backing behind treating veterinary patients with cannabis, and to provide advice of the legal ramifications that can result from using these treatments. Unfortunately, while cannabis may have potential for treating ailments, the products on the market are illegal as well as potentially dangerous. Therefore, veterinarians should not stock, treat with, or recommend cannabis products as this usage could result in a formal investigation by the Veterinary Board in the state in which they are licensed.

2. Growth in Popularity of Alternatives to Medications

As pet lovers, the primary goal is keeping furry clients happy, healthy, and pain free. However, in a world of ever-changing trends, how do owners know what is best for their pets and what is just the newest health fad? Traditionally, veterinarians have been sought out to help guide these decisions but, in this changing climate, reliance upon Dr. Google is becoming more common—and vet visits are becoming less so. An increasing number of people are searching for natural alternatives to medications and opting for diets for their pets that are grain free, raw, and antibiotic free. Pet owners are also more commonly using their own homeopathic remedies. While these trends are mainly driven by consumerism and distrust in big pharma, the growing desire for at-home remedies can result in unsafe, unethical, and even illegal outcomes.

3. Veterinarian Responses to Fads

Veterinarians must rely upon scientific research and laws as guidance. Fortunately, with two of the more well-known fads, scientific evidence is relatively cut and dry: grains are not evil and eating raw meat can cause a slew of health problems, such as contracting salmonella. However, when it comes to homeopathic remedies for fleas and ticks, joint pain, dry skin, and even neurologic conditions, the evidence is much harder to come by. This is largely due to the lack of regulations on many products that consumers are using for remedies. There are no US Food and Drug Administration (FDA) regulations, for example, on essential oils, herbs, or nutraceutical pills, meaning there is no regulatory body confirming what is on the label; therefore, nothing confirming what is in the bottle.

Despite the lack of FDA regulation and any associated concerns expressed by veterinarians, the desire to use natural derivatives is growing among pet owners and, one specific derivative is getting plenty of press lately: cannabis.

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4. Two Types of Cannabis Compounds

Cannabis, dating back 6000 years, is the only plant genus that contains the molecular compounds called cannabinoids. The two most notable compounds are tetrahydrocannabinol (THC) and cannabinol (CBD).[1] While poorly divided, taxonomically speaking, cannabis is easily divided into two broad types based on the biochemical makeup. These two divisions are commonly referred to as marijuana and hemp.

The US Drug Enforcement Administration (DEA) classifies marijuana as a schedule 1 drug, which falls in the same category as heroin and cocaine. Due to its recreational use, it is the more well known of the two cannabis plants. Marijuana contains high amounts of THC, the psychoactive cannabinoid, and low amounts of CBD, the antipsychoactive compound.

Hemp, on the other hand, is grown for its seed and fiber properties. Hemp has low levels of THC and high levels of CBD (at least when compared with marijuana). Unlike marijuana, it is not possible to get high off the hemp plant. In fact, one would die of smoke inhalation before reaching high enough levels of THC from hemp to achieve a recreational high.[2] This is due to the low concentration of THC and the fact that CBD is the antipsychoactive that blocks the marijuana high. Because of that, some people refer to hemp as "anti-marijuana."

Industrial hemp usage is legal in the United States but, oddly enough, actually growing industrial hemp is illegal. In fact, since 1937, it has been illegal to grow any variety of hemp in the United States. Under current law, imported hemp products are subjected to zero-tolerance standards for THC, even though the average amount of THC in marijuana is 20%, while the average amount in hemp is 0.3%. Somewhat illogically, the United States government does not distinguish between these two very different plants grown for completely different purposes.

5. Note About State Laws

In 2017, the number of states permitting industrial cultivation of hemp exceeded the number of states that have legalized medicinal marijuana (33 versus 29 to date). So far, though, few farms have begun cultivating hemp due to resistance from the DEA. This is because, while legalized in certain states, both marijuana and hemp are illegal federally.

6. Cannabis for Human Medicinal Purposes

So, what is it in these plants that has led to medicinal use? About 20 years ago, scientists discovered a system in the brain that responds to the compounds found in cannabis, specifically in marijuana.[3] The system is called the endocannabinoid system and has been shown to play a role in the cardiovascular, digestive, endocrine, immune, reproductive, and nervous systems. The discovery sparked interest in finding specific chemicals in marijuana that could be targeted to treat specific conditions. Since that time, research on medical marijuana has increased significantly but, with the schedule 1 classification, doing approved research is still difficult.

While there are plenty of studies that show promising results in treating conditions, in order to officially conduct research on cannabis, scientists must first get approval from the DEA and the FDA. While such studies have shown that cannabis can help manage pain and muscle spasms in multiple sclerosis, as well as improve symptoms of schizophrenia and Tourette's syndrome, too few of the studies were controlled clinical trials with placebo treatments.[4]

These results have been mirrored in the series of studies permitted by the DEA at the Center of Medical Cannabis Research, University of California–San Diego. The conclusion of these 13 studies was broad but simple: "cannabis may be useful medicine for certain indications." Many researchers worried about the risk to users though, with some patients becoming addicted (10%) and others finding the effects "intolerable."[5]

7. FDA-Approved Marijuana Drugs for Humans

Despite the unanswered questions and research-related challenges, there are currently three FDA-approved drugs made from marijuana in the United States. Marinol® and Cesament® are used to treat nausea in chemotherapy and AIDS patients, while Epidiolex® is used to treat children's epilepsy. Furthermore, Sativex® is a drug developed in the United Kingdom that has been approved in over 24 countries to treat muscles spasms from multiple sclerosis and cancer pain, and it may be approved in the United States soon to treat pain associated with breast cancer.

8. Cannabis-Based Products and Pets

Because of the clinical evidence performed to date and experimental evidence by marijuana users, who have self treated successfully, it is no wonder that people want to use cannabis-based products to help their animals. Given how difficult it is to get research approved for cannabis use in humans, one can imagine the level of difficulty involved in performing cannabis research in animals.

The most commonly used cannabis products on the veterinary market for treatment of animals all contain CBD oil. CBD can be extracted from marijuana or hemp and has claims to treat numerous disorders, including behavioral issues, seizures, and pain. While many veterinarians would welcome a safe and effective new way to treat diseases such as arthritis or epilepsy, lack of legality and solid clinical studies makes the situation uncertain.

Veterinary medical uncertainty has not stopped an array of products from popping up on the market. At conferences, one can be bombarded by naturopathic vendors that appear reputable, making claims on their products that cannot be substantiated. This makes it difficult to differentiate fact from fiction and, unless veterinarians are up to date on the current American Veterinary Medical Association (AVMA) and federal standards, they may be tricked into stocking these products at their practices.

In a study that was performed by the Department of Clinical Sciences and College of Veterinary Medicine and Biomedical Sciences at Colorado State University, published in the *Journal of the American Holistic Veterinary Medical Association* and *Scientific Report*,[6] veterinarians were assigned three objectives: find out which cannabis products pet owners purchased, their reasons for the purchase, and whether they perceived a difference in their pet while using the product. The results of this study included 632 pet owners (88.1% dog owners, 11.9% cat owners) who have purchased hemp products from an online site. Most of the dog and cat owners (77.6% and 81.8%, respectively) indicated that they use the hemp product for an illness or condition diagnosed by a veterinarian.

The most common conditions eliciting treatment in dogs included seizures, cancer, anxiety, and arthritis. The illnesses or conditions treated in cats were comparable, with cancer, anxiety, and arthritis as the most common. The most common side effects reported by both dog and cat owners were sedation and overactive appetite. When dog owners were asked about the perceived positive impacts of the hemp, they reported the highest impact in relief from pain (64.3%), followed by helping with sleep (50.5%), and relief from anxiety (49.3%). Cat owners perceived the highest impacts as relief from pain (66%), followed by reduced inflammation (56.3%) and help with sleep (44%). This information supports the growing anecdotal stories of the effects of cannabis in pets. In addition, this information provides a platform for researchers seeking to perform clinical studies on not only the effectiveness of hemp but also the adverse outcomes associated with the use of hemp.

Interestingly, this study also surveyed pet owners about their disclosures to their veterinarian about the hemp products used. Just under half of the participants had spoken with their veterinarian about the product, with most indicating that their veterinarian responded positively (61.7%), some expressing no opinion (30.7%) and very few responding negatively (7.7%). While most veterinarians would agree that anything having a positive impact on a pet is, in fact, positive, in this case, it is still illegal. In a recent article by the AVMA titled, "Cannabis: What Veterinarians Need to Know,"[7] the AVMA cautions pet owners against the use of chews, oils, and nutritional supplements containing CBD, citing the FDA as its regulatory beacon.

Currently, the FDA does not approve the use of marijuana or hemp in any form in animals because of the lack of evidence about the safety and effectiveness of the products. The DEA stated in 2017 that "cannabinoids are not found in hemp, except in trace amounts. Therefore, extracts that contain more than trace amounts of cannabinoids must be part of the cannabis plants that are defined as marijuana and regulated as a schedule 1 controlled substance."

In all this legislation, it might appear that hemp is unfairly getting a bad name; however, the American Society for the Prevention of Cruelty to Animals (ASPCA) poison control center has recently reported an influx of calls and claims that ingestion of hemp-based CBD products causes the same clinical signs as ingestion of marijuana (products containing THC). It is not known whether toxicity is due to quality control issues in unregulated products, differing metabolism rates of CBD, or varying amounts of CBD in products despite label claims. The most common clinical signs include ataxia, depression, mydriatic pupils, hyperesthesia, and urinary incontinence. While rare, other signs include vomiting, tremors, and seizures with multiple deaths reported due to aspiration.[8] For this reason, the FDA and AVMA caution pet owners against using these products and the FDA has issued numerous warnings to companies that sell products containing cannabidiol.

9. Conclusion

Overall, studies indicate great potential for cannabis as a treatment modality. If research was less restricted, more safety and dosing studies could be conducted. This would likely help explain, and ultimately prevent, poison-related deaths and begin to address concerns.

What is important to remember is that pet owners aren't the people who face significant consequences for trying these products. Although it is illegal to sell products containing cannabinoids, and illegal to purchase products containing them, the only parties as of now who have been threatened to be held legally responsible are veterinarians and the cannabinoid-producing companies.

Here is just one example of how a state medical board perceives veterinary use of cannabis-based treatments: The California Veterinary Medical Board states that, while marijuana is legal for adults 21 years and over, cannabis is illegal for use in animals.[a]

In conclusion, the use of cannabis products for animals warrants the attention of veterinarians and researchers and could one day be a wonderful treatment modality, but it cannot currently be recommended or stocked by veterinarians. It is suggested that both the promises and perils of medical marijuana for animals point to the need for science-based education, regulation, and research. So, while the aim is to do what is best for the patient, it is most appropriate to advocate for change while remaining within the confines of the law. It is possible that one day cannabis will be a legal and accepted treatment in the veterinary community, but many steps must be achieved before then.[9]

Acknowledgments

Declaration of Ethics

The Author has adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Author has no conflicts of interest.

References and Footnote

1. Sawler J, Stout JM, Gardner KM, et al. The genetic structure of marijuana and hemp. *PLoS ONE* 2015;10:e0133292.
2. West DP. Hemp and marijuana: myths & realities. 1998. Available from: https://www.votehemp.com/PDF/myths_facts.pdf.
3. Vaida B. Medical marijuana: what the research shows. Available from: https://www.webmd.com/pain-management/features/medical-marijuana-research-web#1. Accessed February 28, 2018.
4. Koppel BS, Brust JCM, Fife T, et al. Systematic review: Efficacy and safety of medical marijuana in selected neurologic disorders: Report of the Guideline Development Subcommittee of the American Academy of Neurology. *Neurology* 2014;82:1556–1563.
5. Hill KP. Medical marijuana for treatment of chronic pain and other medical and psychiatric problems: a clinical review. *J Am Med Assoc* 2015;313:2474–2483.
6. Kogan LR, Hellyer PW, Robinson NG. Consumers' perceptions of hemp products for animals. *J Am Holistic Vet Med Assoc* 2016:42;40–48.
7. Cannabis use and pets. Available from: https://www.avma.org/resources-tools/animal-health-and-welfare/cannabis-use-and-pets.
8. Herzog H. Think twice before giving medical marijuana to your pet. *Anim Studies Repository* October 12, 2016. Available from: https://www.wellbeingintlstudiesrepository.org/aniubpos/58/.
9. Meola SD, Tearney CC, Haas SA, et al. Evaluation of trends in marijuana toxicosis in dogs living in a state with legalized medical marijuana: 125 dogs (2005–2010). *J Vet Emerg Crit Care* 2012;22:690–696.
10. Clark PA, Capuzzi K, Fick C. Medical marijuana: Medical necessity versus political agenda. *Med Sci Monit* 2011;17:RA249–RA261.

[a]See the Veterinary Medical Board's Guidelines for Veterinarian Discussion of Cannabis Within the Veterinarian-Client-Patient Relationship: Effective January 1, 2020. Available from: https://www.vmb.ca.gov/forms_pubs/cannabis_discussion.pdf.

How to Avoid Problems During and After Pre-Purchase Examinations

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Whether the veterinarian is a prospective owner, trainer, agent, or veterinarian, the pre-purchase examination process is where a lot of things can go wrong which can cause a multitude of problems, and accusations, later. This exposure is true whether the examination is for a purchase, a lease with a purchase option, or only for lease. This paper provides an outline of common ethics concerns and proposes best practices for the practitioner. Authors' addresses: Equine Law Group, LLC, 12008 South Shore Boulevard, Suite 105, Wellington, FL 33414 (Chapman); Yellowstone Equine Hospital, 356 West Yellowstone Avenue, Cody, WY 82414 (Vlahos); e-mail: ascesq1@cs.com. *Corresponding author.

1. Ethics Concerns

With respect to pre-purchase and pre-lease examinations, ethical concerns for the veterinary practitioner fall into several categories of concerns. Not all of these concerns involve lapses, acts, or omissions by the veterinarian, but all of them implicate the veterinarian's role as an agent having a duty to the client of the veterinarian. The general categories of ethical concern, which are further discussed below, include the following:

- Failure to identify the client.
- Existence of a conflict of interest by relationship, ownership, fee structure, or agency.
- Full disclosure of known *and* potential conflicts.
- Full disclosure of pre-existing conditions and treatments.
- Reasonable investigation of pre-existing conditions and treatments.
- Proper recordkeeping of the examination process.
- Consistency between invoicing and examination report.

This article therefore discusses the ethical considerations when working with prospective purchasers and lessors during pre-purchase and pre-lease examinations, the exposure from the perspective of the examining veterinarians, and then suggests best practices from the various perspectives of whomever the veterinarian might represent in the purchase or lease transaction examination.

2. Identify for Whom the Veterinarian Is Working

Knowledge of the identity of the client, the principal for whom the veterinarian is examining the horse, is very important. Often, the intermediaries in the purchase or lease transaction have economic and noneconomic interests at stake in the completion of the transaction, which may cause the information in the examination to be conveyed to the prospective purchaser or lessee in a biased manner. If the veterinarian does not directly communicate findings

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and report to the person or entity for whom the veterinarian is the agent, then the veterinarian can have no confidence that the examination findings have been accurately conveyed. For the veterinarian, this is problematic, because if there is a dispute later between purchaser and seller relating to a pre-existing condition or treatment and whether the condition or treatment was properly disclosed, the veterinarian may find the accused seller misrepresenting the information conveyed to the veterinarian or his or her findings conveyed to the purchaser.

The practitioner, in a pre-purchase or pre-lease examination posture, is working as an agent on behalf of a principle: *someone* or *some entity*. Because of this special relationship, the veterinarian will have duties to that principal: to provide proper examination and to properly report. Those duties fall into not only the category of malpractice, which is not the subject of discussion here, and into the nature of fiduciary duties, and ethical failings discussed herein.

3. Fiduciary Duties of the Veterinarian

The existence of a special relationship, created by the relative positions of the parties, such as in a veterinarian-client relationship, wherein the veterinarian knows that the client is relying upon the experience and specialized skills and position of the veterinarian to properly conduct, and convey the findings of, a pre-purchase or pre-lease examination. This duty arises from the position in which the parties place each other, whether or not there is a contract for services.[a]

The most basic fiduciary duty is the duty of loyalty, which, in the context of pre-purchase examinations, obligates the veterinarian to put the interests of the client first, ahead of the veterinarian's self-interest. That duty of loyalty requires the veterinarian to refrain from exploiting the relationship with the client for the veterinarian's personal benefit, meaning for benefit beyond being paid to conduct the pre-purchase examination.[d] A fiduciary duty arises expressly by contract when the parties specifically agree to a relationship, such as the attorney-client or agent-principal relationship, that is considered to be a fiduciary relationship.[e] By that definition, such duties exist equally in the veterinarian-client relationship.

The client justifiably relies upon the veterinarian, as the agent, to exercise a certain requisite level of skill and diligence in the pre-purchase or pre-lease examination. That duty does not end by clearing conflicts of interest and then examining the horse. Rather, duties extend to properly investigating the prior history of the horse, noting the limits of the investigation and disclosures obtained, and in ensuring the examination report actually arrives in the hands of the client.

Should the practitioner get past the "relationship test," then the next areas of concern for the examining practitioner relate to what the veterinarian is told and by whom.

Consider that specter of the presence of a pre-existing medical condition of the horse and an owner or owner's agent's failure to disclose that medical history has the potential to directly affect the prospective purchaser's ability to make an informed decision whether to lease and ultimately purchase the horse. It is customary in the equine industry to have a horse evaluated extensively by a licensed equine veterinarian prior to purchase (hereinafter referred to a pre-purchase examination [PPE]). It is also customary for a potential lessee to have a less extensive evaluation of a horse at the time a lease commences, only to have their veterinarian perform a more extensive radiographic, ultrasound, and endoscopic evaluation prior to any eventual purchase.

However, the scope and extent of PPE imaging and diagnostic testing is often premised upon the previous medical history of the horse as provided by the seller, lessor, or their agent. Consider that if the selling or leasing party is not forthcoming to the examining veterinarian, then the scope of the examination will be curtailed. This places the examining veterinarian, in a difficult position, opining as to the present health of the horse, while potentially not having been fully informed of the pre-existing conditions or prior treatments of the horse.

When this delta between present examination to past, relevant information is compared against the ethical consideration that the single most important goal of the examining veterinarian is to provide the buyer or lessee with information as to the health and soundness of the prospective horse, then the potential for misleading information being construed from the pre-purchase or pre-lease examination is great.

Prospective purchasers and lessors rely upon the veterinarians to provide adequate information so that those parties may make an informed decision to proceed or decline the purchase or lease. Consider, however, upon whom the veterinarian relies. At the time of the examination, the examining veterinarian relies extensively, if not exclusively, on the medical history and related information as provided by the seller or lessor at the time of the examination.

The failure to disclose the pre-existing conditions of a horse denies the client of the examining veterinarian the opportunity to make an informed decision to lease the horse, and may subsequently place the purchaser or lessor, as well as the horse, at risk of serious injury. Consider that the American Association of Equine Practitioners (AAEP) *Guidelines for Reporting Pre-purchase Examinations* contains two material statements:

- "…It is the buyer's responsibility to determine if the horse is suitable…"; and
- "…It remains the sole responsibility of the veterinarian to determine the extent and depth of each examination."[b]

In some cases, given the extent of the chronic disease, condition, or off-label medication use present in a horse at the time of the examination, had the history been disclosed, a reasonable equine veterinarian would not find such a horse healthy for the intended purpose then or at any time in the future. Therein lies several ethical pitfalls for the veterinarian. The AAEP *Position on Sale Disclosure* provides guidance that:

- "AAEP supports the position that when a horse is sold, any known invasive surgery, disease, injury, or congenital defect which is not apparent, should be disclosed to the intended buyer by the owner and/or agent."
- "The AAEP supports disclosure of ownership by single or multiple owners of a horse at the time of offering for sale."[c]

4. Conflicts of Interest and Self Dealing

Conflicts of interest arise when the practitioner has some relationship, interest, or inherent bias that is affected by the examination of the horse. An equity interest in the horse or business that owns the horse is a clear example. More nuanced is a present business relationship with the seller of the horse. A personal, intimate relationship with the seller or one of the selling entity's principals presents another form of ethics conflict. Most commonly, a conflict arises when a business relationship of the practitioner with the seller exists. Any of these relationships should cause the practitioner to either clear the conflicts through written disclosure and acceptance by the client, or (and appropriate in most circumstances of conflict) decline engagement for the pre-purchase or pre-lease examination.

The veterinarian's duties to identify and clear or avoid conflicts of interest are part of what was previously described herein as "fiduciary duties." Such duties are not always considered by examining veterinarians, although the ethical guidelines of the AAEP promote their existence and observance.[f]

5. Concerns from the Perspective of the Prospective Purchaser or Lessee

If the veterinarian is examining a horse as the veterinarian for a client intending to purchase or lease a horse, there are key considerations to keep in mind:

- What disclosures as to the health and soundness history has the client of the veterinarian and the veterinarian received from the seller or lessor or their agents?
- What disclosures as to the health and soundness history has the client of the veterinarian and the veterinarian received from the client's own agents?
- What disclosures have been made from the seller or lessor or their agents to the client of the veterinarian or the veterinarian as to the regular course of treatment, maintenance, medication, medicine, training, and shoeing for the horse?
- How have any of those disclosures been transmitted, such as in writing or orally?
- Is the examining veterinarian (or the practice), someone (or an entity) who has little or no financial or business relationship to the seller or lessor or their agents?
- Has the examining veterinarian disclosed to the client any relationship that does exist between the veterinarian and the seller, lessor, or their agents?
- Who recommended the veterinarian as the veterinarian for the examination?
- What is the understanding as to by whom the veterinarian is employed? The actual purchaser/lessor or their agent? Someone else?
- Has the veterinarian confirmed who is the client and how so?
- Has the veterinarian been informed by the seller/lessor and their agent, as well as the client's agent of the intended purpose of the horse which the veterinarian is examining?
- Has the veterinarian been told whether the horse is being considered for competition at a particular level of a particular discipline, for investment, resale, or for use and retirement?
- Who is directing the veterinarian as to the scope and extent of the examination (i.e., number and location of radiographs)?
- Did the veterinarian provide a written examination directly to the client?
- Did the veterinarian do so before the client approved the purchase or lease and closed the transaction?
- If the veterinarian is then asked to execute an insurance health certificate for the new owner or lessee, what statements will the veterinarian be required to make to the insurance company? (To wit: the veterinarian's certificate often makes statements in answer questions as to past history or conditions of the horse).
- Upon whose information did the veterinarian rely when executing that insurance certificate? (Note that knowingly providing false information to an insurance company could negate coverage or form the basis for a claim against the veterinarian by the client of the veterinarian or the insurance company).

Clients have certain legal rights to full disclosure. Florida, Kentucky, and California in particular have laws that specifically address horse sales, while other states follow their consumer protection laws.[g]

Without proper disclosure to the veterinarian, as the examining veterinarian, of the prior conditions, health, and treatment of the horse, the veterinarian cannot render an opinion upon which the client can use to make an informed decision whether at all to purchase, lease with an option, or lease. Further, the client cannot insist upon removal of disclaimers, or the inclusion of exceptions or pre-conditions in the transaction to account for any pre-existing conditions of the horse.

The veterinarian really is traveling in the dark without guidance if not informed of what has been going on with the horse and what the program is to keep the horse healthy and sound. Further, the veterinarian may not appreciate the complex business and financial relationships amongst all of the parties to the transaction that might affect the accuracy or level of detail that flows to the veterinarian as the veterinarian makes decisions. The veterinarian should also save texts, emails, scans, photos, and attachments related to the examination and discussions of the findings thereof. The veterinarian should preserve what the veterinarian was informed concerning the history of the horse and about the pre-purchase examination or pre-lease examination.

6. Concerns for Agents

Agents in equine transactions are those who represent a principal, usually for commission or other compensation. If the veterinarian is being compensated by anyone in an equine purchase or lease transaction, it is likely the veterinarian is an agent. If others are speaking to the veterinarian on behalf of the buyer or seller, then they are agents. Often, whether the veterinarian was an agent, and for which party or parties, becomes an issue. If the veterinarian is working for, or being compensated by, multiple parties to a transaction, then the veterinarian is considered a "dual agent." Some states, for example Florida, require disclosure of a veterinarian's agency, dual agency, commission, and require consent of the buyer and seller or lessor and lessee.[h]

Because these general principals apply to agents, as an agent of the purchaser or lessee, the veterinarian may have his or her own perspective on the above set of bullet-point concerns, which the veterinarian should consider during the pre-purchase examination or pre-lease examination process. As an agent, the veterinarian should be mindful and take care to note where information is coming from, how it is relayed, and how the veterinarian discloses it to the agent's principal. It is not infrequent that in a purchase or lease dispute, someone says, "I told the agent," or "the agent did not tell me."

If the veterinarian is the prospective buyer's agent, the veterinarian should insist on copies of all of the seller's or lessor's veterinary records, or the contacts to obtain them. The veterinarian should then obtain those records and be sure they are given to the pre-purchase veterinarian. The veterinarian must obtain a written pre-purchase examination from the veterinarian and send that, along with the records, to the prospective buyer, the principal.

If the veterinarian is the seller or lessor's agent, the veterinarian should be sure to disclose any knowledge about the horse and make it clear, and document the transmission of information and provide or offer access to the veterinary records. Remember the examining veterinarian, is relying upon these representations while examining the horse, so accuracy is important. Further, the veterinarian may find the representations are included in a later insurance certificate, so be accurate to avoid any misadventure in an insurance coverage dispute later.

The point is, as the veterinarian conducting the examination goes about the role in a purchase or lease transaction, whether speaking to the other side of the transaction, be it other agents or principals, or communicating with the pre-purchase veterinarian, or communicating with their own principal, the veterinarian should keep a documented record of what is being said, by whom and when. The veterinarian should also save texts, emails, scans, photos, and attachments. That documentation may be useful later.

7. Best Practices for Pre-Purchase and Pre-Lease Examining Veterinarians

With the above concerns in mind, there are some best practices the examining veterinarian might consider undertaking the following practices:

- Note in written records and written pre-purchase examination report who exactly was present at the pre-purchase examination.
- Note as well who defined the scope of the examination.
- Find out and note the intended purpose of the purchase or lease.
- Note what was disclosed about the past health and soundness history of the horse and from whom each of the disclosures was made.
- Obtain the contact information of the principal (the prospective buyer or lessee) for whom the veterinarian are actually working and send that principal a copy of the written pre-purchase examination report.
- Prepare a written pre-purchase examination report contemporaneously or immediately after with the examination.
- Avoid subjective opinion in any report. The report should consist of clinical observations, from which the buyer can draw conclusions.
- Avoid the same when interpreting radiographs.
- The veterinarian should, however, explain findings adequately in the report for a lay person to understand, and in further detail if asked.
- Do not accept an agent's word that the agent will send the report to the principal. The examining veterinarian will want to do this and retain a copy of that transmittal.

- Note in written records any subsequent conversations the veterinarian has with the prospective buyer or lessee should the veterinarian have occasion to speak with them.
- Do not let the agent retain the veterinarian as the agent's veterinarian for the examination—the veterinarian is working for the prospective buyer or lessee and any reports and billing and report distribution should reflect that agency.

Experience has shown that a large part of equine transaction disputes concern allegations of non-disclosure of prior health or soundness issues. When the fingers start pointing, the veterinarian does not want to be accused of not informing someone of something. Conversely, to avoid accusation, the veterinarian should be able to dive into the records and demonstrate who told the veterinarian what, or did not disclose, during the pre-purchase examination or pre-lease examination process. The veterinarian should also be able to definitely articulate for whom the veterinarian was working at the time of the examination. An ounce of prevention to understand and record matters at the time of the examination is worth a pound of cure to try and recreate from memory and intention what happened at a pre-purchase examination or pre-lease examination in the past.

With those thoughts in mind, the next time a pre-purchase or pre-lease examination is on the horizon, take a moment to stop and go through standard practices and adjust them so that they become best practices.

Acknowledgments

Declaration of Ethics

The Authors have adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Authors have no conflicts of interest.

Footnotes

[a]See *Watkins v. NCNB Nat. Bank of Florida, N.A.*, 622 So.2d 1063, 1065 (Fla. 3d DCA 1993) (quoting *Bankest Imports, nc. v. Isca Corp.*, 717 F.Supp. 1537, 1541 (S.D.Fla. 1989) ("To establish a fiduciary relationship, a party must allege some degree of dependency on one side and some degree of undertaking on the other side to advise, counsel, and protect the weaker party"). See also *Taylor Woodrow Homes Fla., Inc. V. 4/46-A Corp.*, 850 So.2d 536, 540 (Fla. 5th DCA 2003) (quoting *Quinn v. Phillips*, 93 Fla. 805, 113 So. 419, 421 (1927)). "A fiduciary relationship is based on trust and confidence between the parties where 'confidence is reposed by one party and a trust accepted by the other.'" Such a relationship may arise from an express contract or may be implied in law. *Id*.

[b]AAEP Guidelines for Reporting Pre-Purchase Examinations (2009). https://aaep.org/guidelines/aaep-ethical-and-professional-guidelines/aaep-position-statements/sale-issues.

[c]AAEP Position On Sale Disclosures (1998). https://aaep.org/guidelines/aaep-ethical-and-professional-guidelines/aaep-position-statements/sale-issues.

[d]See, e.g.: Restatement (Third) of Agency §8.01 (2006); see also *Capital Bank v. MVB, Inc,* 644 So. 2d 515, 520 (Fla. 3d DCA 1994) ("A fiduciary owes to its beneficiary the duty to refrain from self-dealing, the duty of loyalty, the overall duty to not take unfair advantage and to act in the best interest of the other party, and the duty to disclose material facts").

[e]See *Capital Bank*, supra, 644 So. 2d at 518.

[f]See, e.g., footnotes c and f herein.

[g]See. e.g.: Fraud in Horse Sales: Florida's Rule 5H and Unfair and Deceptive Acts by Equine Sellers, Agents, and Others, The Florida Bar Journal, Volume 92, No. 9, November 2018. https://www.floridabar.org/the-florida-bar-journal/fraud-in-horse-sales-floridas-rule-5h-and-unfair-and-deceptive-acts-by-equine-sellers-agents-and-others/.

[h]*Id*., fn e, herein: " Undisclosed agency and compensation arrangements amongst owners, sellers, agents, trainers, sponsors and other 'facilitators' are common in the horse world and have normalized unfair and deceptive acts that would not be permitted in other industries. The problem is not limited to Florida, nor, indeed, the United States. In England, secret commissions are known, ironically, as 'sweeteners.' Evans, Richard, *Jockey Club Probe Bloodstock 'Fraud,'* DAILY TELEGRAPH (London), Jan. 27, 2004, Sport, at 1."

Musculoskeletal Structure and Function of the Distal Hind Limb

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1. Introduction

The musculoskeletal architecture of the modern horse is a textbook study in the specialized anatomical adaptations of cursorial locomotion. During the peregrination of the equid from North America to the steps of Asia, the frame of the horse grew in stature as they migrated from semitropical into more open savanna environments where speed and endurance were necessary for survival.[1] It is during this period of the horses' evolution that unique locomotor adaptations to the musculoskeletal system developed.[2]

2. Modern Equine Development

Over approximately 55 million years, the fossil records show that multiple toes evolved into a single toe and the bones of the lower limb elongated that resulted in greater potential leverage powered by the major muscle groups concentrated in the upper part of the limb. The sesamoid bones became highly developed, giving the tendo-ligamentous structures of the suspensory apparatus mechanical advantage. The arrangement of a single hardened toe, skeletal adaptations, elongated tendons, and proximal migration of muscle groups made way for a strong, energy-efficient animal whose lower limb function used a high degree of automaticity.[2,3]

3. Structure and Function of Specific Anatomy

The specific adaptations that influence the pelvic limbs work on the principles of using bone shape, bone length, and bone position to increase leverage; tendinous muscle development for passive weight bearing and synchronous joint movement; and the elongation of distal tendons for elastic recoil.[4] These systems work in concert to facilitate the transfer of potential, kinetic, and elastic energy, reducing the chemical energy required of skeletal muscle.[5]

The locomotion characteristics of the horse result in the hindlimbs contacting the ground before the forelimbs in gaits having a suspension phase.[6] Therefore, the ability of the hindlimbs to dissipate the forces of ground impact is essential for lifelong soundness.

In comparison to the straight force vector position of the knee when receiving load, the capability of the hindlimb to dissipate energy is significantly increased by the reciprocal flexing actions of the hock and stifle while decelerating. At no point of the stride do the proximal joints of the pelvic limb receive load in a straight force vector position.[6]

An underpinning function of the tarsal joint is to actively stabilize the leg while dissipating energy during the deceleration phases of the stride.[6] The

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tarsocrural joint has the greatest range of motion of the hock, and the increased leverage provided by the extended moment arm of the calcaneus adds mechanical advantage to the superficial digital flexor tendon (SDFT) and common calcaneal tendon in resisting the tensile forces developed during stance phases.

In contrast to the "open kinetic energy chain system" of thoracic limbs (in which the body mass is suspended within the shoulder girdle by fibrous muscles), the pelvic limbs (via the ball and socket joint of the hip) are in direct contact with the axial spine, which results in a "closed kinetic energy chain system" that is more efficient in storing and releasing energy.[7]

Pelvic limb muscles have been found to have larger volumes and shorter fascicle length than thoracic limb muscles,[8] which facilitate a greater ability to generate explosive power and endurance and serve as a spring dampener to dissipate vibration.[2]

The mechanical apparatus of the hindlimbs has to provide energy for propulsion through the concentric action of muscles, provide energy for deceleration and stability through the eccentric and isometric action of muscles, and store elastic energy within adapted muscle, ligament, and tendon.[4,6,9]

The makeup of the proximal joints of the pelvic limb function to resist the frictional coefficient of the ground reaction by the eccentric action of muscles controlling hip, stifle, and hock flexion during the deceleration phases of the stride.[7,10] In addition, the tendo-musculature and collateral ligaments supporting these joints must resist torsional moments and maintain stability until midstance[2,10,11] and, simultaneously, elastic energy is stored in the adapted soft tissue structures and is used to facilitate propulsion.[4]

There are significant morphological and functional differences between the thoracic and pelvic limbs. Basic functional requirements of the forelimbs and hindlimbs will show that the front limbs bear approximately 60–65% of body weight, as the horse stands and at critical times of the stance phases. Hindlimbs function to dissipate shock, provide stability for deceleration, and provide impulsion for forward movement. These explanations describe basic functions but are too simple for accurate biomechanical assessment and comparative studies with other species.

In general, anatomical morphology dictates the function of structures or physical systems and is best described in this quote by Dr. Milton Hildebrand:

"The degree of specialization of an anatomical structure is proportional to the importance for the species survival."

Some examples of forelimb to hindlimb anatomical differences are as follows:

- Stay apparatus: patellar locking (skeletal) of the stifle and tendon of the biceps brachii (soft tissue) of shoulder.
- MT3 is longer than MC3.
- Geometry of MT3 results in a greater resistance to medial/lateral (M/L) and dorsal/plantar (D/P) bending forces.[12]
- The proximal sesamoid bones of the foreleg are larger and more rounded than those of the hindleg.
- The fourth metatarsal bone is larger than the fourth metacarpal bone, providing a greater surface area for the insertion of tendons and structural ligaments.
- The superficial digital flexor tendomuscular system of the hindlimb has very little muscle mass compared to the forelimb, resulting in a more ligamentous function.
- The overall increased length of the caudal tendomuscular system in the hindlimb (SDFT and deep digital flexor tendon [DDFT]) facilities a greater capacity for elastic recoil compared to the front limb.
- Energy saving reciprocal apparatus of the hock and stifle: there is no such apparatus in the foreleg.
- The hock is designed to receive load dynamically, whereas the knee must remain static while loading and at midstance.
- There is no superior check ligament associated with the SDFT in hindlimbs.
- The inferior check ligament associated with the DDFT is significantly smaller in hindlimbs.

4. Anatomy of the Reciprocal Apparatus and Suspensory Apparatus

The superficial flexor tendon/muscle and the fibularis tertius work in concert as mainstays of the "reciprocal" apparatus during rest and to simultaneously flex the hock and stifle during liftoff and initial phases of protraction with a marked degree of automaticity and minimal expenditure of energy.

The superficial flexor muscle originates from the supracondylar fossae situated caudoproximal to the lateral condyle of the femur. Its mass is significantly less than but is much more tendinous than its counterpart on the forelimb. The actual muscle belly is encased in thick myofacia and is reduced to an elongated fibrous muscle adapted to resist chronic tension. The SDFT has no accessory ligament, as its tendon forms a fibrocartilaginous cap, and its retinacula insert on the M/L calcaneal tuberosity and continues distad until its terminal insertion at the plantar/proximal border of the middle phalanx.

The fibularis tertius (formally peroneus tertius) originates on the lateral femoral condyle and courses down the cranial aspect of the tibia, deep to the long extensor, lateral extensor, and tibialis cranialis. Distally, it passes deep to the tendon of the tibialis cranialis and divides into two branches extending and inserting dorsally and laterally into the distal row or tarsal bones, the metatarsal tuberosity of the cannon bone, and laterally onto the fourth metacarpal, respectively.[14]

The fibularis tertius is constituted mainly of tendinous fiber with little skeletal muscle mass lending to its static tensile resistance capabilities.

The deep digital flexor muscle heads originate from the proximal caudal fibula and the caudolateral margin of the proximal tibia. The less-developed deep digital muscle mass and diminished size of the subtarsal accessory ligament of the pelvic limb are consistent with its diminished function compared to the increased need for tensile resistance of the thoracic limb.

The "suspensory apparatus" of the distal limb is the term that describes the mechanism of support and function of the joints of the equine distal limb during the static and dynamic loading phases of the stride. Soft tissue and skeletal adaptations work in concert to provide the loading capacity of the joints of the digit that give horses the fluid locomotion characteristics that humans value. The suspensory apparatus of the modern horse is another example of developmental adaptations that minimize the use of musculature, resulting in an overall decrease in weight and an economical expenditure of energy.

The suspensory apparatus has three primary functions:

- Support
- Shock dissipation
- Impulsion

The anatomical structures involved in the suspensory apparatus are as follows:

- The main body of the suspensory ligament.
- The medial and lateral branches of the suspensory ligament.
- The medial and lateral extensor branches of the suspensory ligament and the common extensor tendon.
- The distal sesamoidian ligaments: straight sesamoidian, oblique sesamoidian, and M/L cruciate.
- The superficial and deep flexor tendons.
- The collateral ligaments of the distal interphalangeal joint.

This system, in combination with the palmar/pastern and collateral ligaments of the digit, functions to maintain the fetlock, pastern, and coffin joint in a straight phalangeal alignment when standing. It also serves to resist over dorsiflexion of the fetlock and hyper flexion of the coffin joint under load.

The suspensory ligament originates from the palmar proximal aspect of the 2nd, 3rd, and 4th metatarsal bones. It courses distally between the splint bones, adjacent to the plantar aspect of the cannon bone, and bifurcates into medial and lateral branches prior to the nodules of the splint bones and subsequently inserting onto to proximal fossae of the medial and lateral proximal sesamoids. It sends two smaller branches dorsodistally to aponeurosis with the common extensor tendon, which ultimately inserts onto the extensor process of the distal phalanx. Muscle fibers found in the body of the suspensory ligament are evidence of the interosseous muscles' adaptation into its present ligamentous morphology and perhaps its ability to withstand the tensile forces generated during the loading phases of the stride. The tensile load on the suspensory ligament increases and decreases dependent of the angulation of the fetlock within each case. The proximal sesamoids and navicular bone are critical to the system by providing significant mechanical advantage to the tendons and ligaments. The well-developed sesamoid bones, in particular the proximal sesamoids, serve to increase the skeletal moment arm of the plantar aspect of the fetlock, giving the flexor tendons mechanical advantage. The distal sesamoid bone (navicular bone) functions to maintain a consistent angle of insertion for the DDFT as it fans out to insert onto the semi-lunar crest of the distal phalanx or P3. The navicular bursae interposes between the flexor surface of the navicular bone and the flexor surface of the DDFT. The DDFT has significant fibrous insertions onto the axial projections of the ungular cartilage.

The straight sesamoidian ligament originates from the distal sesamoidian fibro cartilage situated distally on the medial and lateral proximal sesamoid bones. Functionally, it is a continuation of the main body of the suspensory ligament and is the only one of four distal sesamoidian ligaments that extend distally to the proximal plantar aspect of the middle phalanx. The middle or oblique sesamoidian ligament has two branches. Each branch originates from the bottom of the medial and lateral sesamoid bones, respectively, join together, and insert onto the middle plantar pedicle of the proximal phalanx. As the middle sesamoidian ligament does not cross over the interphalangeal joint, the tensile loads are not directly attributable to the angular position of the fetlock joint. There is very little reporting in the literature as to the specific function of the oblique sesamoidian ligament, but most biomechanical anatomists believe its function is to aid in support of the tensile load on the suspensory apparatus and to give torsional stability to the fetlock joint under load.

The cursorial adaptations to the musculoskeleture of the horse that occurred from his smaller digitgrade posture to the relatively large framed animal of the modern ungulate are examples of the efficient use, storage, and return of energy systems developed over the horses' evolution. The migration of large muscle mass to the proximal body results in the ability to generate large eccentric, concentric, and isometric forces in the stance phases of the stride. The adaptation of musculotendinous bodies like the superficial flexor muscle, the fibularis tertius, and the interosseous muscle results in the ability to resist chronic tensile forces in the deceleration and midstance phases and initiates joint flexion of the pelvic limb during the late stance phase and early swing phase. The resulting loss of muscle mass has made the distal limb much lighter and easier to control the centrifugal forces generated in late swing phase and moment of ground contact.[2]

The size of and locomotion characteristics of the horse dictate a musculoskeletal system that is able to dissipate concussive forces and resist tensile and torsional forces generated during athletic competition. It is this architecture of specialized skeletal, ligament, and tendon adaptations that facilitate the athletic potential of the horse.

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Declaration of Ethics

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Conflict of Interest

The Author has no conflicts of interest.

References

1. Molen M. The evolution of the horse. *J Reprod Fertil* 1975; 23:1–6.
2. Rooney J. *The lame horse.* Cranbury, NJ: AS Barnes and Co., Inc.; 1974.
3. Bernor, RL, Janice CM. The evolution of equid monodactyly: a review including a new hypothesis. *Front Ecol Evol* 2019;7:5–7.
4. Harrison SM, Kawcak CE, Whitton C, et al. Relationship between muscle forces, joint loading and utilization of elastic strain energy in equine locomotion. *J Exp Biol* 2010;213: 3998–4009.
5. Aida H, Hiraga A, Mukai K, et al. Measurements of flexor tendon and suspensory ligament forces during trotting using the Thoroughbred forelimb model. *J Equine Sci* 2014; 25:15–22.
6. Clayton HM, Hobbs SJ. A review of biomechanical gait classification with reference to collected trot, passage, and piaffe in dressage horses. *Animals* 2019;9:763.
7. Ozyigit G, Ozcan R. Cross-sectional geometry of equine metacarpal and metatarsal bones. *J Anim Vet Adv* 2010;9: 971–975.
8. Payne RC, Veenman P, Wilson AM. The role of the extrinsic thoracic limb muscles in equine locomotion. *J Anat* 2004; 205:479–490.
9. Clayton, HM. Horse species symposium: Biomechanics of the exercising horse. *J Anim Sci* 2016;94:4076–4086.0
10. Crook TC, Hodson-Tole EF, Wilson AM. The effect of treadmill speed and gradient on equine hindlimb muscle activity. *Equine Vet J* 2010;42:412–416.
11. Chateau H, Crevier-Denoix N, Lawson SEM, et al. Effect of toe and heel elevation on calculated tendon strains in the horse and the influence of the proximal interphalangeal joint. *J Anat* 2007;210:583–591.
12. Schuurman SO, Kersten, Weijs A. The hind limb is actively stabilized during standing. *J Anat* 2003;202:355–362.
13. Payne, RC, Hutchinson, JR, Robilliard, JJ, et al. Functional specialization of pelvic limb anatomy in horses. *J Anat* 2005;206:557–574.
14. Clayton HM, Flood PF, Rosslein DS. Clinical Anatomy of the Horse, Elsevier Ltd., 2005;76, 81.

How to Evaluate Foot Conformation and Understand the Effect of Shoeing on Load Distribution

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1. Introduction

"Conformation" is a term often used in the assessment of horses by breeders, judges, riders, farriers, and vets and is determined by the skeleton, the length, and shape of the bones and their arrangement with regard to each other. Thus, conformational traits comprise segment lengths, segment angles, and the orientation of the leg to the ground. Many authors consider the ratios of the lengths and angles and their (a)symmetry to be more important than the absolute values. Conformation is mainly influenced by the genetic makeup of a horse and is often breed specific, while other factors (such as nutrition, aging, podiatry) have a much smaller influence.

Foot conformation describes the size, shape, and (a)symmetry of the foot and while genetics also play a large role, the foot—unlike conformation of the rest of the body—is much more influenced by environmental factors, such as usage, nutrition, and especially podiatric management. The foot forms the interface between the ground and the horse and conformation of the foot hence not only influences how the load of the body weight of the horse is distributed over/within the foot, it also influences how it is affecting the rest of the horse.

2. Understanding the Relationship Between Extensor and Flexor Moments

Following Newton's third law, for every action (force) in nature there is an equal and opposite reaction.[1] The force the body generates when in contact with the ground is called ground reaction force (GRF). The GRF has a magnitude and a direction. Its magnitude is dependent on only two factors: how heavy the horse is and how fast it moves. Nothing but those two factors can change that and each foot (and the rest of the leg) has to cope with that. What is influenced by foot conformation (and all the factors that determine foot conformation) is its direction, especially where the GRF vector enters the foot. This point is called the "point of force application" or the "point of zero moment" (POZ). This in turn influences where the GRF vector runs in relation to the joints. As the horse's leg is not straight, the GRF exerts a rotational force on each of the joints (especially the fetlock and coffin joints); this rotational force is called a "moment." The distance between the GRF vector and a joint (the center of rotation to be precise) determines how much "leverage" the GRF has on this joint and it is called the GRF moment arm. The further the GRF vector is

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away from a joint, the bigger its moment arm and hence leverage on this joint. If nothing would counteract this, the leg (and the horse) would simply collapse. The GRF acts on the front of the horse's leg, also called the extensor side (as this is where leg extension happens). To prevent the leg from collapsing, there needs to be an equal force on the other side (the flexor side of the leg) to counteract this. This is achieved by the spring-like properties of the suspensory apparatus and the deep and superficial flexor muscle-tendon units and their supporting ligaments in combination with their moment arms around each joint[2]; the moment arms are the distances between the tendons and the center of rotation of each joint; hence, the flexor moment is the product of the force in those soft-tissue structures and their moment arms. These moment arms do not change as they are morphologically constrained by the presence of sesamoid bones: the proximal sesamoid bones at the level of the fetlock and the navicular bone at the level of the coffin joint. Increasing the moment arm of tendons/muscles is indeed the "job" of sesamoid bones, thus decreasing the force on the tendon/muscles and hence protecting their associated soft-tissue structures from overloading. In the case of the horse leg, every increase in extensor moment will require an increase in flexor moment. As the flexor moment arm is constant this will result in an increase in force in the flexor tendons/suspensory ligament. A more detailed explanation of horse leg biomechanics can be found in the book by Wilson and Weller.[3]

3. How Does Foot Conformation Influence the Extensor/Flexor Moment System?

In the most simple terms: the longer the toe, the further forward the POZ is positioned and the further away the GRF vector is from the joint center of rotation, thus increasing the extensor moment arm at all joint levels and increasing the total extensor moment. This requires an increase in flexor moment to prevent the leg from collapsing and increases the force on the flexor tendons/suspensory ligament. Lengthening of the toe is obviously a normal physiological effect that is caused by horn growth and its effect has been described.[4,5] Shortening the toe or elongating the heels moves the POZ further back and the GRF vector closer to the center rotation of the joints, thus resulting in smaller moment arms on the extensor side, an overall smaller extensor moment, and hence flexor moment and smaller forces in the flexor structures. Shortening the toe can obviously be achieved by trimming and/or shoeing. Heel extensions and heel wedges have a similar effect in terms of moving the POZ backward and an overall decrease in flexor moment; however, heel wedges have the additional effect of unloading the deep digital flexor tendon (DDFT) and shifting the load to the other flexor structures.

Changes in conformation and moments not only affects the tendons, but also other musculoskeletal structures. For example, a change in tendon force also affects the sesamoid bones they are associated with. As the force in the tendons go up, the more pressure and strain they exert on their respective sesamoid bone. This is well documented for the navicular bone where every degree change in the solar border of the pedal bone results in a 4% change in strain in the DDFT and the pressure it puts on the navicular bone under.[6]

Changes in conformation (natural or podiatry related) also changes the way bones and joints are loaded. For example, heel wedges increase the pressure in the dorsal area of the coffin joint.[7]

4. Lateromedial Conformation

So far only the leg has been considered as a two-dimensional structure with its movement constrained to the sagittal plane. While horse anatomy is optimized for movement in the sagittal plane, there is of course movement in the other planes as well albeit to a much smaller degree. At each joint the GRF vector exerts a moment in 3D and if there is an increase of the moment on one side, this will result in an increase on the other side and an uneven loading of the joint surfaces as well as an uneven strain in the collateral ligaments. The GRF always follows the direction of the extension. If there is a lateromedial imbalance of the foot with the medial side higher than the lateral side, this will result in an increase in pressure on the medial side and an increase in strain in the lateral collateral ligament.

5. How Does This Translate into the Real World?

Using Newtonian physics to explain leg mechanics in a horse leave one vital component out: the "bio" in "biomechanics." Unlike (most) manmade structures, biological tissues can heal and horses can use their legs differently. Indeed, looking at the conformation of horses standing does not equal how they use their legs,[8,9] and horses show change in their locomotion changes to compensate for growth related changes in conformation.[10] It also does not take into account the effect of surfaces on biomechanics or on vibrations (which are also an important factor in the development of orthopedic disorders).

Despite all these other factors, epidemiological studies have shown that there is a correlation between foot conformation and injury. It has been shown that the odds suffering from DDFT lesions and navicular bone pathology change with solar angle of the pedal bone.[11] Horses with a mediolateral foot imbalance have been shown to be more prone to collateral ligament problems,[12] although this correlation was much more subtle than the relationship between dorsopalmar foot conformation and problems with the navicular apparatus.

Due to the clinical nature of these studies it is, however, unclear as to what is cause and what is effect. Many horses suffering from foot-related lameness enter a vicious cycle as it has been shown that horses with palmar foot pain adopt a toe-first landing pattern, which shifts the POZ forward and in turn increases the strain in the flexor structures and the pressure on the navicular bone.[13]

6. Conclusion

Foot conformation influences the load distribution not only within the musculoskeletal structures within the foot but also the rest of the leg. The majority of orthopedic problems in horses are degenerative in nature and the result of repetitive overloading that exceeds the natural repair capacity of the body tissues. Their development is multifactorial; however, considering the fragility of some of the musculoskeletal structures optimization of load, distribution is key and paying attention to foot conformation is absolutely vital.

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Declaration of Ethics

The Author has adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Author has no conflicts of interest.

References and Footnote

1. Newton I. *Philosophiæ naturalis principia mathematica* (*Mathematical principles of natural philosophy*). London, UK: 1687.
2. Alexander RM, Bennet-Clark HC. Storage of elastic strain energy in muscle and other tissues. *Nature* 1977;265:114–117.
3. Wilson AM, Weller R. The biomechanics of the equine limb and its effect on lameness. In: Ross M, Dyson S, eds. *Diagnosis and management of lameness in the horse*. Philadelphia, PA: W.B. Saunders, 2011.
4. Van Heel MC, Moleman M, Barneveld A, et al. Changes in location of centre of pressure and hoof-unrollment pattern in relation to an 8-week shoeing interval in the horse. *Equine Vet J* 2005;37:536–540.
5. Moleman M, van Heel MC, van Weeren PR, et al. Hoof growth between two shoeing sessions leads to a substantial increase of the moment about the distal, but not the proximal, interphalangeal joint. *Equine Vet J* 2006;38:170–174.
6. Eliashar E, McGuigan MP, Wilson AM. Relationship of foot conformation and force applied to the navicular bone of sound horses at the trot. *Equine Vet J* 2004;36:431–435.
7. Viitanen MJ, Wilson AM, McGuigan HR, et al. Effect of foot balance on the intra-articular pressure in the distal interphalangeal joint in vitro. *Equine Vet J* 2003;35:184–189.
8. Unt VE, Evans J, Reed SR, et al. Variation in frontal plane joint angles in horses. *Equine Vet J* 2010;(38):444–450.
9. Wilson A, Agass R, Vaux S, et al. Foot placement of the equine forelimb: Relationship between foot conformation, foot placement and movement asymmetry. *Equine Vet J* 2016; 48:90–96.
10. Van Heel MC, van Weeren PR, Back W. Compensation for changes in hoof conformation between shoeing sessions through the adaptation of angular kinematics of the distal segments of the limbs of horses. *Am J Vet Res* 2006;67: 1199–1203.
11. Holroyd K, Dixon JJ, Mair T, et al. Variation in foot conformation in lame horses with different foot lesions. *Vet J* 2013;195:361–365.
12. Reeve D, Mair T, Dixon J, et al. Is there a relationship between lateromedial foot imbalance and distal interphalangeal joint collateral ligament injuries? *J Equine Vet Sci* 2013;10:858.
13. Wilson AM, McGuigan MP, Fouracre L, et al. The force and contact stress on the navicular bone during trot locomotion in sound horses and horses with navicular disease. *Equine Vet J* 2001;33:159–165.

[a]Dixon JJ, Mair T, Bolas N, et al. Variation in foot conformation in lame horses with different foot lesions. *Vet J* 2013;195: 361–365.

How to Understand Lameness: The Link Between Force and Movement Asymmetry

Thilo Pfau, Dr.-Ing., FHEA

Veterinary decision making during the equine lameness examination follows a logical structure that is well suited for the incorporation of additional knowledge. The "lameness mechanism" nicely links reduced force production with the affected limb to the major visual indicators of lameness: head nod and hip hike. Newtonian mechanics provides supporting evidence for this link. Modern sensor or camera-based techniques allow for a straightforward quantification of head and pelvic movement asymmetry as decision-making aids—in particular for overcoming the limits of the human visual system and for reducing bias after the elimination of pain via diagnostic analgesia. Because all stages of the lameness examination can be quantified with technological aids, i.e., straight line, lunge, ridden exercise, flexion tests, and improvement after diagnostic analgesia, these aids can also be used in symmetrical bilaterally lame horses. Additional measurements, such as the movement of the withers (compared to the movement of the head), provide extra information that is not easily appreciated by eye and can help differentiate between true forelimb lameness and horses showing a compensatory head nod. Author's address: Department of Clinical Science and Services, The Royal Veterinary College, University of London, Hawkshead Lane, North Mymms, Hatfield, AL9 7TA, United Kingdom; e-mail: tpfau@rvc.ac.uk.

1. Decision Making During the Lameness Examination

The veterinary lameness examination typically follows a logical structure with the overall aims of (1) establishing whether the horse is lame or not, (2) grading the severity of one (or more) detected gait deficit(s), and (3) to localizing the source(s) of the deficit(s).[1] The structure, which typically involves a gait assessment in different gaits, on different surfaces, in-hand, on the lunge and/or ridden, before/after flexion tests, and before/after diagnostic analgesia, is meant to facilitate the detection and grading of lameness as well as identification of the most promising regions for conducting further investigative steps, typically involving diagnostic imaging. However, the multitude of different exercise conditions, under which the horse needs to be assessed, also poses a challenge to human decision making: not always will all detected signs be in agreement. Thus, human decision making in situations like these can be "suboptimal."[2] The level of intra- and interobserver agreement for the veterinary lameness exam is well documented. The reported low level of agreement[3,4] may be related to the fact that there seem to be a multitude of "features" that experienced veterinarians will consider when visually observing a horse for signs of lameness and sometimes lameness scoring also involves a second source of variability, such as a rider and his/her influence on the horse's movement.[5]

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2. A Common Mechanism

As a consequence of the multistage process followed during the lameness examination, identifying a unifying "mechanism" that is applicable to most (or ideally all) lame horses would be advantageous for reducing the complexity of quantifying sensitive and specific movement parameters for differentiating between nonlame and lame horses. Commonly, diagnostic analgesia is instrumental in identifying the anatomical region that appears to be causing pain during movement, i.e., the horse moves substantially differently after eliminating the pain from an anatomical region or from a specific structure.[6,7] Common logic indicates that if pain is experienced within a limb that an animal will aim to reduce the force that is produced by this limb; as an analogy, imagine a stone in one of your shoes and how this affects your willingness to make use of the affected limb during walking (or even running).

3. How to Assess Force

After having identified a (unifying) mechanism, namely decreased forces produced with the affected limb, the next question is: what is the best method to detect a change in force production? Of course, one can make use of sophisticated (and more or less expensive) devices, such as force platforms, force shoes, or pressure mats. These devices measure the force produced during ground contact and produce accurate and precise readings of the ground reaction forces, i.e., the force exerted from the ground onto the animal when a limb (or multiple limbs) is in contact with the surface.[8–11]

4. Kinematics of Lameness

For centuries, veterinarians and farriers have found a much easier way of identifying the affected limb that does not require the measurement of force.[12] It simply involves careful visual observation of a horse in motion. Typically performed, and most easily explained, in trot, it comes down to identifying the existence and severity of a head nod, hip hike, or pelvic hike as an indicator of the existence and grade of lameness.

Newtonian mechanics can then be used to explain how these kinematic (movement) features are directly related to kinetic changes (changes in force), in particular the reduction in force production during the stance phase of the lame limb.[13]

5. Head Nod and Hip Hike and the Link to Force Asymmetry

Head nod and hip hike are features that have been described in multiple studies with two- or three-dimensional kinematics and more recently also with the use of inertial measurement units.[14–17] Both features are typically described in trot, a two-beat, diagonal gait with simultaneous ground contact of diagonal pairs of limbs.[18] The two-beat nature of the trot is advantageous, as there is a clear differentiation between the period of ground contact of a diagonal pair of limbs, the following aerial phase, subsequently followed by the ground contact of the opposite diagonal pair of limbs, and finally a second aerial phase. This means that the full stride cycle can be divided easily into two halves, namely, "down then up" during ground contact, upward movement continued into the aerial phase and then downward movement in the second half of the aerial phase, leading into the stance phase of the other diagonal pair.

In the nonlame horse, the two halves of the trot stride are expected to follow near-identical vertical movement of the upper body, and the horse is producing the same amount of force with both front limbs. In the front limb lame horse, which produces less force with the affected front limb, there will be less vertical movement during the stance phase of the lame limb and more vertical movement during the stance phase of the sound limb.[9,14]

The situation is slightly more complicated for the hindlimb lame horse: the hip hike, often described as an increased vertical movement of the tuber coxae on the side of the lame limb, is a paramount sign of hindlimb lameness.[15] At first sight, this indicator may appear counter-intuitive: why would there be increased movement on the side of the lame limb? Does this not contradict the paradigm of "less force, less movement"? A closer look at the timing of the increased movement amplitude on the side of the lame limb indicates that this movement is actually happening during the ground contact of the nonlame limb.[13,15,19]

The same mechanism applies to forelimb and hindlimb lameness: less vertical movement during the stance phase of the lame fore or hindlimb. It is simply the case that the increased rotation of the pelvis during nonlame stance further amplifies the increased vertical movement during the nonlame stance phase. The nature of the rotation—when the nonlame limb is in ground contact—means that it amplifies the movement amplitude on the contralateral side, i.e., on the side of the lame limb. The reduced force during lame stance has the opposite effect: restricted rotation of the pelvis. Hence, the already reduced vertical movement is not amplified to the same degree on the contralateral (nonlame) side.

6. Newton's Laws of Motion and Math

Newton's laws of motion explain why head nod and hip hike are such important parameters for identifying and grading lameness. Experience shows that head nod and hip hike are reliable indicators of lameness. However, there is a more compelling argument that links the kinematic signs of lameness to the underlying force changes–Newton's second law of motion. It states that when a force F is acting on an object of mass m, it causes the object to accelerate by a (or in equation form, $F = m*a$). So, less vertical force F will lead to less vertical acceleration a (the mass m of the horse of course stays the same). Secondly, mathematically, acceleration is related to velocity (the speed of the movement) and to displacement (how much the object moves) by integration over time. Effectively, reduced force production means less acceleration of the attached body part, a lower speed, and a reduced amplitude of movement (displacement).

As a consequence, head nod and hip hike, which logically relate to reduced force production in the lame limb, can also be derived from Newton's second law of motion and some math.

7. Quantification of Movement Asymmetry

Now that the relationship between head nod and hip hike and the underlying mechanism of reduced force production are clear, think about how to make use of technology to aid human decision making during the lameness examination. It has been shown that humans have a limited ability to appreciate movement asymmetry below a threshold of 20 to 25% amplitude difference.[20] In a horse with a typical vertical movement amplitude of 60–100 mm for the upper body during a trot stride cycle, this level of 20–25% translates into 12–25 mm of movement asymmetry that may be necessary to detect this asymmetry with confidence. Modern technology is more advanced than that. Camera-based three-dimensional motion capture systems can be calibrated to below millimeter accuracy over capture volumes large enough to cover an entire riding arena.[21] Inertial sensors are accurate (for quantifying displacement during near-cyclical movement) down to a few millimeters[22,23] and have the additional advantage of in-built data loggers or wireless links extending to ranges of 50 m or more. Hence, these techniques provide the necessary freedom for the horse to move naturally (without the need for a treadmill that might cause unwanted movement artefacts[24]) and allows movement asymmetry to be quantified during all stages of the lameness examination, including the response to diagnostic analgesia.[25–29]

8. What About Bilateral Lameness?

In the context of movement asymmetry measurements to aid lameness examinations, sooner or later the question arises: "But what about the bilaterally lame horse? It does not move asymmetrically." The answer to this question is two-fold: first, as outlined above, technology may pick up subtle movement asymmetries that can be hard to detect consistently by eye. Previous research shows that some bilaterally lame horses indeed show subtle movement asymmetries[30] and some mild pre-existing asymmetries on the straight may be exacerbated on the lunge.[31,32] The second point, however, is more essential: in much the same way that horses are put on the lunge, flexion tests are being performed and diagnostic analgesia is administered and then the horse is observed by eye. These same tools (lunge, flexion tests, and diagnostic analgesia) still exist when measuring movement asymmetry,[33] and the freedom of movement afforded by modern technology makes it easy to do this wherever the horse may be. Hence, a near-symmetrical bilaterally lame horse will then show changes in asymmetry measurements either on the lunge, after flexion test, or after diagnostic analgesia. Having an objective, quantitative measurement might contribute to limiting the "expectation bias" that can affect judgment of intrahorse changes, e.g., after diagnostic analgesia.[34]

9. Lameness Versus Movement Asymmetry

A recent editorial has initiated discussion about the definition of lameness and the impact of technological aids on that definition.[33] Although there clearly are different opinions about this topic,[5,35] it appears important to gather further relevant information that can feed into the continued discussion and address topics, such as the variability of gait asymmetry measurements and its sources,[21,36] the agreement with expert decision making,[37] in general, and for various applications and disciplines, and contemplating to what extent incorporating further measurements into the decision making process could be useful.[38]

10. More Than Head Nod and Hip Hike?

An example of a recent advancement is the (re-) incorporation of withers movement into the measurement process.[39] First investigated many years ago,[14,40] a recent study in horses with induced lameness has shown the potential benefit of making use of withers movement asymmetry when differentiating between a "true" head nod shown in a forelimb lame horse and a "compensatory" head nod in reaction to a hindlimb lameness.[39] The different patterns of head-and-withers movement have been described in horses with naturally occurring gait asymmetries[41] and also in horses presented to veterinary specialist centers for lameness investigations (Persson unpublished).[a]

11. Future Trends?

Further miniaturization of sensor and wireless technology combined with improvements in wireless data transmission and data storage capacity as well as availability of cheaper sensor technology driven by ubiquitous usage in smartphones, intelligent fitness, and home management-related products will likely lead to further development of the field of equine movement asymmetry assessment. Decreased costs will make technology available to many more people in the equestrian field. The possibility to synchronize many sensors with little effort and transmit or log data will lead to tools that can measure additional anatomical areas of the horse.[38] Increasing the use of artificial intelligence will lead to many more tools combining different sensors.

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Declaration of Ethics

The Author has adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

Dr. Pfau is owner of EquiGait, Ltd., which provides gait analysis products and services.

References

1. Ross MW. Lameness in horses: Basic facts before starting. In: Ross MW, Dyson SJ, eds. *Lameness in the horse*. 2nd ed. Philadelphia: Elsevier Saunders, 2011;3.
2. Rey A, Goldstein RM, Perruchet P. Does unconscious thought improve complex decision making? *Psychol Res* 2009;73:372–379.
3. Keegan KG, Dent EV, Wilson DA, et al. Repeatability of subjective evaluation of lameness in horses. *Equine Vet J* 2010;42:92–97.
4. Keegan KG, Wilson DA, Wilson DJ, et al. Evaluation of mild lameness in horses trotting on a treadmill by clinicians and interns or residents and correlation of their assessments with kinematic gait analysis. *Am J Vet Res* 1998;59:1370–1377.
5. Bathe A, Judy CE, Dyson SJ. Letter to the Editor: Do we have to redefine lameness in the era of quantitative gait analysis? *Equine Vet J* 2018;50:273.
6. Ross MW. Bilaterally symmetrical forelimb or hindlimb lameness. In: Ross MW, Dyson SJ, eds. *Diagnosis and management of lameness in the horse*. St. Louis: Saunders, 2003;60–73.
7. Ross MW. Coexistent lameness. In: Ross MW, Dyson SJ, eds. *Diagnosis and management of lameness in the horse*. 2nd ed. St. Louis: Saunders, 2011.
8. Weishaupt MA, Wiestner T, Hogg HP, et al. Compensatory load redistribution of horses with induced weightbearing hindlimb lameness trotting on a treadmill. *Equine Vet J* 2004;36:727–733.
9. Weishaupt MA, Wiestner T, Hogg HP, et al. Compensatory load redistribution of horses with induced weight-bearing forelimb lameness trotting on a treadmill. *Vet J* 2006;171:135–146.
10. Chateau H, Robin D, Simonelli T, et al. Design and validation of a dynamometric horseshoe for the measurement of three-dimensional ground reaction force on a moving horse. *J Biomech* 2014;42:336–340.
11. Van de Water E, Oosterlinck M, Pille F. The effect of perineural anaesthesia and handler position on limb loading and hoof balance of the vertical ground reaction force in sound horses. *Equine Vet J* 2016;48:608–612.
12. Liautard AFA. *Lameness of horses and diseases of the locomotory apparatus*. New York: W.R. Jenkins, 1888. Available at: https://books.google.co.uk/books?id=BcYwAQAAMAAJ.
13. Pfau T. Sensor-based equine gait analysis: more than meets the eye? *UK Vet Equine* 2019;3:102–112.
14. Buchner HH, Savelberg HH, Schamhardt HC, et al. Head and trunk movement adaptations in horses with experimentally induced fore- or hindlimb lameness. *Equine Vet J* 1996;28:71–76.
15. May SA, Wyn-Jones G. Identification of hindleg lameness. *Equine Vet J* 1987;19:185–188.
16. Keegan KG, Yonezawa Y, Pai PF, et al. Evaluation of a sensor-based system of motion analysis for detection and quantification of forelimb and hind limb lameness in horses. *Am J Vet Res* 2004;65:665–670.
17. Keegan KG, Pai PF, Wilson DA, et al. Signal decomposition method of evaluating head movement to measure induced forelimb lameness in horses trotting on a treadmill. *Equine Vet J* 2001;33:446–451.
18. Hildebrand M. Symmetrical gaits of horses. *Science* 1965; 150:701–708.
19. Starke SD, May SA, Pfau T. Understanding hind limb lameness signs in horses using simple rigid body mechanics. *J Biomech* 2015;48:3323–3331.
20. Parkes RSV, Weller R, Groth AM, et al. Evidence of the development of 'domain-restricted' expertise in the recognition of asymmetric motion characteristics of hindlimb lameness in the horse. *Equine Vet J* 2009;41:112–117.
21. Hardeman AM, Serra Bragança FM, Swagemakers JH, et al. Variation in gait parameters used for objective lameness assessment in sound horses at the trot on the straight line and the lunge. *Equine Vet J* 2019;51:831–839.
22. Pfau T, Witte TH, Wilson AM. A method for deriving displacement data during cyclical movement using an inertial sensor. *J Exp Biol* 2005;208:2503–2514.
23. Warner SM, Koch TO, Pfau T. Inertial sensors for assessment of back movement in horses during locomotion over ground. *Equine Vet J* 2010;42:417–424.
24. Buchner HHF, Savelberg HHCM, Schamhardt HC, et al. Kinematics of treadmill versus overground locomotion in horses. *Vet Q* 1994;16:87–90.
25. Maliye S, Voute L, Lund D, et al. An inertial sensor-based system can objectively assess diagnostic anaesthesia of the equine foot. *Equine Vet J* 2013;45:26–30.
26. Maliye S, Voute LC, Marshall JF. Naturally-occurring forelimb lameness in the horse results in significant compensatory load redistribution during trotting. *Vet J* 2015;204: 208–213.
27. Maliye S, Marshall JF. Objective assessment of the compensatory effect of clinical hind limb lameness in horses: 37 cases (2011–2014). *Am J Vet Res* 2016;249:940–944.
28. Rungsri PK, Staecker W, Leelamankong P, et al. Use of body-mounted inertial sensors to objectively evaluate the response to perineural analgesia of the distal limb and intra-articular analgesia of the distal interphalangeal joint in horses with forelimb lameness. *J Equine Vet Sci* 2014;34: 972–977.
29. Pfau T, Spicer-Jenkins C, Smith RK, et al. Identifying optimal parameters for quantification of changes in pelvic movement symmetry as a response to diagnostic analgesia in the hindlimbs of horses. *Equine Vet J* 2014;46:759–763.
30. Keegan KG, MacAllister CG, Wilson DA, et al. Comparison of an inertial sensor system with a stationary force plate for evaluation of horses with bilateral forelimb lameness. *Am J Vet Res* 2012;73:368–374.
31. Pfau T, Jennings C, Mitchell H, et al. Lungeing on hard and soft surfaces: Movement symmetry of trotting horses considered sound by their owners. *Equine Vet J* 2016;48:83–89.
32. Rhodin M, Egenvall A, Andersen PH, et al. Head and pelvic movement asymmetries at trot in riding horses in training and perceived as free from lameness by the owner. *PLoS One* 2017;12:e0176253.
33. van Weeren PR, Pfau T, Rhodin M, et al. Do we have to redefine lameness in the era of quantitative gait analysis? *Equine Vet J* 2017;49:567–569.
34. Arkell M, Archer RM, Guitian FJ, et al. Evidence of bias affecting the interpretation of the results of local anaesthetic nerve blocks when assessing lameness in horses. *Vet Rec* 2006;159:346–349.
35. Adair S, Baus M, Belknap J, et al. Response to Letter to the Editor: Do we have to redefine lameness in the era of quantitative gait analysis. *Equine Vet J* 2018;50:415–417.
36. Sepulveda Caviedes MF, Forbes BS, Pfau T. Repeatability of gait analysis measurements in Thoroughbreds in training. *Equine Vet J* 2018;50:513–518.
37. Pfau T, Caviedes MFS, McCarthy R, et al. Comparison of visual lameness scores to gait asymmetry in racing Thoroughbreds during trot in-hand. *Equine Vet Educ* 2018.

38. Bosch S, Serra Bragança F, Marin-Perianu M, et al. EquiMoves: a wireless networked inertial measurement system for objective examination of horse gait. *Sensors* 2018;18: 850.
39. Rhodin M, Persson-Sjodin E, Egenvall A, et al. Vertical movement symmetry of the withers in horses with induced forelimb and hindlimb lameness at trot. *Equine Vet J* 2018; 50:818–824.
40. Peloso JG, Stick JA, Soutas-Little RW, et al. Computer-assisted three-dimensional gait analysis of amphotericin-induced carpal lameness in horses. *Am J Vet Res* 1993;54: 1535–1543.
41. Pfau T, Noordwijk K, Caviedes MFS. Head, withers and pelvic movement asymmetry and their relative timing in trot in racing Thoroughbreds in training. *Equine Vet J* 2018;50: 117–124.

Employing Therapeutic Shoeing Concepts—A Farrier's Perspective

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1. Introduction

Farrier science has long been appreciated for its effectiveness against differing equine lamenesses. Basic biomechanical principles have been noted throughout published literature since the beginning of farrier practice.[1] As farrier ideals and concepts have matured, a hoof care provider's approach to the application of therapeutic shoeing may also need to be reviewed to enable a more progressive approach to equine foot care.

While there may be a correlation between aesthetically pleasing workmanship and functional shoeing, sometimes practitioners have to look further into the foot when lameness enters the equation. Basic shoeing principles may fall short when pathology is cited in the distal limb. In many cases, attention to the smallest of details can mean the difference between success or failure for the equine athlete and for the farrier.

While the mature equine skeleton offers a robust, bony structure, the hoof capsule can adapt in various ways to accommodate loading pressure due to its structure and pliability. The structural integrity of the capsule can be altered by weight, conformation, moisture, and the horse's adaptation to pathology.[2] Therefore, a practitioner must consider the effectiveness and sustainability of the shoeing principles that are being employed during the shoeing process.

Managing diagnosed pathology with the integration of therapeutic shoeing can be effective, but also have a sense of fluidity. When dealing with equine pain, the lameness level can fluctuate in both a positive and negative direction over time. This can be due to the progressive nature of certain lamenesses or successful rehabilitation.

To offer the horse the best possible prognosis, it can be beneficial for both the farrier and veterinarian to meet to discuss cases. Gaining detailed information about each other's perspective can enable a rehabilitation roadmap to incorporate the right components of both professions. Therapeutic shoeing can easily be contradictory if opposing hoof distortions, topical diseases, and pathologies are present. Therefore, the use of diagnostic imaging to appreciate the affected structures, coupled with a thorough examination of the hoof capsule, can be the most streamlined approach to implementing a well-thought-out shoeing prescription. Both practitioners should be aware of the capsule's ability to respond to changes that accompany differing therapeutic shoeing modalities. Appreciation of this can be experienced in the clinical lameness level changing, or visualized

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in the hoof capsule's response to loading forces and hoof capsule adaptations.

2. Static Assessment

Static evaluation is an invaluable tool in assessing limb and hoof capsule abnormalities. The author typically starts static evaluation of the horse discussing the performance issues with the rider, owner, or trainer. Performance notes from the rider can be beneficial to the hoof care provider. Within this conversation, dialogue regarding training tendencies and/or difficulties can be discussed in relation to shoe modifications to offer support or enhancement of movement.

Static evaluation can also include interpretation of imaging, historical shoeing, hoof quality, and functionality.

3. Hoof Function

Hoof capsule landmarks have been noted in the literature to reference the center of rotation,[3] and the apex of the coffin bone. These reference points can be used to assess balance and locomotive function.

The hoof capsule can also be assessed in terms of robustness, correctness, and its ability to rejuvenate horn in an even and balanced manner.

While the concept of hoof capsule balance is important in terms of locomotion efficiency, the hoof capsule's fundamental role of protection and dissipating large amounts of energy must be considered to encourage healthy horn rejuvenation. Ensuring the internal structures of the hoof are correctly stimulated and supported can be considered a primary principle of hoof care practice.

A variety of hoof balance principles are often assessed in a stationary position. The author regularly finds that high-level sport horses often fail to meet these expectations and prefers to trim and shoe the horse based around balance principles that involve dynamic movement. Shoe placement, when based around the center of rotation, can offer a reliable means of limiting stress on the limb during locomotion.[4] Once the foot is balanced in an anterior/posterior plane, the shoe can then be assessed into individual quadrants to assess shoe balance. Ideally, the shoe would offer even support under the limb around the bordering margins of the capsule. Shoe balance can offer the sport horse greater limb stability under peak force loading during locomotion (Fig. 1).

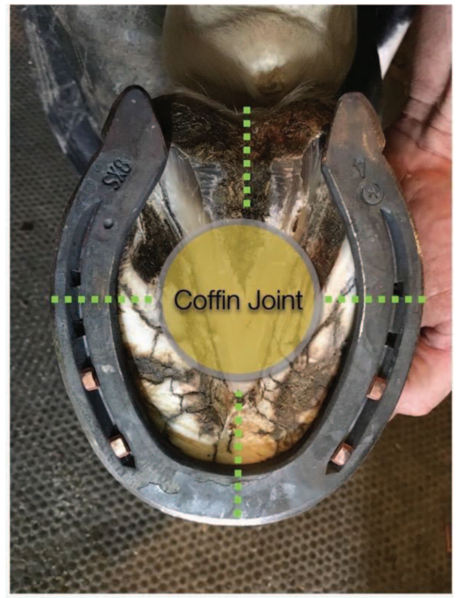

Fig. 1. Shoe balance can offer the sport horse greater limb stability under peak force loading during locomotion.

Due to the hoof capsule's pliability under the body weight of the horse during stance and locomotion, the capsule can become distorted and therefore inefficient at dampening the vibrations caused through locomotion if not corrected at regular intervals. The hoof capsule has been well noted for deformation in the heel region.[5] Contracted, underslung, and crushed heel structures are some of the most common forms of heel region distortion. External hoof capsule distortions can often impact the structure, health, and function of the relative underlying anatomical dermal layers. This dysfunction is often one of the first causes of concussion-based lameness.[5]

The solar region of the hoof capsule is the primary interface between the distal limb and the ground surface.[4] The neuro-sensory capabilities of the hoof capsule are relayed to the horse's brain by way of the outer hoof wall. This sensory feature can enable the horse to perceive ground undulations, load, and pain.

Hoof mass is a key component of a structurally functional capsule. The use of hoof testers can allow identification of sensitive areas across the capsule's solar surface, while also providing an indication of hoof mass or density.

Without the use of diagnostic imaging to establish baseline sole metrics, a practitioner can use hoof testers to decipher hoof mass or density. Hooves with high saturation levels or poor sole mass will deform and create an unfavorable reaction almost immediately against light hoof tester pressure. In the author's opinion, hooves that lack solid density often acquire dysfunctional capsule distortions with more ease than their counterparts with well-formed, functional foot quality.

The frog can be used to help identify hoof capsule depth to assist basic balance guidelines.

The coffin bones solar elevation—the distance and angulation from the terminal arch to the distal/dorsal border of the coffin bone—can be a reliable means of assessing solar contour.[6] To further elaborate, trimming the frog to the live apex, the solar elevation of the capsule can be identified by measuring the distance and angulation of the horny solar surface (Fig. 2).

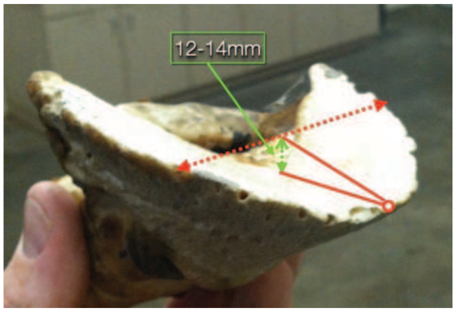

Fig. 2. Trimming the frog to the live apex, the solar elevation of the capsule can be identified by measuring the distance and angulation of the horny solar surface.

This landmark can be fundamental to restoring function to the capsule. The author finds that once the solar contour is identified, often there is no need to remove any extra sole mass to otherwise gain trimming landmarks (Fig. 3).

This can allow the farrier the opportunity to leave more sole mass within the trim and gain further integrity within the capsule.

The hoof capsule's ability to perform can also be influenced by the interaction with bacteria, fungus, and environmental conditions. Hoof quality can be negatively affected by keratinophilic infections and alternating saturation levels. Neutralizing saturation levels with topical treatments can be an effective means to avoiding not only hoof distortions but infections that lay on the epidermal structures of the capsule.[2] Therefore, animal husbandry can positively impact a standardized shoeing prescription.

The assessment of skeletal conformational deviations can play a significant role in understanding the loading and enrollment patterns of each limb.

Fig. 3. Once the solar contour is identified, often there is no need to remove any extra sole mass to otherwise gain trimming landmarks.

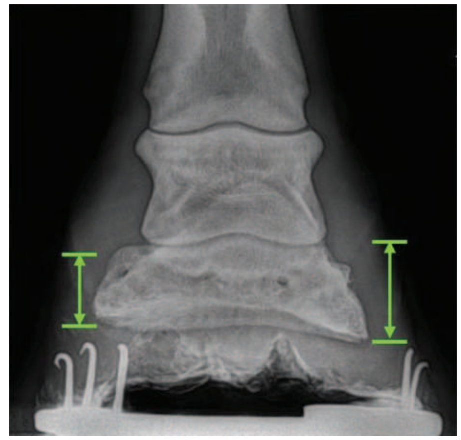

Fig. 4. Conformational misalignments can be represented internally by asymmetric coffin bone architecture which can be viewed radiographically. This is probably caused through uneven loading pressure over the capsule, internal vascular compression, and the coffin bone's ability to demineralize and reabsorb bone.

Conformational misalignments may be represented by way of hoof distortions or localized decrease in foot quality or minimized proliferation of horn. The capsule's response to loading pressure can also be seen in wall separations, crushed heels, and prolapsed frogs. Uneven dissipating force can be responsible for some hoof capsule distortions.[4]

In the author's experience, conformational misalignments can also be represented internally by asymmetric coffin bone architecture and this can be viewed radiographically. This relationship is probably caused through uneven loading pressure over the capsule, internal vascular compression, and the coffin bone's ability to demineralize and reabsorb bone (Fig. 4).

To accurately define the severity of common limb deviations, it can be beneficial for the practitioner to align himself in front of the horse's carpus during the viewing process to ensure a standardized and reliable means of observation. From this perspective, the practitioner can assess the relevance of the horse's age in relation to physis maturity or limb/hoof capsule-loading expectations. Common limb deviations can include offset, rotational, and axial skeletal misalignments.

Conformationally, skeletal misalignments may require the hoof care provider to make adjustments to the shoe to help ease the loading and/or enrollment phase. This can be made possible by way of shoe selection with differing break-over patterns or shoe branch modifications.

4. Dynamic Assessment

Initial dynamic evaluation can be considered an extension of the static conformation assessment. The author will watch the horse move in straight lines on a hard surface that offers some reliable traction for the horse. Observing the interaction of the hoof capsule and initial ground contact during locomotion can offer valuable information to the expectations of the limb in relation to medio-lateral balance. Trying to view the final milliseconds of the landing phase can offer the practitioner valuable information on how the horse is landing in a medio-lateral plane but also in an anterior/posterior arrangement.

Breaking the evaluation into 2 segments may allow the practitioner a better observation of the horse's movement and potential lameness.

The thoracic limb is generally best observed when the equine is trotting directly toward the assessor. During this assessment, interference and landing patterns of the front limbs can be noted. Lameness may be represented in asymmetric gait abnormalities, or the limb's axial or abaxial changes in limb landing and placement.

The pelvic limb is best assessed when the horse is moving away. It is during this evaluation method when hind-limb abnormalities are best represented. Conformational implications can be viewed along with lameness. Pelvic limb lameness, like other lamenesses, can be subtle and multifaceted due to the complex arrangement of the reciprocal apparatus. Viewing hip movement, or fetlock descent may offer some initial insight to any potential affected limb.

In addition to straight-line dynamic assessment, viewing the horse on a lunge line can offer insight into lamenesses that occur while the horse is performing in a circular motion. It is also during this phase of dynamic assessment that the horse may be viewed transitioning through lead changes. Abnormalities to evaluate are reluctance to initiate leads and dorso-cranial phases of stride.

To supplement dynamic evaluation, palpation of the digital pulse, located at the fetlock, can offer insight to potential inflammation. The horse's ability to enhance blood flow to the digit can be a reliable means of locating which limb is affected if inflammation is present within the capsule.

5. The Application of Therapeutic Shoes

The sustainability of a shoeing prescription must be taken into consideration when implementing any shoeing concept. This aspect of therapeutic shoeing can be one of the most challenging aspects of foot care. Manipulation of the capsule can be detrimental to the hoof capsule's structure, function, and performance if the shoeing prescription challenges the capsule's structural integrity.

The center of pressure can have a significant impact on the sustainability of a shoeing prescription.[4] The center of pressure's stationary landmark is typically 3/8 inch back from the apex of the frog, and slightly axial in placement. The center of pressure is also transient in nature when the horse is in locomotion due to the changing body mass above.

While some shoe packages are well known for their effectiveness against certain lamenesses, consideration of the effect of the center of pressure movement must be assessed in order to ensure the shoeing prescription is sustainable.

The center of pressure can affect a shoeing prescription in various ways. Pressure plate studies have indicated that the center of pressure can be manipulated through the use of graduated or wedge shoes.[7] While this aspect of hoof care can be appreciated in terms of anterior or posterior elevation, shoe modifications that alter the medio-lateral landing patterns can also inherently manipulate the center of pressure. Therefore, asymmetric shoe patterns, when used in a deformable surface, may affect the center of pressure movement.

Any shoeing prescription's effectiveness can alter when the capsule is elevated or suspended off the ground for long periods without the recruitment of other structures within the hoof capsule's solar surface.[4] The capsule's ability to resist the mechanical redirection of pressure may need to be assessed on a case-by-case, breed-by-breed basis. While some horses will adapt to change well, others may, over time, see a decline in overall foot health and quality. Indications of negative effects of the center of pressure shifts can include crushing of the heel structure, deforming wall quality, or induced medio-lateral balance issues. Poor horn structure may need to be put into a load-sharing capacity to reduce the negative effects of center of pressure movements. Incorporating the sole and frog into a load-sharing capacity may help the hoof care provider to implement therapeutic shoeing with less complications over longer durations.

When evaluating the sustainability of a shoeing prescription or concept, one must consider the entire shoeing period to offer a valid shoeing prescription. Horses that perform in a deformable substrate may experience the effects of asymmetric shoe shapes in a greater capacity depending on the depth of footing. In theory, while the asymmetrical shoe shape may be transferring energy to opposing structures, it may often also set up a passive anterior/posterior or medio-lateral capsule imbalance.

In cases where shoe modifications are employed for soft-tissue injury, in the author's opinion, veterinary diagnostics are needed to assist the therapeutic shoeing program. In cases of soft-tissue injury, repeated imaging can offer insight as to when to reduce or remove the therapeutic value of differing asymmetric shoe shapes.

6. Surface Conditions

Track and arena surfaces can offer differing amounts of shock and slide reduction. Arena surfaces can alter the slide phase of stride.[8] While the ideal amount of slide upon landing is not yet quantified, the shoeing package must offer the necessary amount of traction to allow rider safety and for the horse to perform in a controlled manner. Shoe selection can be fundamental in offering the correct amount of traction for the horse, rider, and discipline.

The level of pathology and shoe selection may need to be assessed in relation to the horse's workload. While some therapeutic shoeing modalities offer little traction but significant therapeutic value, therapeutic sport horse shoeing can be one of the more difficult shoeing modalities to navigate due to the necessity of traction. Retaining effective traction in a shoeing prescription can be achieved by ensuring concavity on the distal surface of the shoeing package.[4]

Alternative methods of adding therapeutic value to a shoeing can include the use of temporary orthotics, bar shoes, or stabilizer pads that are welded or riveted into place.

7. Summary

While historically the farrier's role in foot care has been widely accepted as a means of maintenance and capsule protection, it can also be a valid and effective means of lameness management.

New information in the form of force plate studies coupled with revised biomechanical principles has seen a near revolution in farriery in the past decade. The review of these principles with attention to the hoof capsule's response to conformation, disease, and pathology may be the most effective means of veterinary and farrier response to lameness.

As an accompaniment to distal limb imaging and sports medicine, therapeutic shoeing can be an effective means of addressing equine lameness, ensuring that the shoeing prescription is detailed, is essential to success.

For farriers, the detection of the smallest of details may contraindicate standardized approaches to widely accepted equine foot care. This element of farriery may be one of the defining aspects of the craft. Therefore, the interpretation of the capsule's overall health, integrity, and conformation should be taken into consideration when therapeutic cases are presented or being reevaluated.

Acknowledgments

Declaration of Ethics

The Author has adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Author has no conflicts of interest.

References

1. Hickman J, Humphrey M. *Hickmans farriery*. 2nd ed. London, UK: J.A. Allen & Co, Ltd; 1988.
2. Curtis S. *Corrective farriery: A textbook of remedial horseshoeing volume 2*. Newmarket, UK: R&W Communications; 2006.
3. Duckett D. The external reference points of the equine hoof. Self published paper; 2008.
4. Morrison M. The Thoroughbred racehorse foot: Evaluation and management of common problems, in *Proceedings*. Am Assoc Equine Pract 2013;59:443–451.
5. Bowker R. Contrasting structural morphologies of "good" and "bad" footed horses, in *Proceedings*. Am Assoc Equine Pract 2003;49:186–209.
6. Ramey P. Care and rehabilitation of the equine foot. 1st ed. Georgia: Hoof Rehabilitation Publishing, LLC; 2011.
7. Colhan P, Leach D, Muir, G. Centre of pressure location of the hoof with and without hoof wedges. *Equine Exercise Physiol* 1991;3:113–119.
8. McClinchey HL, Thomason JJ, Runciman RJ. Grip and slippage of the horse's hoof on solid substrates measured ex vivo. *PeerJ* 2016;4:e2164.

Inhaled Ciclesonide in Horses with Severe Equine Asthma: Results of a Large Prospective European Clinical Trial

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Inhaled ciclesonide, a corticosteroid prodrug, has been shown to be an effective and safe treatment for horses with experimentally-induced equine asthma exacerbations; however, the efficacy and safety of this approach has not yet been reported under field conditions. Authors' addresses: Royal (Dick) School of Veterinary Studies, University of Edinburgh, Easter Bush Veterinary Centre, Roslin EH25 9RG (Pirie); Boehringer Ingelheim Pharma GmbH & Co KG, 55216 Ingelheim, Germany (Mueller); Boehringer Ingelheim Vetmedica GmbH, 55216 Ingelheim, Germany (Engel, Albrecht, von Salis-Soglio). e-mail: scott.pirie@ed.ac.uk. *Corresponding and presenting author.

1. Introduction

The purpose of this study was assess the efficacy and safety of ciclesonide, administered via a novel equine-specific non-pressurized inhaler[a], in horses with severe equine asthma (sEA) under field conditions.

2. Materials and Methods

This is a prospective, multicenter, placebo-controlled, randomized, double-blinded study. Two-hundred and twenty-four client-owned horses with clinical signs of sEA were randomized (1:1 ratio) to receive an inhaled ciclesonide (343 μg/actuation) solution or placebo (0 μg/actuation) via the inhaler[a] for a total of 10 days, 8 actuations q12h for 5 days, followed by 12 actuations q24h for 5 days. The primary outcome was a success/failure analysis, with treatment success defined as a $\geq$30% reduction in weighted clinical score between day 0 and day 10 $\pm$ 1. Additionally, owner-perceived improvements in Quality of Life (QOL) were assessed at days 5 $\pm$ 1 and 10 $\pm$ 1.

3. Results

At day 10 $\pm$ 1, the treatment success rate was significantly ($P < 0.0001$) greater in ciclesonide-treated horses (73.4% [80/109]) than in the placebo group (43.2% [48/111]). At day 5 $\pm$ 1 and day 10 $\pm$ 1, improvement in QOL was significantly greater ($P <$ 0.0001 and P = 0.0001, respectively) in the ciclesonide-treated horses (60.2% and 69.3%, respectively) than in the placebo group (32.7% and 43.4%, respectively). The overall number of adverse events (AEs) was low, with no serious AEs, and was equally distributed between the groups.

Research Abstract—for more information, contact the corresponding author

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4. Discussion

Despite the markedly superior clinical efficacy of ciclesonide relative to the placebo, a "placebo effect" was identified, which likely contributed in part to the clinical improvement observed in the ciclesonide-treated group. Ciclesonide inhalation solution administered by the inhaler[a] was well tolerated and effective at reducing clinical signs and improving QOL in severely asthmatic horses.

Acknowledgments

Declaration of Ethics

The Authors have adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

This publication followed the GPP3 guidelines. Drs. Engel, Albrecht, and von Salis-Soglio are employees of Boehringer Ingelheim Vetmedica GmbH, the marketing authorization holder of Aservo Equihaler with ciclesonide as active ingredient. Dr. Mueller is an employee of Boehringer Ingelheim Pharma GmbH & Co KG. Dr. Pirie has acted as consultant to Boehringer Ingelheim Vetmedica GmbH. Dr. Albrecht is co-inventor on a patent regarding the use of ciclesonide in horses.

Footnote

[a]Soft Mist™ inhaler, EquiHaler®, Boehringer-Ingelheim.

A Retrospective Study of Exercise-Induced Pulmonary Hemorrhage and Asthma in Barrel Racing Horses in Texas

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Exercise-induced pulmonary hemorrhage (EIPH) and asthma in barrel racing horses is a common disease across the United States. Bronchoalveolar lavage (BAL) of horses suspected of EIPH is warranted to fully characterize the noninfectious respiratory disease of performance horses. Authors' addresses: Kindred Biosciences, 1555 Bayshore Hwy, Ste 200, Burlingame, CA 94010 (Sundman); Texas Tech University School of Veterinary Medicine, 7671 Evans Drive, Amarillo, TX 79106 (Hunyadi); University of California-Davis, School of Veterinary Medicine, Davis, CA 95616 (Chigerwe); e-mail: emilysundman@hotmail.com. *Corresponding author; †presenting author.

1. Introduction

This study was to evaluate the bronchoalveolar lavage (BAL) fluid cytological results of barrel racing horses with exercise-induced pulmonary hemorrhage (EIPH), asthma, or both.

2. Materials and Methods

A retrospective study was conducted of 95 horses diagnosed with noninfectious respiratory disease and BAL results at a private practice in Texas.

3. Results

EIPH only was diagnosed in 28/95 (30%) BAL samples, asthma only was diagnosed in 25/95 (26%) BAL samples, and EIPH and asthma was diagnosed in 42/95 (44%) BAL samples. A history of EIPH was not predictive of a diagnosis of EIPH or asthma. Of the BAL results consistent with asthma only, the primary elevated cell type was mast cell; followed by samples with both elevated eosinophils and mast cells. No cytological differences in frequency of elevated inflammatory cell types were found between horses diagnosed with EIPH and those without a diagnosis of EIPH.

4. Discussion

The study showed a substantial percentage (44%) of the horses examined had evidence of both EIPH and asthma on BAL cytologic evaluation. Comorbidities of EIPH and asthma is a common diagnosis in barrel racing horses in this study.

Acknowledgments

Declaration of Ethics

The Authors have adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Authors have no conflicts of interest.

Research Abstract—for more information, contact the corresponding author

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Neonatal Dysphagia and Racing Performance in Standardbreds Born Near Unconventional Natural Gas Development Activity

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A clustering of dysphagic foal cases occurred on a Pennsylvania Standardbred farm located in an area of active unconventional natural gas development. Increased concentrations of polycyclic aromatic hydrocarbons were found in the well water. Racing performance of the formerly dysphagic foals was not impacted. Authors' addresses: Littleton Equine Medical Center, 8025 S Santa Fe Drive, Littleton, CO 80120 (Mullen), Cornell University, College of Veterinary Medicine, 602 Tower Road, Ithaca, NY 14853 (Delvescovo, Ainsworth); Valley Agricultural Software, King Ferry, NY 13081 (Eicker); e-mail: kmullen@littletonequine.com. *Corresponding and presenting author.

1. Introduction

The authors were unaware of studies examining environmental exposures, neonatal dysphagia and athleticism. Foals born on the affected Pennsylvania (PA) farm and an unaffected New York (NY) farm owned by the same proprietor were evaluated. Dams either spent their entire 11-month gestation on one farm or moved to the other farm in late gestation.

2. Materials and Methods

A comprehensive investigation of equine physiological parameters and environmental chemical exposures (2014–2016), and racing performance of foals born (2012–2017) on the PA and NY farms was performed.

3. Results

Seventeen of 65 foals born (2014–2016) were dysphagic; all on the PA farm. Odds of dysphagia increased with the dam residing on the PA farm for each additional month of gestation. Colts were more likely to be dysphagic. Prior to installation of a water filtration system, PA water concentrations of 3,6-dimethylphenanthrene, fluoranthene, pyrene, and triphenylene exceeded those in NY. On the PA farm, 13/24 normal and 13/18 dysphagic foals raced; 47/67 normal NY foals raced. There were no differences in the percentage to race, or earnings per start or speed indices between dysphagic and normal foals.

4. Discussion

Evidence showed an increased prevalence of dysphagia in foals born near unconventional natural gas development, which did not impact subsequent racing performance.

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Declaration of Ethics

The Authors have adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Authors have no conflicts of interest.

Practical Clinical Research Results to Consider When Testing for PPID in Horses

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1. Introduction

Thyrotropin-releasing hormone (TRH) stimulation of adrenocorticotropic hormone (ACTH) has become a common method for diagnosis of pituitary pars intermedia dysfunction (PPID).[1] When testing for PPID, factors to consider include repeatability of testing during the year,[2] time requirements for centrifugation after blood collection,[3] effects of stress on basal ACTH concentrations, the duration of efficacy of thawed TRH after it has been frozen for storage, and the stability of ACTH concentration after freezing. All of these factors potentially may affect test results and were investigated to aid practitioners to obtain consistent reliable results when testing for PPID in horses.

2. Duration of Effectiveness of Frozen/Thawed TRH to Stimulate ACTH Release in Horses

Introduction

Many equine practitioners freeze single doses of TRH following removal of a single dose from a multidose vial. Typically, prior to use, the TRH is thawed and taken to the farm to be used when testing a potential PPID horse. If the horse owner declines testing, the veterinarian has TRH that has been frozen and thawed. Anecdotally, TRH can only be frozen and thawed once for an optimum and consistent response. The potency and stability over time of TRH after one freeze/thaw cycle is unknown. This study was designed to determine the duration of effectiveness of TRH in horses following one freeze/thaw cycle when stored at 5°C over time.

Materials and Methods

The TRH stimulation test used in each of these studies was conducted as follows: blood was collected into a purple top tube[a] for basal ACTH (T0-ACTH) followed by IV administration of 1 mg TRH[b] (1 mL). Blood was then collected exactly 10 minutes post-TRH administration (T10-ACTH). Blood samples were centrifuged and plasma was frozen at −80°C until ACTH analysis using a chemiluminescent immunoassay at the Animal Health Diagnostic Laboratory, Cornell University, Ithaca, NY. Determination of positive, negative, and equivocal status for PPID was according to the 2019 Equine Endocri-

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nology Group recommendations for the diagnosis and treatment of PPID.

Ten horses ($PPID^+$ and $PPID^-$) were enrolled, mean age, 18.8 years (range, 12–25 years). Horses were first paired by PPID status and randomized into 2 groups of 5 horses (each group contained 4 $PPID^-$ and 1 $PPID^+$). Thirty 1-mg/mL doses of constituted TRH were frozen (−20°C) 28 days prior to testing. Fourteen days prior to testing, ten doses of TRH were thawed and kept at 5°C until administration. The remaining 20 doses of TRH were thawed on the first day of testing (Day 0) and stored at 5°C until administration. On Day 0, all horses were TRH stimulation tested using TRH thawed same day. The TRH stimulation procedure was repeated post-thaw on Days 14, 28, 42, and 56. In order to avoid potential carryover effects of multiple TRH stimulation procedures administered every 2 weeks, horses in Group 1 had the TRH stimulation repeated on Days 14 and 42 (post-thaw TRH), whereas Group 2 horses had the TRH stimulation repeated on Days 28 and 56 (post-thaw TRH). All T10-ACTH samples were centrifuged following collection and plasma frozen (−80°C) until analysis at Cornell Animal Health Diagnostic Center. Data were analyzed using a mixed model with repeated measures to compare T10-ACTH and the percent increase (T0-ACTH to T10-ACTH) of ACTH after TRH stimulation, using horse as the subject and day as the repeated effect. Pearson's correlation coefficients were used to examine relationships, and Bland-Altman plots were constructed to compare T10-ACTH on Days 14, 28, 42, and 56 to the T10-ACTH on Day 0.

Results

There was no effect of Group ($P > .25$), so when appropriate, data were combined for analysis. There was no effect of day post-thaw on T10-ACTH ($P = .13$) or the percent increase of T0-ACTH to T10-ACTH after TRH stimulation ($P = .36$). Pearson's correlation coefficients indicated strong relationships between T10-ACTH on day 0 and all other days ($R > 0.98$, $P < .001$). Bland-Altman plots indicated an average day bias of 9.4 pg/mL in all horses compared to day 0, with 95% limits of agreement at −38.8 to 57.4 pg/mL.

Discussion

In this study, the TRH stimulation procedure produced repeatable ACTH concentrations in samples collected 10 minutes after administration of TRH in horses when using TRH that had been frozen, thawed, and stored at 5°C for up to 56 days.

3. The Effect of Trailering and Dentistry on Resting Adrenocorticotropic Hormone Concentration in Horses

Introduction

Several studies have concluded that pain, stress, and concurrent illness were only likely to affect diagnostic usefulness of resting ACTH when severe.[4] The objective of this study was to identify whether trailering or teeth floating (common stressful situations/procedures) increase plasma ACTH levels in horses that might interfere with testing for PPID.

Materials and Methods

Twelve PPID-negative horses were randomized into 3 groups of 4 horses per group. Each group was randomly assigned to an initial treatment: dentistry (DN), trailered (TR), or stabled controls (CN). Following initial treatment, each horse group was randomly assigned to each of the two remaining treatment groups; thereby, each horse group underwent all three treatments. Plasma was collected from all horses prior to each treatment and used as the baseline basal ACTH. The DN horses were placed in stocks, sedated with 0.1 to 0.3 mg/lb xylazine IV, and following mouth speculum placement, teeth were floated[c]. The TR group was loaded on a 6-horse slant trailer and hauled for 40 minutes. Immediately following the dental procedure and trailer ride, post-procedure (P0) plasma samples were collected. Plasma samples were then collected from all horses at 15, 30, 60, and 120 minutes post-procedure. Plasma P0 samples from the CN horses were taken when the TR horses returned. Plasma samples were frozen (−80°C) until analysis at Cornell Animal Health Diagnostic Center. Data were confirmed for normality using the Shapiro-Wilk statistic, and then analyzed using a mixed model with repeated measures (i.e., each horse as its own control), with main effects of treatment (CN, DN, TR) and time, and day × time as the repeated effect. Statistical significance was designated at $P < .05$. Data were summarized as mean ± SE.

Results

No change occurred in ACTH over time in the CN or DN horses ($P = .14$). ACTH was higher in TR compared to CN ($P = .026$) and DN ($P = .016$) horses. In TR horses, ACTH was higher than baseline (PRE) immediately after trailering (T0; $P = .0003$). By 30 minutes post-trailering, as a group, there were no differences in mean basal ACTH compared to PRE concentrations ($P = .55$). One horse in the study maintained elevated ACTH concentrations until the 120-minute time point.

No significant difference in resting ACTH concentrations over time was observed in horses undergoing dentistry procedures compared to baseline. A 40-minute trailer ride resulted in significantly increased basal ACTH concentrations in horses up to 30 minutes post-unloading.

Discussion

In these horses, collecting blood within 30 minutes (in all horses) and up to 120 minutes (in one horse) after trailering resulted in elevated resting ACTH concentrations that could interfere with PPID testing. Based on results of this study, blood should not be collected for resting ACTH concentration determination for at least 30 minutes after trailering.

4. TRH Repeatability in PPID-Negative and PPID-Positive Horses

Introduction

Even though TRH stimulation of ACTH has been used as a diagnostic test for equine PPID, it is unknown whether the T10-ACTH response to TRH is repeatable in individual horses. The purpose of this study was to conduct TRH stimulation tests at 4-week intervals, beginning in February and ending in June, in horses with and without PPID to determine the repeatability of the T10-ACTH, over time.

Materials and Methods

Twelve horses, 5 PPID positive ($PPID^{+}$), 5 PPID negative ($PPID^{-}$), and 2 PPID equivocal with a mean age of 18.8 years (range, 12 to 25 years) were enrolled. Basal ACTH concentration from blood collected in January was used to identify PPID status of each horse. The TRH stimulation procedure was performed on day 0 (February 13) and repeated on Days 28, 56, 84, and 112. The subsequent samples were compared to the T10-ACTH samples collected on Day 0. Data were confirmed for normality using the Shapiro-Wilk statistic, and then analyzed using a mixed model with repeated measures to compare T10-ACTH and the percent increase of ACTH after TRH stimulation, using horse as the subject and day as the repeated effect. Pearson's correlation coefficients were used to examine relationships between T10-ACTH on days 28, 56, 84, and 112 to T10-ACTH on day 0. Bland-Altman plots were constructed to compare T10-ACTH on Days 28, 56, 84, and 112 to the T10-ACTH on Day 0.

Results

The mean basal ACTH in $PPID^{-}$ horses was 17.6 ± 0.7 pg/mL and 61.4 ± 9.2 pg/mL (T10-ACTH), with a 349 ± 41% increase in T10-ACTH after TRH stimulation. The mean basal ACTH in $PPID^{+}$ horses was 43.5 ± 3.6 pg/mL (basal) and 410 ± 58 pg/mL (T10-ACTH), with a 948 ± 194% increase in T10-ACTH after TRH stimulation. Repeated measures analysis indicated no effect of day on T10-ACTH (P = .40), or the percent increase of T10-ACTH after TRH stimulation (P = .12). Pearson's correlation coefficients indicated strong relationships between T10-ACTH on Day 0 and all other days ($R > 0.70$, $P < .01$). Bland-Altman plots indicated an average day bias of 27 pg/mL in all horses compared to day 0, with a day bias of 10 pg/mL in $PPID^{-}$ (with 95% limits of agreement at −101 to 122 pg/mL) and 43 pg/mL in $PPID^{+}$ (with 95% limits of agreement at −493 to 581 pg/mL) horses. The Immulite intra-assay CV was 9.3%, which accounts for most of the observed day bias.

Discussion

The TRH stimulation procedure produced repeatable ACTH concentrations in samples collected 10 minutes after administration of TRH in horses collected at 4-week intervals over 112 days from February through June. Observed variation of T10 ACTH over the duration of the study resulted in 2/5 PPID negative horses classified as positive, once and twice, respectively. Additionally, the T10 ACTH in 1/5 PPID positive horses tested equivocal at one time point. The results of this study stress the importance of using the combination of owner history, clinical signs, and laboratory data when determining the proper diagnosis of PPID.

5. Effect of Delayed Plasma Centrifugation on Equine ACTH Concentration

Introduction

If stored at room temperature (21°C), ACTH level in blood decreased soon after collection.[6] Multiple recommendations exist for the timing of centrifugation of chilled samples from sample collection. In the United States, a discordance exists between laboratory recommendations concerning centrifugation time from sample collection. Realistically, many equine ambulatory practitioners do not have the ability to centrifuge the sample within 2 to 4 hours. This study was conducted in order to determine the length of time whole blood can be stored refrigerated prior to centrifugation and maintain accurate ACTH concentration.

Materials and Methods

On day 0, 5 mL of whole blood from each of 10 horse (Five PPID positive and 5 PPID negative) was collected into each of 6 ethylenediaminetetraacetic acid (EDTA) tubes and immediately placed in a refrigerator at 7°C. One tube from each horse was centrifuged within 15 minutes of collection, followed by centrifugation of one tube from each horse at 4, 8, 12, 24, and 36 hours following collection. At each time, centrifuged plasma was pipetted into 1.5 mL polypropylene tubes and stored at −80°C. None of the plasma samples were turbid, hemolyzed, or icteric. Plasma was shipped frozen with cold packs overnight to the Animal Health Diagnostic Center of Cornell University in Ithaca, NY for analysis. The percent change from baseline (PCFB) was reported to standardize the data given that baseline values differed.

Results

The absolute changes over time revealed no pattern of variation. The mean PCFB was 2.8% ± 7.96% (95% CI,: –2.9%, 7.0%). There was no evidence of significant time effect from the repeated measures model with a P-value of .5056. There was no evidence of significant time effect on the level of ACTH in PPID positive or PPID negative horses. Three of 10 enrolled horses exhibited variation in ACTH concentration at 1 time point that changed the diagnostic interpretation of PPID status from PPID negative to equivocal, PPID positive to equivocal and PPID negative to equivocal, respectively. In 2 of the 3 horses, the variation was less than the intra-assay variability (9.3%) whereas the ACTH was increased 16.7% in the third horse.

Discussion

This work demonstrated that refrigeration (4°C) of whole blood for up to 36 hours prior to centrifugation and freezing did not significantly affect plasma ACTH concentrations. Laboratory diagnostic results alone should not be utilized to classify a horse as PPID positive or negative. The history and clinical signs in conjunction with laboratory diagnostic results should always be utilized for the diagnosis of PPID.

6. Effect of Various Freezing Protocols on ACTH Plasma Concentration

Introduction

ACTH has been reportedly understood to be fragile in whole blood samples and is affected by heat and time spent on erythrocytes prior to centrifugation.[7,8] Equine ACTH has been shown to be stable without centrifugation for up to 8 hours stored at 21°C or 4°C[6] and was stable in plasma stored at −20°C and −80°C for 30 days.[6] If plasma samples cannot be shipped the day of collection to the respective laboratory, plasma should be frozen until shipment. It is imperative for the veterinarians to understand if freezing plasma has any negative effects on the stability of equine basal ACTH concentration. The objective of the study was to determine the stability of ACTH in plasma after freezing for different lengths of time prior to determination of basal ACTH concentration.

Materials and Methods

Twelve horses (5 mares, 6 geldings, and 1 stallion) ranging in age from 14 to 29 years from the Middle Tennessee State University herd were screened for ACTH in May with levels found to range from 12.4 pg/mL to 62.0 pg/mL (10 horses < 30 pg/mL = negative, >2 horses 50 pg/mL = positive). In September, 1.0 mg of TRH[a] suspended in 1 mL of saline was administered intravenously to the same 12 horses. Ten minutes later, blood samples were collected in EDTA tubes and refrigerated at 5°C until centrifuged at 1000×*g* for 10 minutes within 2 hours of collection. Plasma was stored in microcentrifuge tubes and frozen for variable lengths of time and conditions. Basal ACTH concentrations were measured at day 0. Plasma samples were stored at −80°C for 3, 7, 30, 60, and 90 days, or stored at −20°C for 3, 7, 30, and 60 days, or stored between ice packs in a freezer to mitigate fluctuation of temperature due to opening and closing of the freezer door at −20°C for 3 and 7 days prior to determination of basal ACTH concentration. Plasma was shipped frozen with cold packs overnight to the Animal Health Diagnostic Center, Cornell University, Ithaca, NY. Samples were batch analyzed for plasma ACTH concentration determined by chemiluminescent immunoassay previously validated for horses. ACTH concentrations were compared to baseline (non-frozen day 0 plasma) for each storage method using a mixed model with repeated measures in which each horse served as its own control and day was the repeated effect. Statistical significance was set at $P \leq .05$.

Results

Mean basal ACTH concentration on day 0 for plasma stored at −80°C was 392.2 pg/mL that declined 6.9% to a low of 365.0 pg/mL by day 90 ($P = .047$). Through day 60, the PCFB never varied more than 2% and was not different ($P > .62$) from day 0. On day 90, the PCFB was −6.9% and different from baseline ($P = .030$). Across the 90-day storage, overall degradation was observed ($P = .034$).

Mean basal ACTH concentration on day 0 for plasma stored at −20°C was 392.2 pg/mL that declined 5.3% to 371.4 pg/mL by day 60. The ACTH concentrations at day 0 and day 60 were not different ($P = .18$). The PCFB was lower by day 60 ($P = .035$). Across the 60-day storage, degradation was observed at −20°C ($P = .004$).

Mean basal ACTH concentration at day 0 for plasma stored between ice packs at −20°C was 392.2 pg/mL that declined 1.1% to 387.9 pg/mL by day 7. No degradation of basal ACTH was observed by day 7 in either the ACTH concentrations ($P > .36$) or the PCFB ($P > .24$).

Discussion

In a practice situation, it is unlikely that samples would be held for more than just a few days. This work shows that keeping frozen plasma stored in an ordinary household refrigerator freezer without keeping it between ice packs to reduce temperature fluctuation is sufficient to preserve testing reliability. For research or epidemiologic purposes, it should be considered that after 60 days ACTH levels declined when stored at −80°C.

7. Conclusions

TRH that has been frozen and thawed (once) was effective for at least 56 days when TRH was kept refrigerated after thawing. Trailering horses for 40 minutes increased basal ACTH for at least 30 minutes (and up to 120 minutes in one horse) post trailering. Results of T10 ACTH from TRH stimulation testing was repeatable from January through early June in the United States (Latitude 35° 50′ 44" North). Basal ACTH concentration determination is reliable from whole blood that has been refrigerated for up to 36 hours prior to centrifugation. Plasma samples for ACTH determination can be frozen in a refrigerator freezer at −20°C, for up to 30 days or up to 60 days at −80°C with no decrease in ACTH concentration.

Acknowledgments

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Declaration of Ethics

The Authors have adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

Authors S.T. Grubbs, K.N. Shepard, and D.L. Neal are employees of Boehringer Ingelheim Animal Health USA, Inc.

Authors J.C. Haffner and R.M. Hoffman are employees of Middle Tennessee State University.

Animal Care and Use

These studies were conducted by permission of Middle Tennessee State University Institutional Animal Care and Use Committee by protocols 19-2005, 19-2008, 19-2004, 17-2002, and 17-2013.

References and Footnotes

1. Horn R, Bertin FR. Evaluation of combined testing to simultaneously diagnose pituitary pars intermedia dysfunction and insulin dysregulation in horses. *J Vet Intern Med* 2019;33: 2249–2256.
2. Copas VE, Durham AE. Circannual variation in plasma adrenocorticotropic hormone concentrations in the UK in normal horses and ponies, and those with pituitary pars intermedia dysfunction. *Equine Vet J* 2012;44:440–443.
3. Shepard KN, Haffner JC, Neal DL, et al. Effect of delayed plasma centrifugation on equine adrenocorticotropic hormone concentration. *J Vet Diagn Invest* 2019;31:585–587.
4. Durham AE. Endocrine disease in aged horses. *Vet Clin Equine Pract* 2016;32:301–315.
5. Rosner B. Guidelines for judging the significance of a *P*-value. *Fundamentals of biostatistics*. 8th ed. Boston, MA: Cengage Learning; 2016, 219.
6. Prutton JSW, Kass PH, Watson JL, et al. Pre-analytical stability of adrenocorticotrophic hormone from healthy horses in whole blood, plasma and frozen plasma samples. *Vet J* 2015; 204:123–124.
7. Reisch N. Preanalytical stability of adrenocorticotropic hormone depends on time to centrifugation rather than temperature. *Clin Chem* 2007;53:358–359.
8. Rendle DI, Litchfield E, Gough S, et al. The effects of sample handling and N-phenylmaleimide on concentration of adrenocorticotrophic hormone in equine plasma. *Equine Vet J* 2015; 47:587–591.

[a]Vacutainer®, Becton, Dickinson and Company, Franklin Lakes, NJ 07417-1880.

[b]Thyrotropin-releasing hormone, Sigma-Aldrich, Inc., Bellefonte, PA 16823-0048.

[c]PowerFloat®, Calgary, AB T2C 5S7, Canada.

Review: Optimizing the Efficacy of Oral Omeprazole

Ben Sykes, BSc, BVMS, MS, MBA, DACVIM, DECEIM, PhD

Oral omeprazole is the cornerstone of equine gastric ulcer syndrome treatment. To optimize its efficacy, it should be administered after a brief, overnight starvation period with the horse fed a roughage-based meal 60 to 90 minutes later. To reduce the impact of drug-drug interactions, any concurrent medications should be administered at the time of feeding. Author's addresses: Equine Clinic, Massey University, Palmerston North 4474, New Zealand; Veterinary Postgraduate Unit, University of Liverpool, Neston L69 3BX, United Kingdom; e-mail: b.sykes@massey.ac.nz.

1. Introduction

Acid-suppressive therapy is the cornerstone for treatment of equine gastric ulcer syndrome.[1] The efficacy of oral formulations for the treatment of equine squamous gastric disease is well documented,[2–4] although it has been demonstrated that monotherapy with oral omeprazole is less efficacious for the treatment of equine glandular gastric disease (EGGD).[5–7] However, a recent study with a long-acting, injectable formulation of omeprazole reported high healing rates for EGGD with acid suppression alone.[8] This reinforces the need to optimize the efficacy of oral omeprazole for the treatment of both equine squamous gastric disease and EGGD. However, despite its widespread use, until recently little attention has been given to the factors that affect efficacy of oral omeprazole. The purpose of this article is to discuss these factors with specific focus on the role that diet, feeding, and administration of concurrent medications play. The review is based on the published, peer-reviewed literature.

2. Materials and Methods

Feeding has significant impact on both the bioavailability and acid-suppressive capacity of oral omeprazole. When compared with administration on an empty stomach, the feeding of *ad-libitum* hay reduces the bioavailability of oral omeprazole by 50% to 66%.[9–11] This decreased bioavailability is reflected in a decreased acid-suppressive capacity such that the average percentage of time each day that the pH exceeds 4 within the ventral stomach was less than 40% in one study, even at a dose of 4 mg/kg PO q24h.[12] Although the benchmark for healing in horses is not known, in humans the percentage time that pH should exceed 3 or 4 is 66% for glandular and squamous disease, respectively,[13] meaning that the average effect achieved under *ad-libitum* feeding conditions in horses is likely to be subtherapeutic in many animals. Further, in the group receiving *ad-libitum* hay, minimal, if any acid suppression was observed over a 5-day period in 3/6 animals at the same dose.[12]

The timing of feeding is also important in maximizing oral omeprazole's efficacy. Horses are considered constant acid secretors, but there is a significant prandial component to the pattern of gastrin release.[14] Proton pump inhibitors are prodrugs that require the parietal cell to be activated for the prodrug to be converted to its active form,

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and thus to inhibit acid secretion. Coinciding the timing of feeding, and as such peak gastrin concentration, with peak plasma drug concentrations is expected to maximize the number of proton pumps inhibited with any given dose. Maximal serum concentration occurs at around 45 to 90 minutes[10,11,15,16] and it is important that feeding occurs within this period.

Lastly, the type of meal may be important. Gastric distention plays a role in gastrin release with larger amounts of gastrin released more rapidly in response to voluminous, roughage-based meals when compared with smaller grain meals.[14]

3. Results

Combining the effects of overnight fasting, the timing of feeding, and the type of feed given, the author recommends the following approach to optimizing the efficacy of oral omeprazole:[17]

- Withhold feed from 10:00 pm the evening before (or limit evening feeding such that the evening meal is consumed by 10:00 pm).
- Administer omeprazole orally at 6:00 to 7:00 am.
- Feed 60 to 90 minutes later. The feed at this time should consist of 1 to 2 large flakes of alfalfa hay or a highly palatable roughage substitute, followed by concentrate feeding (if necessary).

The impact of concurrent administration of other medications should also be considered. In other species, sucralfate has been shown to decrease the bioavailability of omeprazole. As such, sucralfate should not be given at the same time as omeprazole. Instead, the timing of its administration should be alongside the morning and evening feeding. Lastly, other acid suppressive drugs such as ranitidine (and other H_2-receptor antagonists), or misoprostol (a parietal cell PGE_2-receptor agonist), should not be administered concurrently as they reduce activation of the proton pump and, in turn, decrease the rate of conversion of the omeprazole prodrug to its active form. If drugs such as misoprostol are going to be administered concurrently, then timing should be offset similarly to the administration of sucralfate.

4. Discussion

The technique described above is relatively easily implemented in many stables where horses are normally stalled overnight. The main drawback of the approach is the negative perception of owners of having the horse off feed overnight, particularly because the *ad-libitum* provision of feed has been considered a cornerstone of equine gastric ulcer syndrome prevention for many years. However, the author views this approach as one that reinforces the natural behavioral tendency for horses to fast overnight,[18,19] and one that simply ensures that drug administration occurs prior to the horse eating in the morning. It is also important to consider that, although the horse is not eating for 8 to 10 hours overnight, the stomach is only empty for a relatively short part of this period. Importantly, the advantage of the above approach is to maximize absorption and efficacy of oral omeprazole, which in turn is expected to optimize its efficacy.

5. Conclusion

The enforcement of small management changes during the treatment period with oral omeprazole can result in significantly longer durations of intra-day acid suppression, and in turn optimize the efficacy of oral omeprazole. Further, an awareness of the potential for drug-drug interactions can also optimize the likelihood of a positive therapeutic outcome.

Acknowledgments

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Declaration of Ethics

The Author has adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Author is employed by Massey University and The University of Liverpool. In the past 3 years he has worked in a paid capacity, either as a consultant, employee, or paid speaker for Bova Australia, Bova UK, Luoda Pharma, Virbac, Dechra, Kelato, Purina Animal Nutrition, and Prydes Australia, all of whom have products in their portfolio related to gastrointestinal health.

References

1. Sykes BW, Hewetson M, Hepburn RJ, et al. European College of Equine Internal Medicine—Consensus statement equine gastric ulcer syndrome (EGUS) in adult horses. *J Vet Intern Med* 2015;29:1288–1299.
2. Andrews FM, Sifferman RL, Bernard, et al. Efficacy of omeprazole paste in the treatment and prevention of gastric ulcers in horses. *Equine Vet J* 1999;31:81–86.
3. Lester GD, Smith RL, Robertson ID. Effects of treatment with omeprazole or ranitidine on gastric squamous ulceration in racing Thoroughbreds. *J Am Vet Med Assoc* 2005;227: 1636–1639.
4. MacAllister CG, Sifferman RL, McClure SR, et al. Effects of omeprazole paste on healing of spontaneous gastric ulcers in horses and foals: a field trial. *Equine Vet J* 1999;31:77–80.
5. Sykes BW, Sykes K, Hallowell GD. A comparison of three doses of omeprazole in the treatment of gastric ulceration in the horse: A randomised, blinded clinical trial. *Equine Vet J* 2015;47:285–290.
6. Sykes BW, Sykes K, Hallowell GD. A comparison between pre- and post-exercise administration of omeprazole in the treatment of EGUS: A randomised, blinded clinical trial. *Equine Vet J* 2014;46:422–426.

7. Sykes BW, Sykes K, Hallowell GD. A comparison of two doses of omeprazole in the treatment of EGUS: A blinded, randomised, clinical trial. *Equine Vet J* 2014;46:416–421.
8. Sykes BW, Kathawala K, Song Y, et al. Preliminary investigations into a novel, long-acting, injectable, intramuscular formulation of omeprazole in the horse. *Equine Vet J* 2017;49:795–801.
9. Daurio CP, Holste JE, Andrews FM, et al. Effect of omeprazole paste on gastric acid secretion in horses. *Equine Vet J* 1999;31:59–62.
10. Sykes BW, Underwood C, McGowan CM, et al. The effect of feeding on the pharmacokinetic variables of two commercially available formulations of omeprazole. *J Vet Pharm Ther* 2015;38:500–503.
11. Sykes BW, Underwood C, McGowan CM, et al. The effects of dose and diet on the pharmacokinetics of omeprazole in the horse. *J Vet Pharm Ther* 2017;40:172–178.
12. Sykes BW, Underwood C, Greer R, et al. The effects of dose and diet on the pharmacodynamics of omeprazole in the horse. *Equine Vet J* 2017;49:1–7.
13. Bell NJV, Burget D, Howden CW, et al. Appropriate acid suppression for the management of gastro-oesophageal reflux disease. *Digestion* 1992;51:59–67.
14. Sandin A, Girma K, Sjöholm B, et al. Effects of differently composed feeds and physical stress on plasma gastrin concentration in horses. *Acta Vet Scand* 1998;39:265–272.
15. Sykes BW, Underwood C, McGowan CM, et al. Pharmacokinetics of intravenous, plain oral and enteric-coated oral omeprazole in the horse. *J Vet Pharm Ther* 2015;38:130–136.
16. Sykes BW, Underwood C, McGowan CM, et al. Pharmacokinetics and bioavailability of five commercially available formulations of omeprazole. *J Vet Pharm Ther* 2016;39:78–83.
17. Sykes BW. Courses for horses: Rethinking the use of proton pump inhibitors in the treatment of equine gastric ulcer syndrome. *Equine Vet Educ* 2019;31:441–446.
18. Ellis AD, Redgate S, Zinchenko S, et al. The effect of presenting forage in multi-layered haynets and at multiple sites on night time budgets of stabled horses. *Appl Anim Behav Sci* 2015;165:88–94.
19. Husted L, Sanchez LC, Baptiste KE, et al. Effect of a feed/fast protocol on pH in the proximal equine stomach. *Equine Vet J* 2009;41:658–662.

Ureterolithiasis in 15 Horses: Clinical and Ultrasonographic Findings

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Ureterolith diagnosis required transrectal ultrasound. Horses showed variable presenting complaints. Multifocal uroliths and significant renal disease were common. Authors' addresses: William R. Pritchard Veterinary Medical Teaching Hospital (Dillenbeck); Department of Surgical and Radiological Sciences (Whitcomb, Vaughan, Katzman), Department of Medicine and Epidemiology (Magdesian), School of Veterinary Medicine, University of California-Davis, Davis, CA, 95616; e-mail: lindadillenbeck@hotmail.com. *Corresponding and presenting author.

1. Introduction

Urolithiasis of the bladder and kidneys is well described. Ureterolithiasis has been infrequently reported.

2. Materials and Methods

Medical records of horses that underwent transcutaneous (renal) and transrectal (ureteral/bladder) ultrasound from 2002–2019 were reviewed. Horses with ureteral calculi were included.

3. Results

Ureteroliths were identified in 15 horses, including 10 geldings, 1 stallion, and 4 mares, ranging from 4–35 years old (median, 20 years). Presenting complaints included inappetence ($n = 6$), abnormal urination (5), colic (4), pyrexia (3), weight loss (3), lethargy (3), neurological signs (2), and laminitis (1). Hematologic abnormalities primarily included neutrophilia (9) and hyperfibrinogenemia. (6) Blood urea nitrogen and/or creatinine were elevated in 12/15 horses. Urethral stones were removed in 2 geldings prior to ultrasonography. Transrectal ultrasound detected ureteroliths in the proximal (5), mid (8), or distal (3) portion of the right (8) or left (7) ureter. One horse had 2 ipsilateral stones. All horses showed significant renal abnormalities, including nephrolithiasis (13). Cystoliths were identified in 3 horses. Six horses were euthanized. Three horses underwent surgical removal via perineal urethrostomy (2) or flank ureterotomy (1) and were discharged despite major complications. In another horse, spontaneous passage allowed cystoscopic removal. Five additional horses were discharged without removal.

4. Conclusion

Horses with ureteroliths show variable presenting complaints and were unlikely to be diagnosed prior to referral. Transrectal and transcutaneous ultrasound were necessary to identify all ureteroliths,

Research Abstract—for more information, contact the corresponding author

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multifocal urolithiasis, and significant renal pathology that accompanied most cases.

Acknowledgments

Declaration of Ethics

The Authors have adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Authors have no conflicts of interest.

How to Perform Whole-Blood Transfusions in the Horse

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1. Introduction

Transfusions in equine medicine are a relatively rare occurrence when compared to their usage in small animals or humans. The volume of blood product required, availability, potential reactions, and cost are all factors for their limited use. Despite these constraints, a transfusion can be a life-saving procedure that can be accomplished in the field with some forethought. While this topic has been described previously, there are some new and very important updates that must be considered when deciding on donor horses. In addition, further research has altered our understanding of transfusion reactions and transfused red blood cell survival times.

Goals of Transfusions

The goals of a blood product transfusion usually fall within one of four categories in horses:

1. To improve oxygen delivery to tissues
2. To provide immunoglobulins
3. To provide oncotic support
4. To provide clotting factors

Some of most common reasons for a whole blood transfusion are as follows:

Adult

- Hemorrhage
  —External—trauma/laceration, guttural pouch mycosis
  —Internal—uterine artery rupture, post colic surgery, splenic laceration, neoplasia
- Immune-mediated hemolytic anemia
- Red maple toxicity

Foal

- Neonatal isoerythrolysis
- Hemorrhage
  —External—umbilical bleed, laceration
  —Internal—fractured rib, internal organ trauma

Triggers for Whole-Blood Transfusion Therapy

When deciding whether a patient requires a transfusion, it is important to evaluate the entire patient in addition to any laboratory data. It may be obvious in a patient with severe acute blood loss who is showing signs of cardiovascular shock, but a patient with a more chronic condition may be significantly more difficult to assess. Assessment of heart rate, respiratory rate, mucous membrane color, periph-

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Table 1. Emergency Drugs for Allergic or Anaphylaxis Reactions During a Whole Blood Transfusion

Drug	Dosage	Route
Anti-inflammatories		
Prednisolone sodium succinate	1 mg/kg	IV
Dexamethasone	0.05–0.1 mg/kg	IV or IM
Antihistamine		
Hydroxyzine hydrochloride	0.5–1 mg/kg	PO or IM
For severe allergic and anaphylaxis		
Epinephrine 1:1000	5 mL/ 500 kg	IV or IM

eral perfusion, and degree of pain will assist in determining the need for a whole-blood transfusion.[1]

In cases of anemia, there are many hematological parameters that can be measured to help determine the need for a transfusion including packed cell volume (PCV), total protein (TP), lactate, hemoglobin, P_vO_2, and anion gap.[1,2] It is important to remember that PCV and TP will not assist in determining the need for a transfusion in acute blood loss as the values will remain with reference range for up to 24 hours or until fluid therapy is commenced. Serial monitoring of PCV and TP can provide valuable information on the patient and thus in conjunction with clinical appearance of the horse determine the need for a transfusion. In many acute hemorrhage cases, a decrease in TP will precede the drop in PCV.[2] Clinical signs are usually not seen in horses with acute anemia until the PCV drops below 20%, while chronic cases of anemia may not show signs until the PCV is approximately 12%. Lactate concentration will rise with decreased oxygen delivery to tissues and values greater than 4 mmol/L after crystalloid fluid resuscitation may indicate the need for a transfusion assuming the horse does not have any other conditions which could lead to hyperlactatemia (i.e., colic). Point of care lactate meters are inexpensive (<$350) and easy to use, thereby increasing the ability of many ambulatory practitioners to use this stall-side test. A handheld stall side analyzer[a] can provide lactate, hemoglobin, P_vO_2, Hct, and anion gap, although the device is cost prohibitive to most non-referral practices. If stall-side laboratory testing is not available, the practitioner will need to rely on clinical signs of poor oxygen delivery, specifically tachycardia, tachypnea, and peripheral perfusion.

2. Materials and Methods

Whole-Blood Transfusion Supplies

- PCV/TP microhematocrit tubes
- Clippers
- Surgical scrub
- Alcohol or sterile saline
- 4 × 4 gauze
- 2% lidocaine neat
- 3-mL syringe
- 25-gauge needle
- Sterile gloves
- #15 scalpel blade
- 10- (or 12-) gauge 3-inch catheters[b] (preferred, or large gauge needle in blood collection kit)
- Catheter suture ties or tape/stapler
- White tape and/or self-adhesive elastic bandage[d]
- Empty cardboard tubes from self-adhesive elastic bandage rolls
- Sterile dry blood collection bags[c]
  —3–4-L collection bags (adults)
  —1-L collection bags (foals)
  —Collection tubing size of 12 French (4 mm) or 15 French (5 mm)
- Acid-citrate-dextrose (ACD; anti-coagulant) or other anti-coagulant
  —Some collection bags come with ACD already provided in the bag
- Blood filtration fluid administration set[d]
  —Blood filter should be at least 40–200 micron
  —Most sets are 15–20 drop/mL (with the exception of high flow sets)
  —A new administration set is required for every 3–4 L of blood administered
- Emergency Drugs (Table 1)
  —Epinephrine 1:1000
  —Dexamethasone 5 mg/mL or prednisolone sodium succinate
  —Hydroxyzine hydrochloride

Blood-Collection Procedure

1. Check to ensure donor PCV/TP is adequate for donation and meets all donor guidelines (see Results section).
2. Prepare collection bags with appropriate amount of anticoagulant.
   a. A 1:9 ratio is used (ACD:blood) this works out to adding approximately 100 mL of ACD to each 1-L bag or 400 mL to a 4-L bag.
   b. Ensure that all the lines have been coated with the anticoagulant also to prevent clots from forming in the lines during collection.
3. The horse's mane should be braided or taped out of the way to ensure it will not contaminate your catheter site or your hands during the procedure.

Fig. 1. A secured 12-gauge 3-inch catheter[b] in the jugular vein aligning the catheter up the jugular (pointing to the head).

Fig. 2. Using gravity to assist flow and gently rocking the collection bag as blood is collected from the donor horse. The horse can have access to a hay net or feed during the collection process.

4. Shave jugular groove with wide margins.
5. Perform a sterile skin preparation to the entire shaved area.
6. Using a small amount of 2% lidocaine neat, block the skin where the catheter is to be inserted.
7. Using the #15 scalpel blade, perform a small skin cut-down.
   a. This will drastically improve your ability to insert the large bore catheter by reducing skin drag.
8. Perform another sterile skin preparation to the entire shaved area.
9. Don sterile gloves.
10. Place the 10-gauge catheter into the jugular vein aligning the catheter up the jugular (pointing to the head).
11. With this large bore catheter, it is sometimes easier to place the catheter all the way into the vein with the stylet seated in the catheter (instead of pushing the catheter off the stylet).
    a. By placing the catheter opposite to normal downward placement, gravity will assist in flow and increase collection speed.
    b. If blood flow is slow, the catheter should be replaced as it may be against the side of the vessel or on a blood valve. A normal 30-minute blood collection may end up taking hours if the flow is impeded.
12. Secure catheter to neck by suture ties or tape (Fig. 1).
13. Aseptically, connect the catheter to the collection tubing and bag.
14. Hold off the jugular vein below the catheter. This must be continually held throughout the collection.
    a. A leftover cardboard roll from self-adhesive bandage rolls can be placed in the jugular grove and firmly taped to the neck with white tape to occlude the jugular and reduce the need for personnel to maintain occlusion.
15. Place the collection bag as low as possible to allow gravity flow of blood and unclamp the collection tube to start the collection (Fig. 2).
16. Gently rock the collection bag as blood is collected to gently mix the anticoagulant and the blood.
    a. If mixed too vigorously, the red cells may be damaged, and the quality of blood will be markedly reduced.
17. Throughout the blood collection, donor mucous membrane color, capillary refill time, heart rate, respiratory rate, peripheral extremity temperature should be monitored.
18. Once the bag is filled (weighing the bag is the most accurate method of determining the volume of blood in the bag), clamp the lines ensuring that no air enters the bag.
19. A maximum of 20% of blood volume can be collected at one time from a donor horse.
    a. Example: Blood volume (body weight 500 kg $\times$ 8%) $\times$ 20% = 8 L.

Additional Notes on Blood Collection

Blood transfusions should be treated as an aseptic procedure and all materials should be handled appropriately.

Having access to a hay net or feed during the collection process can reduce boredom and improve compliance. If necessary, light sedation can be used. Administration of crystalloid fluids to the donor is recommended if the maximum blood withdrawal has been performed. Five to 10 L of lactated Ringer's solution is usually given when 8 to 10 L of blood have been collected. The fluids can be administered through the collection catheter after the procedure is completed or during the blood collection through a second intravenous catheter.

Administration of Transfusions

Whole-Blood Volume

The volume of blood transfusion required can be calculated using various formula; however, in most cases it is impractical to collect and administer more than 8 to 10 L at one time. The volume administered should reflect the patient status and response to the blood transfusion. If the patient is in hypotensive shock, it is key to provide your patient with resuscitation fluids to improve peripheral perfusion and cardiac output **prior** to commencing the blood transfusion.[2,3] It is also important to discuss with the owner that administration of intravenous fluids (either crystalloids, colloid, or whole blood) will increase peripheral blood pressure and may increase bleeding (thereby worsening the patient's condition); however, lack of fluid therapy will cause hypoxemic damage to tissues and organs.

As a general guide, whole blood is administered at a rate of **20 mL/kg**. Usually 30% to 40% of the blood deficit is corrected with a single transfusion. If you like to do math, you can also calculate the following:

The blood deficit can be determined using the following formula:

$$\text{Blood Deficit} = \frac{(\text{desired PCV} - \text{current PCV})}{\text{desired PCV} \times 0.08 \times \text{body weight (kg)}}$$

Or you can use the following formula:

$$\text{Litres of whole blood needed} = \frac{\text{Desired PCV} - (\text{recipient PCV} \times 0.08 \times \text{body weight (kg)})}{\text{Donor PCV}}$$

Transfusion Rates of Administration

The rate of administration of a transfusion is best described as "the rate that is best for your patient." If the patient is in hemodynamic shock and will die without the immediate transfusion administration, then administering the transfusion as fast as possible is the ideal rate in an emergency. If the patient has been stabilized (even partially) then the administration should start slower to allow for time to identify potential transfusion reactions. In most cases, it will be very difficult to reach the upper range of the administration rates as most available blood administration sets have narrow bore tubing and slow flow through the in-line filter. **Do not run a transfusion without the use of an in-line blood filter** as clots and fibrin from the blood product can cause fatal outcomes (Fig. 3).

Fig. 3. Blood filtration and administration set[d] (15 drops/mL) attached to a 4-L transfusion bag[c] of whole blood.

It is very important that the blood transfusion be completed within 4 to 6 hours as the risk of bacterial contamination of the product is much higher after being left at room temperature for this amount of time. Whole blood should not be administered cold and proper warming (if refrigerated) needs to be done very gradually to reduce damage to cells and/or proteins in the product.

Whole-Blood Administration (Fig. 4)

- Start at **0.1 mL/kg over at least 10 to 15 minutes**
- Start at 1 drop every 1 to 2 seconds in a 500-kg horse with a 20 drop/mL administration set
- Gradually increase the rate over the next 20 minutes
- Continue at **10 to 20 mL/kg/hour** until completed
- Essentially a very fast drip in a foal or full open administration in adults with a 20 drop/mL administration set

3. Results

Blood Donors

In the ideal situation, a blood donor horse will be blood typed and identified as Aa, Ca, and Qa nega-

Fig. 4. A horse receiving a blood transfusion. It is important that the blood transfusion be completed within 4 to 6 hours to reduce the risk of bacterial contamination of the blood product.

tive (both antigens and antibodies). If this is not possible, the donor should be a healthy male horse with no history of previous blood product administration (including whole blood, serum, plasma, antitoxins, etc.). Alternatively, a maiden mare can be used with the same criteria. The donor horse should be at least 450 kg, negative for equine infectious anemia (EIA), equine viral arteritis (EVA), be up to date on vaccinations and deworming and have a PCV >35% and TP >69 g/L. Most Quarter Horses, Standardbreds, and Morgans are negative for Qa and Aa antigens, making them good donor candidates.

Recent investigations into equine serum hepatitis (Theiler's disease) has identified equine parvovirus and equine hepacivirus (Non Primate Hepacivirus) as possible causes of the highly fatal condition. It is therefore strongly recommended that all blood donors are tested for viremia prior to blood collection to reduce the risk of equine serum hepatitis in recipients.[4–6] While not possible in emergency situations, potential clinic donors should be screened and a commercially available test for viruses associated with equine serum hepatitis is now available[f]. When considering commercial blood products, the center for veterinary biologics notice No. 19–03 indicates that "*All horses used as donor animals for the manufacture of APHIS -regulated antibody, antitoxin, serum, and plasma products must test negative for the presence of equine parvovirus-hepatitis in blood samples.*"

Blood Typing and Cross Matching

Blood typing and cross matching are an important part of ensuring safe transfusion; however, commercial laboratory cross matching may take up to 24 hours and blood type results can take up to 3 weeks. Currently, a commercial stall side major ± minor crossmatch gel column agglutination test is available for horses which can be completed in less than 20 minutes[g]. A recent study found fair agreement that was blood type dependent, between this major crossmatch test and reference standard methods in horses.[7] A second study used a modified canine rapid gel assay which if commercialize may also be a useful alternative test for stall side testing.[8] A stall-side blood type immunochromatographic strip test is available for Ca blood types[h]; however, the more important Qa and Aa blood types strip tests have yet to be released.[9]

In an emergency scenario, the delay of laboratory test results is impractical, and most transfusions are done without compatibility results. Fortunately, most horses do not have pre-formed alloantibodies (pre-existing antibiotics against red blood cell (RBC) antigens).[2] Mares who have given birth or horses that have had previous transfusion of blood products (including plasma) are at higher risk of a transfusion reaction.

Blood typing and testing for alloantibodies is recommended for any potential clinic donors to identify possible horses to be used in emergency situations.

Cross matching both major (recipient plasma to donor RBC) and minor (donor plasma to recipient RBC) is recommended if a blood transfusion is anticipated. For example, in cases of ongoing hemorrhage, when a horse might require a second transfusion, or if the horse has a planned surgical procedure which may result in severe bleeding. It is important that the laboratory cross match procedure identifies both hemolysis and agglutination incompatibilities. A cross match is also recommended if a horse requires repeated transfusions as alloantibodies can be produced in horses in less than 7 days.[10]

4. Discussion

Monitoring

During a transfusion, the patient should be monitored very closely for any signs of a transfusion reaction. It is recommended to assess the patient every 5 to 10 minutes for the first 30 minutes of the transfusion then every 15 to 30 minutes until the transfusion is completed. A monitoring form will assist in identifying any trends in parameters and is an important piece of the medical record. At each assessment, the horse should have the heart rate, respiratory rate, rectal temperature, mucous membranes, and attitude recorded. Monitoring should also assess for the presence of any skin reactions (urticaria), agitation, tremors, or signs of anaphylaxis.

Transfusion Reactions

In horses, plasma transfusion reactions have been reported in 10% of foal transfusion cases and 0% to 10% of adult transfusion cases,[11,12] whereas a rate of 16% of adult horses receiving whole blood had a transfusion reaction with 3 of 44 transfusions being life threatening or fatal.[1] Transfusion reactions can be categorized into hemolytic and non-hemolytic reactions. Hemolytic reactions result in hemolysis of RBCs and can be acute as a consequence of preformed alloantibodies or delayed through rapid production of antibodies. Unfortunately, there are no specific treatments for hemolytic reactions only supportive therapies, therefore, it is best to prevent possible reactions through cross matching or blood typing. Recently, it has been shown that transfused red blood cells survive longer in circulation (T½, 33.5 days) than previously thought and that the incompatible cross matched transfusions have a drastically decreased RBC survival in the donor (T½, 4.7 days).[13] Evidence of a hemolytic reaction include signs of worsening cardiovascular shock (tachycardia, tachypnea), fever, restlessness, hemoglobinemia, hemoglobinuria, and worsening anemia following the transfusion. The delayed immune-mediated hemolysis may be seen up to 3 to 5 days after transfusion.

Non-hemolytic reactions include volume overload, bacterial contamination, microembolization, electrolyte imbalances, fever, allergic/anaphylaxis, and Theiler's disease (equine serum hepatitis). There does not appear to be a specific protection from non-hemolytic reactions in cross match compatible blood transfusion in the literature.[14]

If signs of a transfusion reaction are noted, stop the transfusion and perform a complete evaluation of the horse. If the reaction is mild and there is no sign of hemolysis or bacterial contamination of the blood product (i.e., concerns over asepsis or time at room temperature), the transfusion can be restarted at a slow rate and the patient monitored closely as the rate is once again gradually increased.

If allergic or anaphylaxis reactions are observed, the transfusion should be stopped and the patient may be treated with anti-inflammatories, antihistamines, or epinephrine depending on the severity of the reaction (Table 1). The efficacy of antihistamines in horses is generally poor; however, the author has had some success with hydroxyzine. Horses may become agitated after administration of an anti-histamine, especially diphenhydramine, and should thus be avoided in a severely compromised patient. Again, with mild reactions the transfusion may be restarted at a slow rate after administration of the appropriate medications and the patient monitored closely as the rate is once again gradually increased (Fig. 5). For more severe reactions, a new blood donor may be required.

Donor information, commercial product lot numbers, and details of the transfusions including all monitoring sheets should be included in the medical record. This information can be invaluable if the horse requires another transfusion or has a transfusion reaction.

Fig. 5. The urticaria in this horse occurred during a whole blood transfusion following colic surgery. The transfusion was stopped, the horse was given a dose of dexamethasone and hydroxyzine hydrochloride. Fifteen minutes later, the transfusion was recommenced with the same blood product at the starting administration rate and no further reactions were noted.

Acknowledgments

Declaration of Ethics

The Author has adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Author has no conflicts of interest.

References and Footnotes

1. Hurcombe SD, Mudge MC, Hinchcliff KW. Clinical and clinicopathologic variables in adult horses receiving blood transfusions: 31 cases (1999–2005). *J Am Vet Med Assoc* 2007; 231:267–74.
2. Mudge MC. Acute hemorrhage and blood transfusions in horses. *Vet Clin Equine* 2014;30:427–436.
3. Frazer ML. Review of fluid therapy in acute blood loss, in *Proceedings*. Am Assoc Equine Pact 2013;59:458460.
4. Tomlinson JE, Kapoor A, Kumar A, et al. Viral testing of 18 consecutive cases of equine serum hepatitis: A prospective study (2014–2018). *J Vet Intern Med* 2019;33:251–257.
5. Tomlinson J, Van de Walle G, Divers T. What do we know about heptatitis viruses in horses? *Vet Clin Equine* 2019;35: 351–362.
6. Meister T, Tegtmeyer B, Postel A, et al. Equine parvovirus-hepatitis frequently detectable in commercial equine serum pools. *Viruses* 2019;11:461.
7. Fenn M, Bortsie-Aryee, A, Perkins G, et al. Agreement of stall-side and laboratory major crossmatch tests with the reference standard methods in horse. *J Vet Intern Med* 2020:1–8.
8. Casenave P, Leclere M, Beauchamp G, et al. Modified stall-side crossmatch for transfusions in horses. *J Vet Intern Med* 2019;33:1775–1783.

9. Luethy D, Owens SD, Stefanovski S, et al. Comparison of tube, gel, and immunochromatographic strip methods for evaluation of blood transfusion compatibility in horses. *J Vet Intern Med* 2016;30:1864–1871.
10. Wong PL, Nickel LS, Bowling AT, et al. Clinical survey of antibodies against red blood cells in horses after homologous blood transfusion. *Am J Vet Res* 1986;47:2566–2571.
11. Hardefeldt LY, Keuler N, Peek SF. Incidence of transfusion reactions to commercial equine plasma. *J Vet Emerg Crit Car* 2010;20:421–425.
12. Wilson EM, Holcombe SJ, Lamar A, et al. Incidence of transfusion reactions and retention of procoagulant and anticoagulant factor activities in equine plasma. *J Vet Intern Med* 2009;23:323–328.
13. Tomlinson JE, Taberner E, Boston RC, et al. Survival time of cross-match incompatible red blood in adult horses. *J Vet Intern Med* 2015;29:1683–1688.
14. Hart KA. Pathogenesis, management and prevention of blood transfusion reactions in horses. *Equine Vet Educ* 2011;23:343–345.

[a]i-Stat handheld system, Abbott, Princeton, NJ 08540.
[b]Angiocath™, BD, Sandy, UT 84070.
[c]Blood Collection Bag (1 L, 4 L dry, or 3 L with ACD anticoagulant) Jorgensen Laboratories, Inc., Loveland, CO 80538.
[d]Blood Administration Set or Transfusion and Infusion Set, Jorgensen Laboratories, Inc., Loveland, CO 80538.
[e]Vetrap™, 3M, St. Paul, MN 55144-1000.
[f]Equine Serum Hepatitis PCR panel for regulatory purposes—Equine Parvovirus and Equine Hepacivirus (EqHV) (Non Primate Hepacivirus—HPHV) PCR, Cornell University, Animal Health Diagnostic Center.
[g]Equine Gel Test Crossmatch, Alvedia, Limonest, France.
[h]Quick Test Equine Blood Typing, Alvedia, Limonest, France.

Serum and Cerebrospinal Fluid Phosphorylated Neurofilament Heavy Concentrations as a Biomarker of Equine Neurodegenerative Diseases

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Increased serum and cerebrospinal fluid concentrations of phosphorylated neurofilament heavy, a protein unique to neurons, can aid in the diagnosis of neurologic disease. However, normal values do not exclude neurologic disease. Authors' addresses: Department of Population Health and Reproduction, School of Veterinary Medicine, University of California-Davis, Davis, CA 95616 (Edwards, Donnelly, Finno); Rood and Riddle Equine Hospital, PO Box 12070, Lexington, KY 40580-2070 (Reed); Department of Clinical Studies, New Bolton Center, University of Pennsylvania School of Veterinary Medicine, Kennett Square, PA 19348 (Johnson); Mary Anne McPhail Equine Performance Center, Department of Large Animal Clinical Sciences, Michigan State University, East Lansing, MI 48824 (Valberg); e-mail: laedwards@ucdavis.edu. *Corresponding and presenting author.

1. Introduction

Antemortem diagnosis of equine neurologic diseases is challenging. Phosphorylated neurofilament heavy (pNfH) could serve as a biomarker for neurologic diseases.

2. Materials and Methods

A commercial, research pNfH ELISA was used to measure pNfH in serum and cerebrospinal fluid (CSF) of 51 neurologically normal horses, 26 necropsy-confirmed cervical vertebral compressive myelopathy (CVCM)-affected horses, 64 necropsy-confirmed equine neuroaxonal dystrophy-affected horses or equine degenerative myelopathy (eNAD/EDM)-affected horses, and 9 Shivers-affected horses.

3. Results

In normal horses, the median serum pNfH was 0.08 ng/ml (95% CI 0.07–0.15; range 0.07–0.59 ng/ml) and median CSF pNfH was 1.26 ng/ml (95% CI 1.06–1.52; range 0.07–2.85 ng/ml). Serum pNfH of CVCM horses and serum and CSF pNfH of Shivers horses were comparable to normal horses. Median serum pNfH was 0.07 ng/ml (95% CI 0.07–1.13; range 0.07–52.6 ng/ml) in eNAD/EDM horses. Median CSF pNfH levels were comparable across neurologic groups

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with broad ranges in eNAD/EDM 1.78 ng/ml (95% CI 1.5–2.28; range 0.07–137.8 ng/ml) and CVCM-affected horses was 3.07 ng/ml (95% CI 1.15–29.9; range 0.20–109.3 ng/ml). There was no effect of sex on serum or CSF pNfH levels; however, age was a significant variable among neurologically normal, eNAD/EDM, and CVCM groups.

4. Discussion

Serum pNfH of >1 ng/ml is supportive of eNAD/EDM (P = 0.01). CSF pNfH of >3 ng/ml is supportive of either eNAD/EDM or CVCM (P = 0.0001). Values below these levels do not rule out neurologic disease.

Acknowledgments

Declaration of Ethics

The Authors have adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Authors have no conflicts of interest.

Impact of Concurrent Treatment with Omeprazole on Phenylbutazone-Induced Gastric Ulceration in Horses

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Omeprazole ameliorates phenylbutazone-induced gastric glandular ulceration, but may increase the rate of intestinal complications. Risk of complications should be considered when co-administering omeprazole and phenylbutazone in horses. Authors' address: Department of Veterinary Clinical Sciences, Equine Health Studies Program, School of Veterinary Medicine, Louisiana State University, Baton Rouge, LA 70803; e-mail: hbanse1@lsu.edu. *Corresponding and presenting author.

1. Introduction

Phenylbutazone is commonly prescribed to treat painful or inflammatory disorders, but has been associated with gastrointestinal adverse effects. Anecdotally, omeprazole is prescribed to reduce the risk of phenylbutazone-induced gastric ulceration, but the efficacy and safety of this practice remains unknown.

2. Materials and Methods

Twenty-two horses with equine glandular gastric disease (EGGD) and equine squamous gastric disease scores ≤ 2 were included in the study. Horses were assigned to treatment groups: phenylbutazone (PBZ; 4.4 mg/kg PO q12h), phenylbutazone plus omeprazole (PBZ/OME; 4 mg/kg PO q24h), or placebo (CON) in a randomized block design based upon initial EGGD score. Horses were treated for up to 14 days. Gastroscopy was performed weekly. CBC and biochemistry were performed at day 0 and study end. Horses were observed daily for signs of colic and/or diarrhea.

3. Results

EGGD score increased over time, with PBZ increasing more than PBZ/OME (P = .04). Total plasma protein decreased in PBZ (P = .003) and PBZ/OME (P = .01). Rate of intestinal complications, including large or small colon impaction, diarrhea, necrotizing typhlocolitis, and ulcerative and necrohemorrhagic enterocolitis was higher in PBZ/OME

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(6/8) versus CON (0/6; P = .02) but not PBZ/OME versus PBZ (2/8; P = .3).

4. Discussion

Administration of omeprazole ameliorated PBZ-induced glandular ulcers (EGGD) but was associated with an increase in intestinal complications. Caution should be exercised when co-prescribing NSAIDs and omeprazole in horses.

Acknowledgments

Declaration of Ethics

The Authors have adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

Dr. Banse has previously performed consultancy work for and received research funding from Boehringer Ingelheim. The other authors have no conflicts of interest.

Factors Affecting Successful Ultrasound-Guided Injection of the Podotrochlear Bursa Using a Palmarolateral Approach

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Navicular bursa visibility is significantly improved with caudal foot placement and distention. Success rates support the technical challenge of podotrochlear bursa injections. Authors' addresses: Stephansmuehle Pferdepraxis, Hilpoltstein, Germany (Espinosa-Mur); Department of Surgical & Radiological Sciences (Whitcomb, Galuppo); Department of Population Health & Reproduction (Kass), School of Veterinary Medicine, University of California-Davis, Davis, CA 95616; Equitom Equine Clinic, Meldert, Belgium (Vanslambrouck); e-mail: pablosvet@gmail.com. *Corresponding and presenting author.

1. Introduction

Multiple techniques to inject the podotrochlear bursa (PDB) have been described. This study evaluated potential factors for ultrasound-guided (USG) injection success, including effects of limb position on ultrasonographic visibility, with and without PDB distention, and experience levels between ultrasonographers.

2. Materials and Methods

The PDB of 24 cadaveric forelimbs were distended with 0, 1, or 2 ml of iodinated contrast material and saline. Ultrasonographic visibility of the suprasesamoidean region and PDB was graded before and after distention with the limb loaded in three positions (vertical, cranial, and caudal). USG injection of the PDB with methylene blue was then performed using a palmarolateral approach and caudal foot placement. Each ultrasonographer injected 12 limbs (4 limbs with each of the 3 volumes of PDB distention). Limbs were frozen and sectioned to assess accuracy.

3. Results

Ultrasonographic visibility scores of the suprasesamoidean region and PDB were significantly improved using a caudal foot placement, although visibility scores did not affect injection success. Injection success was higher (9/12, 75%) for the experienced versus less experienced ultrasonographer (5/12, 41.6%), but this difference was not significant. PDB distension improved visibility but not injection success.

4. Discussion

Caudal foot placement enhances the visibility of the PDB and suprasesamoidean region. PDB

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distention improves visibility but does not appear to affect injection success; however, the PDB was well-visualized in all limbs before distention with the foot positioned caudally.

Acknowledgments

Declaration of Ethics

The Authors have adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Authors have no conflicts of interest.

Comparison of Radiographic and Magnetic Resonance Imaging Findings in the Proximal Metatarsus in 35 Horses

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Radiographic changes of the proximal third metatarsal bone should not be used as an indicator of proximal suspensory desmopathy but are associated with proximal suspensory enthesopathy. Authors' addresses: Department of Environmental and Radiological Health Science (Hinkle, Selberg, Barrett); Orthopaedic Research Center, Department of Clinical Science (Frisbie), College of Veterinary Medicine and Biomedical Science, Colorado State University, Fort Collins, CO 80523; e-mail: franceshinkle15@gmail.com. *Corresponding and presenting author.

1. Introduction

Comparing radiographs to magnetic resonance imaging (MRI) as a gold standard can help objectively assess the value and limitations of radiographs in specific orthopedic disease processes.

2. Materials and Methods

This retrospective study compared the radiographic and MRI findings of the proximal third metatarsal bone (MTIII) and proximal suspensory ligament (PSL). Single hindlimbs of 35 horses with radiographic and high-field (3T) MRI studies were included and blindly evaluated by two board-certified veterinary radiologists and a radiology resident. The severity and location of the following parameters were assessed: radiographic MTIII sclerosis and lucent regions, MRI metatarsal endosteal sclerosis and edema, cortical proliferation and resorption, and PSL desmopathy. Chi-square analysis was performed on the presence and severity of these findings.

3. Results

Fifty-four percent had radiographic MTIII changes. Forty percent had osseous changes in MTIII on MRI. Forty-three percent had evidence of PSL desmopathy on MRI. No significant association was found between the presence of radiographic changes in MTIII and PSL desmopathy on MRI. A statistically significant association and a positive correlation was found between the severity of radiographic changes and metatarsal proliferation and resorption on MRI.

4. Discussion

These findings indicate that radiographic changes of MTIII do not specify proximal suspensory ligamentous injury. Similar to previous studies, metatarsal enthesopathy and proximal suspensory desmopathy can occur independently.

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Conflict of Interest

The Authors have no conflicts of interest.

Standing PET Imaging of the Racehorse Fetlock: System Validation and Early Descriptive Data

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Positron emission tomography (PET) imaging of the fetlock can be reliably performed in standing horses. A variety of abnormal uptake patterns in racehorses have been recognized in this early data set, including proximal sesamoid bone uptake. Authors' addresses: School of Veterinary Medicine, University of California-Davis, Davis, CA 95616 (Spriet, Edwards, Arndt, Galuppo, Stover); Longmile Veterinary Imaging, 12156 Parklawn Drive, Rockville, MD 20852 (Stepanov, Beylin); Santa Anita Park, 285 W Huntington Drive, Arcadia, CA 91007 (Carpenter, Dowd); e-mail: mspriet@ucdavis.edu. *Corresponding and presenting author.

1. Introduction

A positron emission tomography (PET) scanner, specifically designed to image the equine distal limb under standing sedation, has recently been developed. The goals of this study were to validate the scanning technique and provide early descriptive data.

2. Materials and Methods

Six research horses were imaged twice standing and once under general anesthesia for the validation phase. Twenty-five racehorses (56 fetlocks) were then imaged with a 4-minute scan time per fetlock, 30 minutes after injection of 15 mCi of the substance 18F-NaF.

3. Results

This validation study confirmed the safety and good repeatability of PET. In the racehorse population, increased radiopharmaceutical uptake was most common in the palmar metacarpal condyles (medial condyle, 68%; lateral condyle, 59%). The second most common sites of abnormal uptake were the proximal sesamoid bones (medial, 38%; lateral, 18%). The uptake in the sesamoid bones was most common at the dorsal aspect of the medial proximal sesamoid bone, a site known to be involved in catastrophic fracture.

4. Discussion

These findings confirm the ease of use of standing PET in racehorses and its ability to recognize different uptake patterns. The information presented here is the early data from a study comparing PET with scintigraphy and standing magnetic resonance imaging. This study will provide further information regarding the value of PET in racehorses.

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Funding for this study was received from the Grayson Jockey Club Research Foundation, the Southern California Equine Foundation, the Dolly Green Research Foundation, and the Stronach Group.

Declaration of Ethics

The Authors have adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

Drs. Stepanov and Beylin are employees and shareholders of LONGMILE Veterinary Imaging, division of Brain Biosciences, Inc., a company that designed and manufactured the MILEPET scanner used in this study.

Racing Performance of Yearlings Identified with Subchondral Cystic Lesions of the Distal MC3/MT3 Condyle

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Michael Spirito, DVM; and Dwayne Rodgerson, DVM, MS, DACVS

Racing performance and likelihood to start a race were similar for yearlings with and without nonclinical subchondral cystic lesions of the distal condyles of the third metacarpus/metatarsus on repository radiographs. Authors' addresses: Hagyard Equine Medical Institute, 4250 Iron Works Pike, Lexington, KY 40511 (Miklavcic, Sandow, Spirito, Rodgerson); Pferdepraxis Kühnle, Parkstraße 7, 74532 Ilshofen, Germany (Kühnle); Louisiana State University, School of Veterinary Medicine, Skip Bertman Drive, Baton Rouge, LA 70803 (Perry); e-mail: mitja_miklavcic@hotmail.com. *Corresponding and presenting author.

1. Introduction

Subchondral cystic lesions (SCLs) can be a source of lameness with implications on future athletic performance, and therefore, negatively affect potential buyer's decisions if they are identified on presale radiographs. Some lesions can be nonclinical with no apparent lameness or joint effusion while other cases exhibiting lameness often require surgical management.

2. Materials and Methods

Repository radiograph reports of yearlings at a private practice from 2005 to 2017 were reviewed and race records were collected and analyzed. An affected cohort of 42 horses with SCLs was matched by an unaffected cohort of 84 horses without SCLs of the distal condyles as the hip number above and below the affected horse. An independent samples *t*-test was used to evaluate racing metrics (2-year-old starts and 3-year-old starts, career starts), and monetary performance metrics (2-year-old earnings, 2-year-old earnings per start, 3-year-old earnings per start, career earnings, career earnings per start) between horses with cysts and without cysts. Statistical significance was set a $P < .05$.

3. Results

No significant difference was observed between horses with and without SCLs of the distal condyles both for racing metrics and monetary performance.

4. Discussion

These findings may cause veterinarians to consider recommendations when advising clients on yearlings with nonclincial SCLs. There was a trend for larger cysts with articular involvement to limit per-

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formance. History of treatments pre- or postsale is unknown.

Acknowledgments

Declaration of Ethics

The Authors have adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Authors have no conflicts of interest.

Effects of Aquatic Conditioning on Cartilage and Bone Metabolism in Young Horses

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Walking on an aquatic treadmill has no negative impact on markers of bone and joint metabolism in yearling horses transitioned to an advanced workload on natural surface. Authors' addresses: Texas A&M University, College Station, TX 77843 (Silvers, Leatherwood, Huseman, Much, Martinez, Bradbery); Texas A&M University Large Animal Hospital, College Station, TX 77843 (Arnold, Dominguez, Glass); Michigan State University, East Lansing, MI 44824 (Nielsen); e-mail: brittany_silvers@tamu.edu. *Corresponding and presenting author.

1. Introduction

Aquatic treadmills create buoyancy, which leads to decreased mechanical load on bone and joints. While beneficial in rehabilitation, effects on musculoskeletal health in young horses are not well investigated. The objectives of this study were to determine the influence of early forced exercise (dry vs aquatic) on serum and synovial fluid biomarkers in young horses transitioning to an advanced workload.

2. Materials and Methods

Yearling Quarter Horses were randomly assigned to no exercise (n = 10), treadmill exercise (n = 10), or aquatic treadmill exercise (n = 10; water at 60% wither height). Treadmill and aquatic treadmill exercise walked on treadmills 5 days/week for 112 days before transitioning to a 28-day advanced program on natural sandy surface. Synovial fluid and serum were collected every 28 days for biomarkers of bone and joint metabolism. Radiographs of third metacarpal were taken on days 0, 112, and 140 for radiographic bone aluminum equivalence.

3. Results

There were no treatment effects on cartilage, inflammatory biomarkers, or radiographic bone aluminum equivalence. There was a treatment × day effect ($P < .01$) where osteocalcin decreased in both exercise groups during advanced exercise.

4. Discussion

Changes in markers of cartilage turnover in horses exercised at the walk, whether dry or aquatic, cannot be distinguished from turnout alone; however, bone formation decreases following 28 days of advanced workload on natural surface.

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Acknowledgments

Funding Source

Funding was provided by the American Quarter Horse Foundation.

Declaration of Ethics

The Authors have adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Authors have no conflicts of interest.

How to Determine the Presence of Musculoskeletal Pain in Ridden Horses by Application of the Ridden Horse Pain Ethogram

Sue Dyson, MA, VetMB, PhD, DEO, DipECVSMR, FRCVS

The use of the Ridden Horse Pain Ethogram comprising 24 behaviors can be used to determine the presence of musculoskeletal pain. Display of eight or more behaviors is likely to reflect the presence of musculoskeletal pain, although some lame horses score less than eight. Author's address: The Cottage, Church Road, Market Weston, Diss, IP22 2NX, United Kingdom; e-mail: sue.dyson@aol.com.

1. Introduction

There are many horses that appear sound in hand but have underlying pain-related musculoskeletal problems when ridden. However, horses show a variety of gait modifications in an attempt to reduce pain and minimize lameness, including reducing the range of motion of the thoracolumbosacral region,[1] taking shorter steps, altering limb flight, and increasing body lean.[2] Owners, riders, and trainers may not be able to recognize the signs of lameness. In a study of 506 sports horses in normal work and presumed to be sound, 47% were overtly lame or had other pain-related gait abnormalities (e.g., stiff and stilted canter).[3] In an unrelated study of 201 riding horses in full work and functioning normally, 53% had gait asymmetry when evaluated trotting in hand, which was determined using inertial measurement units.[4] An analysis of 57 dressage and showjumping horses in normal work revealed that 65% exhibited lameness either in hand on the lunge or ridden; 47% showed lameness ridden and 7% were only lame ridden.[5] Riders and trainers often label performance problems experienced during ridden exercise as training-related, rider-related, or behavioral or 'that is just how the horse has always gone.[6,7] Consequently pain-related problems often get insidiously but progressively worse. The inability to perform satisfactorily may result in a decline in the value of the horse and the standards of care.[6] Improved pain recognition will enhance equine welfare.

Many veterinarians have had little training in pain recognition and limited education in identification of low-grade lameness, especially in ridden horses and, therefore, struggle to recognize musculoskeletal pain as a cause of poor performance. Owners are frustrated when they think that their horse has an underlying pain-related problem but are informed by their veterinarian that there is no detectable lameness and the problem must be behavioral. It would, therefore, be useful to have additional tools for owners, trainers, veterinarians, and other paraprofessionals to recognize signs of musculoskeletal pain.

NOTES

Behavioral changes related to experimentally induced orthopedic pain in horses have been described,[8,9] but the features described, such as pawing the ground, are generally not applicable to ridden horses. The most recent advance in the recognition of subtle behavioral changes associated with pain is the investigation of facial expressions.[10] The spectrum of facial expressions exhibited by normal horses under non-ridden circumstances has been described in detail.[11] An "equine pain face" was developed to describe facial features of horses with induced limb pain at rest.[12] A Horse Grimace Scale, consisting of six features ("the ears held stiffly backwards; orbital tightening [the eyelids are partially or completely closed]; tension above the eye; the mouth strained with a pronounced chin; the nostrils strained with flattening of their profile; and prominent strained chewing muscles") was developed to categorize the facial expressions of horses undergoing routine castration, with or without perioperative analgesia.[13] However, it has been suggested that posture changes and overall body tension in resting horses may confound results and that further research is required to test for reliability of "pain grimace" measures.[14] The Equine Utrecht University Scale for Facial Assessment of Pain was developed to assess facial pain expressions in horses with or without abdominal pain and used a 3-point system from "normal = 0" to "maximal visible pain" for nine facial parameters to derive an overall pain scale.[15] This system showed good reliability among four veterinary students and two veterinarians when looking at 10-minute video recordings of stabled horses.

An initial outline of a scheme to assess some aspects of facial expression in ridden horses has been described;[16] however, a detailed description of the results was not documented. Head movement, ear position, teeth grinding, and lip movements were described in a study comparing two groups of young horses (3.5 years of age) when first lunged under a saddle and first ridden at a trot following either a "conventional training approach" or a "sympathetic training approach."[17]

An ethogram is a catalog of behaviors with specific definitions. An ethogram purpose designed to describe facial expressions in ridden horses (FEReq) was developed,[18] and it was shown that it could be applied by observers from variable professional backgrounds with satisfactory agreement. It was also demonstrated that a trained assessor could differentiate between lame and non-lame horses based upon application of the FEReq to photographs of the horses' heads.[19,20]

It has frequently been recognized by the review of patient history that the presence of musculoskeletal pain in horses has long pre-dated its recognition because owners and trainers have failed to recognize the significance of behavioral changes during ridden exercise.[21–30] In horses, some behaviors such as bucking,[29] head tossing,[31] and rearing[32] during ridden exercise have been associated with musculoskeletal pain, and classical headshaking has been associated with trigeminal neuralgia.[33–36] However, the association between other behaviors and pain, such as unwillingness to go forward or being "above the bit," has been poorly documented.

It was postulated that these relatively easily observed signs might be used to develop a Ridden Horse Ethogram that could improve the ability of minimally trained observers to differentiate horses with musculoskeletal pain from those with other behavioral, training, or rider problems.

2. Development of the Ridden Horse Ethogram

The purpose of the initial study was to develop a Ridden Horse Ethogram and to determine whether it could be applied repeatedly by one trained observer (Repeatability Study, 9 horses) and if, by application of a related pain behavior score, lame horses ($n = 24$) and non-lame horses ($n = 13$) could be differentiated.[37] It was hypothesized that there would be some overlap in pain behavior scores among non-lame and lame horses and that, overall, non-lame horses would have a lower pain behavior score than lame horses. The ethogram was developed with 117 behaviors and horses were graded twice in random order by a trained observer using video footage. Overall, there was good correlation between the two assessments ($P < 0.001$; $R^2 = 0.91$). Behaviors that were not consistent across the two assessments were omitted, reducing the ethogram to 70 behaviors. The modified ethogram was applied to video recordings of the non-lame horses and lame horses (Ethogram Evaluation). By the amalgamation of similar behaviors and by omission of markers that showed unreliable results in relation to lameness the Ridden Horse Pain Ethogram was ultimately developed. This comprised 24 behaviors, the majority of which were at least 10 times more likely to be seen in lame horses versus non-lame horses (Table 1) (Figs. 1–6).

The maximum individual occurrence behavior score for lame horses was 14/24, with a median score of 9 and a mean score of 9 (standard deviation [SD] ± 2), compared with a maximum score of 6 for non-lame horses, with a median and a mean score of 2 (SD± 1.4). The following behaviors occurred significantly more frequently in lame than non-lame horses ($P < 0.05$, Chi-square): one or both ears behind vertical for ≥ 5 s, mouth opening with separation of the teeth for ≥ 10 s, tongue out, change in eye posture and expression, front of head $\geq 30°$ in front of the vertical for ≥ 10 s (above the bit), head tossing, tilting the head, unwillingness to go, crookedness, hurrying, changing gait spontaneously, poor-quality canter, resisting or not following the direction of the rider's cues, and stumbling and toe dragging. It was concluded that the presence of 8 or more of the 24 behaviors was likely to reflect musculoskeletal pain.

Table 1. The 24 Behavior Ridden Horse Ethogram, Adapted from Dyson et al[37]

1. Repeated changes of head position (up/down), not in rhythm with the trot
2. Head tilted or tilting repeatedly
3. Head in front of vertical (>30°) for ≥10 s
4. Head behind vertical for (>10°) for ≥10 s
5. Head position changes regularly, tossed or twisted from side to side, corrected constantly
6. Ears rotated back behind vertical or flat (both or one only) ≥5 s; repeatedly lay flat
7. Eyelids closed or half closed for 2–5 s; frequent blinking
8. Sclera exposed repeatedly
9. Intense stare (glazed expression, "zoned out") for ≥5 s
10. Mouth opening ± shutting repeatedly with separation of teeth, for ≥10 s
11. Tongue exposed, protruding or hanging out, and/or moving in and out repeatedly
12. Bit pulled through the mouth on one side (left or right), repeatedly
13. Tail clamped tightly to middle or held to one side
14. Tail swishing large movements: repeatedly up and down/side to side/circular; repeatedly during transitions
15. A rushed gait (frequency of trot steps >40/15 s); irregular rhythm in trot or canter; repeated changes of speed in trot or canter
16. Gait too slow (frequency of trot steps <35/15 s); passage-like trot
17. Hindlimbs do not follow tracks of forelimbs but repeatedly deviate to left or right; on 3 tracks in trot or canter
18. Canter repeated leg changes in front and/or behind: repeated strike off wrong leg; disunited
19. Spontaneous changes of gait (e.g., breaks from canter to trot or trot to canter)
20. Stumbles or trips more than once; repeated bilateral hindlimb toe drag
21. Sudden change of direction, against rider's directions/cues; spooking
22. Reluctance to move forward (has to be kicked ± verbal encouragement), stops spontaneously
23. Rearing (both forelimbs off the ground)
24. Bucking or kicking backward (one or both hindlimbs)

3. Application of the Ridden Horse Pain Ethogram to Horses with Musculoskeletal Pain and Comparison Before and After Diagnostic Anesthesia

To provide further evidence that the behaviors were a reflection of musculoskeletal pain, video recordings of 10 lame horses were reviewed blindly in random order by a trained assessor before and after diagnostic anesthesia resolved the baseline lameness and improved any gait abnormalities seen in canter.[38] The mean and median scores before diagnostic anesthesia were 12.1 and 12 out of 24, respectively (range, 6–14). After lameness resolution, the mean and median scores reduced to 5.9 and 5, respectively (range, 3–10). The marked reduction in behavior scores following resolution of lameness verified a causal relationship between musculoskeletal pain and the behaviors.

An additional study demonstrated that non-trained assessors from different professional backgrounds could differentiate between lame horses before and after diagnostic anesthesia had abolished low-grade lameness (most frequent lameness grade, 2/8) by application of the Ridden Horse Pain Ethogram.[39] Anonymized video recordings of 21 lame horses, ridden by professional riders in trot and canter before and after diagnostic anesthesia had abolished lameness, were reviewed in a random order by a trained assessor and 10 untrained assessors. For each horse, the duration of the recordings before and after diagnostic anesthesia was time matched. The number of behaviors exhibited by the 21 lame horses prior to diagnostic anesthesia ranged from 3.6 to 11.6/24 (median, 9; mean, 9.1). After lameness and overall performance had been substantially improved using diagnostic anesthesia, the number of behaviors was significantly reduced ($P < 0.0001$), ranging from 1.6 to 8.5/24 (median, 4.5; mean, 4.2).

4. Application of the Ridden Horse Pain Ethogram in Real Time

Ten equine veterinarians (the "test observers") (after preliminary training) and an experienced assessor applied the Ridden Horse Pain Ethogram to 20 horse-rider combinations performing a purpose-designed dressage test (8.5 minutes).[40] The horses were a convenience sample, in regular work, and capable of working 'on the bit.' Video recordings of the test were analyzed retrospectively by the experienced assessor. Lameness or abnormalities of canter, saddle-fit, the presence of epaxial muscle tension/pain, and rider-skill-level were determined by independent experts. Sixteen horses were lame, 11 had an ill-fitting saddle, and 14 had epaxial muscle tension/pain. The experienced assessor determined total behavior scores of 3–6/24 for the non-lame horses, 2 lame horses scored 3 and 6, and 14 lame horses scored 8–16. There was no significant difference in real-time scores and video-based scores for the experienced assessor. There was good agreement between the experienced assessor's scores and the mean test observer scores. There was excellent consistency in overall agreement among raters (intraclass correlation, 0.97; $P < 0.001$). There was a significant difference between ethogram scores according to lameness status for real-time ($P = 0.017$) and video ($P = 0.013$) observations by the experi-

Fig. 1. The tail is crooked, being held to the right. The horse is moving crookedly, on three tracks, with the right hindlimb following the track of the left forelimb, and the left hindlimb on an inner track.

Fig. 2. The head is tilted with the nose to the right. The right ear is behind a vertical position.

enced assessor and for the test observers' mean (P = 0.03). There was no significant effect of muscle pain, saddle-fit, or rider-skill on behavior. It was concluded that the Ridden Horse Pain Ethogram was applied consistently by veterinarians with differentiation between non-lame and most lame horses. After appropriate training in its application, the ethogram may provide a useful tool for determining the presence of musculoskeletal pain in horses performing poorly.

5. Application of the Ridden Horse Pain Ethogram and Its Association with Performance

The potential power of the Ridden Horse Pain Ethogram was demonstrated by its application to horses warming up for dressage for a four-star (now five-star) 3-day event.[41] Thirty-five consecutive horses competing on day 2 dressage were each assessed for a minimum of 10 minutes during trot and canter. Horses were classified subjectively as non-lame, lame, or showing a stiff, stilted gait. The Ridden Horse Pain Ethogram was applied by a trained assessor. Cross-country performance was obtained from the competition website; horses were classified as completing, eliminated, or retired. Twenty-seven non-lame horses scored 0–4/24 behaviors (mean and median, 2/24); the most frequently observed behaviors were head behind the vertical ≥10s and mouth open ≥10s. Eight horses with gait abnormalities scored 3–9/24 (median, 7.5; mean, 6). Thirty-four horses started cross-country. Of 28 horses that scored <7, 8 (28.6%) were eliminated or retired. Of 6 horses that scored ≥ 7, 4 (66.7%) were eliminated or retired. The proportion of horses failing to complete was significantly higher ($P < 0.01$, t test) for scores ≥ 7, compared with <7. However, one horse with a stiff, stilted gait scored 9 but completed. Horses can pass a veterinary inspection but show gait abnormalities when ridden, highlighted by be-

Fig. 3. The horse has an intense stare. The bit is pulled through to the left. The tail is swishing. The lips are separated, but not the teeth, so this does not constitute mouth opening. The horse is sweating disproportionately.

havioral changes. Gait abnormalities may compromise cross-country performance in some horses, although a causal relationship between failure to complete and gait abnormalities cannot be proven.

6. The Influence of Rider Size on Ridden Horse Behavior

In a prospective, cross-over, randomized trial, six non-lame horses in regular work, 500–600 kg body weight, were ridden by four riders of similar ability, but different body weights (rider:horse body weight 10–12% [L = Light], >12≤15% [M = Moderate], >15<18% [H = Heavy], >20% [VH = Very Heavy]), performing a standardized 30-minute dressage test.[42] Horses were evaluated throughout the test for the presence of lameness and the Ridden Horse Pain Ethogram was applied in real time. Tests were abandoned for ≥grade 3/8 lameness or ≥10 behavioral markers (assessed in real time). The Ridden Horse Pain Ethogram was also applied retrospectively to video recordings of predefined parts of the test in trot and canter by an experienced assessor.

All 13 H and VH rider tests were abandoned (temporary lameness, n = 12; behavior, n = 1 [10/24 behaviors in canter), as was 1 of 12 M rider tests (temporary lameness). For the retrospective video analysis, there were significant differences among riders in the total sum of behaviors for trot (ANOVA, Bonferroni: M vs H, $P < 0.01$; L and M vs VH, $P < 0.001$; H vs VH, $P < 0.05$). The total number of behaviors correlated positively with rider weight (Spearman: R = 0.4, $P < 0.01$), although in only 1 of 37 tests was the total behavior score ≥8. The numbers of behaviors reflecting head position and facial expression were significantly higher with the heavier riders (ANOVA, Bonferroni: $P < 0.001$–0.05), whereas body markers (head and tail movement) and gait markers (behavior, not kinematics) showed non-significant changes. Statistical comparisons for canter could not be performed because of early abandonment of tests for the H and VH riders.

It was concluded that rider size (height and weight) may influence ridden horse behavior, which may reflect discomfort.

7. Discussion

The observation of 8 or more of the 24 behaviors of the Ridden Horse Pain Ethogram is likely to reflect

Fig. 4. The front of the horse's head is more than 10° behind a vertical position. The tongue is out.

Fig. 5. The front of the horse's head is >30° in front of a vertical position; the ears are behind a vertical position; the horse has an intense stare; the tail is swishing.

the presence of musculoskeletal pain, although some lame horses exhibit less than 8 behaviors. It is important to observe horses from all perspectives (from in front, behind, and the side), performing at least trot and canter and transitions between gaits both going around the periphery of an arena and performing 10-meter diameter circles in rising trot to ascertain comprehensive scoring. Some horses show more signs consistent with pain in canter than in trot or vice versa. However, pain may only be manifested in some horses doing more specialized and physically demanding movements (e.g., shoulder-in, collected trot half-pass, and canter flying changes), so inclusion of these movements in the assessment for some horses is recommended. Observation of a horse working for 5 to 10 minutes should be adequate.

There is no correlation between lameness severity when ridden and the number of behaviors of the Ridden Horse Pain Ethogram that are displayed. It should be borne in mind that if lameness is present in more than one limb, it may not be graded accurately. There is also marked diversity of the occurrence of each of the 24 behaviors, which is not necessarily related to lameness grade but to physical musculoskeletal discomfort and perception of pain by the individual horse.[37–40] However, the presence of eight or more behaviors indicates pain, even if overt lameness is not observed. This is important when assessing a horse prior to purchase, evaluating a horse with a history of poor performance, and when performing routine assessments of sports horses to determine if performance could be enhanced. Early recognition of musculoskeletal pain and accurate identification of the source(s) of pain may enable the successful treatment and, thus, improved performance and minimize the risk of the development of secondary problems.

Training improved the accuracy of interpretation of the FEReq,[37] and the Ridden Horse Pain Ethogram[40] and is strongly recommended. On-line training is available.[43] The definitions for each behavior need to be recognized, understood, and correctly applied. A number of factors need to be assessed before application of the Ridden Horse Pain Ethogram. In some horses, the sclera is visible at rest in one or both eyes, so this observation should not be included in the behavior score. If the bit is too wide, it may erroneously be concluded that it has been pulled through to one side. If the footing is very deep, this may induce hindlimb toe drag, which may not be observed on a better surface.

Some of the features of the Ridden Horse Pain Ethogram could also be influenced by the type of bit and its use and the rider's skill, balance, and use of their hands. Preliminary results indicate that the behavior scores of lame and non-lame horses ridden by riders of differing ability are similar, although work quality may differ[a]. The mouth repeatedly opening with separation of the teeth and the tongue protruding were both significantly associated with lameness.[38] It has been suggested that such evasions could also be a reaction to the presence of a bit[44–47] or an ill-fitting noseband.[48–51] However, such evasive behavior may prompt owners to intro-

Fig. 6. The horse is spooking, not following the rider's cues. The tail is swishing.

duce nosebands, such as a crank noseband with a flash or to tighten nosebands rostral to the bit.

Although saddle fit did not significantly influence behavior scores in one study,[40] an ill-fitting saddle does have the potential to induce abnormal behaviors, which disappear if a better fitting saddle is used.

There are a number of additional features that have not been assessed objectively but that are of potential clinical relevance during ridden exercise: teeth grinding, abnormal breathing noises, grunting, and sweating disproportionate to the level and amount of work, fitness, and environmental temperature. There are features that may be felt by a rider: episodic shooting forwards, absence of rein tension (not taking a contact), symmetrically increasing rein tension (hanging on the reins), asymmetrical rein tension (hanging on one rein more than the other), reduced range of motion of thoracolumbosacral region ("back stiffness"), tension, lack of hindlimb impulsion, and being on the forehand. There are also features of gait that are difficult to reliably measure without high-speed video, such as alterations in canter (e.g., temporal and spatial separation of the hindlimbs during the stance phase). Assessment of blink rate was not performed but may be useful for future studies. Increased blink rate has been linked positively to the amount of dopamine in the basal ganglia of the brain,[52] and dopamine levels may increase as a result of pain.[53]

Definitive differentiation between pain or discomfort induced by tack and other innate behavioral reasons cannot be made on the basis of these studies. When a horse is learning a new movement, it may misunderstand the rider's cues or find it physically difficult due to the unaccustomed use of specific muscle groups, which may result in delayed onset muscular stiffness.[54,55] Conflict behavior[56] or resistant behavior may be displayed, but persistence of such behaviors would not be expected unless there was an underlying pain-related problem. Recognition of changes in behavior facilitates recognition of improvement in performance and willingness to work following improvement or resolution of pain causing lameness using diagnostic anesthesia. The persistence of 8 or more of the 24 behaviors of the Ridden Horse Pain Ethogram is likely to indicate residual musculoskeletal pain, requiring further investigation.

The Ridden Horse Pain Ethogram was developed in sports horses used in the Olympic disciplines in which the horse is expected to work with the front of the head in a vertical position, on the bit, when performing schooling-type work. However, other than head position, the ethogram is readily transferable for other types of work (e.g., jumping), when working individually, although close proximity of other horses may influence behavior.

8. Conclusions

It is concluded that the demonstration of 8 or more of the 24 behaviors of the Ridden Horse Pain Ethogram is highly likely to reflect the presence of musculoskeletal pain in sports horses, although some lame horses score less than 8. It is considered important that those interacting in any way with or responsible for horses are educated about the signs that may reflect pain when horses are ridden (e.g., ears back, mouth opening, tongue out, change in eye posture and expression, going above the bit, head tossing, tilting the head, unwillingness to go, crookedness, hurrying, changing gait spontaneously, poor quality canter, resisting, and stumbling and toe dragging). If changes in body postures and resistance to following commands could be used to alert riders of potential pain, then the welfare of horses could be significantly improved. Horses would not fall victim to harder training practices that could further aggravate musculoskeletal pain or to a punishment-based training regimen to address the animal's unwillingness to follow commands of the rider.

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Declaration of Ethics

The studies were approved by the Clinical Ethical Review Committee of the Animal Health Trust and adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Author has no conflicts of interest.

References and Footnote

1. Greve L, Dyson S, Pfau T. Alterations in thoracolumbosacral movement when pain causing lameness has been improved by diagnostic analgesia. *Vet J* 2017;224:55–63.
2. Greve L, Pfau T, Dyson S. Alterations in body lean angle in lame horses before and after diagnostic analgesia in straight lines in hand and on the lunge. *Vet J* 2018;239:1–6.
3. Greve L, Dyson S. The interrelationship of lameness, saddle slip and back shape in the general sports horse population. *Equine Vet J* 2014;46:687–694.
4. Rhodin M, Roepstorff L, French A, et al. Head and pelvic movement asymmetry during lungeing in horses with symmetrical movement on the straight. *Equine Vet J* 2016;48: 315–320.
5. Dyson S, Greve L. Subjective gait assessment of 57 sports horses in normal work: A comparison of the response to flexion tests, movement in hand, on the lunge and ridden. *J Equine Vet Sci* 2016;38:1–7.
6. McLean A, McGreevy P. Horse-training techniques that may defy the principles of learning theory and compromise welfare. *J Vet Behav* 2010;5:187–195.
7. Hall C, Huws N, White C, et al. Assessment of ridden horse behaviour. *J Vet Behav* 2013;8:62–73.
8. Bussières G, Jacques C, Lainay O, et al. Development of a composite orthopaedic pain scale in horses. *Res Vet Sci* 2008;85:294–306.
9. Lindegaard C, Thomsen M, Larsen S, et al. Analgesic efficacy of intra-articular morphine in experimentally induced radiocarpal synovitis in horses. *Vet Anaesth Analg* 2010;37: 171–185.
10. Gleerup KB, Lindegaard C. Recognition and quantification of pain in horses: A tutorial review. *Equine Vet Educ* 2016; 28:47–57.
11. Wathan J, Burrows A, Waller B, et al. EquiFACS: The equine facial action coding system. *PLoS One* 2015;10: e0131738.
12. Gleerup K, Forkman B, Lindegaard C, et al. An equine pain face. *Vet Anaesth Analg* 2014;42:103–114.
13. Dalla Costa E, Minero M, Lebelt D, et al. Development of the horse grimace scale (HGS) as a pain assessment tool in horses undergoing routine castration. *PLoS One* 2014;9: e92281.
14. Hausberger M, Fureix C, Lesimple C. Detecting horses' sickness: In search of visible signs. *J Appl Anim Behav Sci* 2016;175:41–49.
15. Van Loon J, Van Dierendonck M. Monitoring acute equine visceral pain with the Equine Utrecht University Scale for Composite Pain Assessment (EQUUSCOMPASS) and the Equine Utrecht University Scale for Facial Assessment of Pain (EQUUS-FAP): a scale-construction study. *Vet J* 2015; 206:356e364.
16. Hall C, Kay R, Yarnell K. Assessing ridden horse behavior: Professional judgment and physiological measures. *J Vet Behav* 2014;9:22–29.
17. Visser E, Van Dierendonck M, Ellis AD, et al. A comparison of sympathetic and conventional training methods on responses to initial horse training. *Vet J* 2009;181:48–52.
18. Mullard J, Berger J, Ellis A, et al. Development of an ethogram to describe facial expressions in ridden horses (FEReq). *J Vet Behav* 2017;18:7–12.
19. Dyson S, Berger J, Ellis A, et al. Can the presence of musculoskeletal pain be determined from the facial expressions of ridden horses (FEReq)? *J Vet Behav* 2017;19:78–89.
20. Dyson S, Ellis A, Mullard J, et al. Response to Gleerup: Understanding signals that indicate pain in ridden horses. *J Vet Behav* 2018;23:87–90.
21. Girodroux M, Dyson S, Murray R. Osteoarthritis of the thoracolumbar synovial intervertebral articulations: Clinical and radiographic features in 77 horses with poor performance and back pain. *Equine Vet J* 2009;41:130–138.
22. Meehan L, Dyson S, Murray R. Radiographic and scintigraphic evaluation of spondylosis in the equine thoracolumbar spine: A retrospective study. *Equine Vet J* 2009;41:800–807.
23. Zimmerman M, Dyson S, Murray R. Close, impinging and overriding spinous processes in the thoracolumbar spine: The relationship between radiological and scintigraphic findings and clinical signs. *Equine Vet J* 2011;44:178–184.
24. Dyson S, Murray R. Management of hindlimb proximal suspensory desmopathy by neurectomy of the deep branch of the lateral plantar nerve and plantar fasciotomy: 155 horses (2003–2008). *Equine Vet J* 2012;44:361–367.
25. Dyson S. Proximal injuries of the accessory ligament of the deep digital flexor tendon in forelimbs and hindlimbs: 12 horses (2006–2010). *Equine Vet Educ* 2012;23:134–142.
26. Parkes B, Newton R, Dyson S. An investigation of risk factors for foot-related lameness in a UK referral population of horses. *Vet J* 2013;196:218–225.
27. Dyson S. Hindlimb lameness associated with proximal suspensory desmopathy and injury of the accessory ligament of the suspensory ligament: five horses. *Equine Vet Educ* 2014;26:538–542.
28. Plowright E, Dyson S. Concurrent proximal suspensory desmopathy and injury of the accessory ligament of the deep digital flexor tendon in forelimbs or hindlimbs of 19 horses. *Equine Vet Educ* 2015;27:355–364.
29. Barstow A, Dyson S. Clinical features and diagnosis of sacroiliac joint region pain in 296 horses: 2004–2014. *Equine Vet Educ* 2015;27:637–647.
30. Dyson S, Rasotto R. Idiopathic hopping-type forelimb lameness syndrome in ridden horses: 46 horses (2002–2014). *Equine Vet Educ* 2016;28:30–39.
31. Thomson K, Chan C, Dyson S. Head tossing behaviour in six horses: idiopathic headshaking or musculoskeletal pain? *Equine Vet Educ* 2018;doi:10.1111/eve/13084.
32. Jonckheer-Sheehy V, Delesalle C, van den Belt A, et al. Bad behavior or a physical problem? Rearing in a Dutch Warmblood mare. *J Vet Behav* 2012;7:380–385.
33. Newton S, Knottenbelt D, Eldridge P. Headshaking in horses: possible aetioathogenesis by the results of diagnostic tests and several treatment regimes used in 20 cases. *Equine Vet J* 2000;32:208–211.
34. Berger J, Bell S, Holmberg B, et al. Successful treatment of headshaking in a horse using infrared diode laser deflation and coagulation of corpora nigra cysts and behavioral modification. *J Am Vet Med Assoc* 2008;233:1610–1612.
35. Aleman M, Williams D, Brosnan R, et al. Sensory nerve conduction and somatosensory evoked potentials of the trigeminal nerve in horses with idiopathic headshaking. *J Vet Intern Med* 2013;27:1571–1580.
36. Pickles K, Madigan J, Aleman M. Idiopathic headshaking: is it still idiopathic? *Vet J* 2014;210:21–30.
37. Dyson S, Berger J, Ellis A, et al. Development of an ethogram for a pain scoring system in ridden horses and its application to determine the presence of musculoskeletal pain. *J Vet Behav* 2018;23:47–57.
38. Dyson S, Berger J, Ellis A, et al. Behavioural observations and comparisons of non-lame horses and lame horses before and after resolution of lameness by diagnostic analgesia. *J Vet Behav* 2018;26:64–70.
39. Dyson S, Van Dijk K. Application of a ridden horse ethogram to video recordings of lame horses before and after diagnostic analgesia. *Equine Vet Educ* 2018;doi:10.1111/eve.13029.
40. Dyson S, Thomson K, Quiney L, et al. Can veterinarians reliably apply a whole horse ridden ethogram to differentiate non-lame and lame horses based on live horse assessment of behaviour? *Equine Vet Educ* 2019;doi:10.1111/eve.13104.

41. Dyson S. Application of a ridden horse ethogram to horses competing at a 4-star three-day-event: comparison with cross-country performance. *Equine Vet J* 2019;51:11.
42. Dyson S, Ellis A, Quiney L, et al. The influence of rider: horse bodyweight ratio on equine gait, behaviour, response to thoracolumbar palpation and thoracolumbar dimensions: a pilot study, in *Proceedings.* 14th International Society of Equitation Science Congress, Rome 2018;120.
43. Dyson S. 2019. How to recognise the 24 behaviours indicating pain in the ridden horse. Available at: https://www.equitopiacenter.com/courses/24-behaviors-indicating-pain-in-the-ridden-horse-dr-sue-dyson/. Accessed on February 17, 2020.
44. Manfredi J, Rosenstein D, Lanovaz J, et al. Fluoroscopic study of oral behaviors in response to the presence of a bit and the effects of rein tension. *Comp Exerc Phys* 2009;6: 143–148.
45. Cook W, Mills D. Preliminary study of jointed snaffle vs. cross-under bitless bridles: Quantified comparison of behaviour in four horses. *Equine Vet J* 2009;41:827–830.
46. McGreevy P, Warren-Smith A, Guisard Y. The effect of double bridles and jaw clamping crank nosebands on facial cutaneous and ocular temperature in horses. *J Vet Behav* 2012;7:142–148.
47. Eiseriö M, Roepstorff L, Wesihaupt M, et al. Movements of the horse's mouth in relation to horse-rider kinematic variables. *Vet J* 2013;198:e33–e38.
48. Casey V, McGreevy P, O'Muiris E, et al. A preliminary report on estimating the pressures exerted by a crank noseband in the horse. *J Vet Behav* 2013;8:479–484.
49. Fenner K, Yoon S, White P, et al. The effect of noseband tightening on horses' behavior, eye temperature and cardiac responses. *PLoS One* 2016;11:e0154179.
50. Doherty O, Casey V, McGreevy P, et al. Noseband use in equestrian sports—an international study. *PLoS One* 2017; 12:e0169060.
51. McGreevy P, Doherty O, Channon W, et al. The use of nosebands in equitation and the merits of an international equestrian welfare and safety committee: a commentary. *Vet J* 2017;222:36–40.
52. Swerdlow NR, Wasserman L, Talledo J, et al. Prestimulus modification of the startle reflex: relationship to personality and physiological markers of dopamine function. *Biol Psychol* 2003;62:17–26.
53. Raekallio M, Taylor PM, Bloomfield M. A comparison of methods for evaluation of pain and distress after orthopaedic surgery in horses. *J Vet Anaesth* 1997;24:17–20.
54. Mizuma K, Taguchi T. Delayed onset muscle soreness: involvement of neurotrophic factors. *J Physiol Sci* 2016;66: 43–52.
55. Szymanski DJ. Recommendations for the avoidance of delayed-onset muscle soreness. *J Strength Cond Res* 2001; 23:7–13.
56. Górecka-Bruzda A, Kosińska I, Jaworski Z, et al. Conflict behavior in elite show jumping and dressage horses. *J Vet Behav* 2015;10:137–146.

[a]Dyson S. Unpublished data, March 2020.

High-Power Laser Therapy Improves Healing of the Equine Suspensory Branch in a Standardized Lesion Model

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This standardized controlled study shows that multi-frequency high-power laser therapy significantly improves healing of surgically induced lesions in the suspensory branch. Authors' addresses: Department of Virology, Parasitology & Immunology, Research Group of Comparative Physiology, (Pluim, Plancke, Delesalle); Department of Surgery and Anaesthesiology of Domestic Animals (Martens, Oosterlinck); Department of Veterinary Medical Imaging and Small Animal Orthopedics (Vanderperren); Department of Obstetrics, Reproduction and Herd Health, Unit of Veterinary Epidemiology, (Dewulf); Faculty of Veterinary Medicine, Ghent University, Merelbeke, Belgium; Tierklinik Lüsche, GmbH, Bakum, Germany (Pluim, Koene, Luciani); Department of Clinical Sciences, Utrecht University, Yalelaan 112, Utrecht, the Netherlands (van Weeren); Brussels University Hospital, Radiology Department, Laarbeeklaan 101, 1090 Brussels, Belgium (Kichouh, Van Thielen); Odisee Hogeschool, Campus Terranova, Training Center for Imaging Technologists, Blekerijstraat 23-29, 1000 Brussels, Belgium (Van Thielen); e-mail: mpluim@tierklinik-luesche.de. *Corresponding and presenting author.

1. Introduction

High-power laser therapy (>15 W) is used for treatment of soft-tissue injuries in humans and horses, but standardized controlled studies on its efficacy are lacking. In this study the effect of high-power laser was evaluated in a standardized lesion model in horses.

2. Materials and Methods

In 12 Warmblood horses, lesions were created in all 4 lateral suspensory branches. For 4 weeks, each horse was treated with high-power laser on 2 of the 4 lesioned branches. Follow up with ultrasound and Doppler was performed blinded during and after treatment period. In the short-term study, 6 horses were

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euthanized 4 weeks post-surgery, whereas in the long-term study, 6 horses were further rehabilitated until 6 months and then euthanized. Magnetic resonance imaging (MRI) evaluation was performed blinded on all cadaver limbs.

3. Results and Discussion

Transverse lesion size on ultrasound was significantly smaller in the treatment group after 2 and 3 months (P = .026 and P = .015). The enlargement of the circumference and cross-sectional area of the lesion over time was significantly lower in the short-term treatment group (P = .016 and P = .010). During treatment, laser treated branches showed a significantly increased Doppler signal (P < .001). On MRI, both short- and long-term groups, the mean signal was significantly lower (P = .006) and the cross-sectional area of the lesions significantly smaller (P = .002) in the treated branches. These diagnostic imaging parameters indicate significant enhanced healing of a suspensory branch lesion after high-power laser therapy.

Acknowledgments

Declaration of Ethics

The Authors have adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Authors have no conflicts of interest.

Healthy Practice Measures (Benchmarking) for Solo and Multi-Doctor Practices

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Information technology allows massive accumulation of operational and experiential data. Practice owners have opportunities to compare data from their practices against history and cohorts. Plan and decide what, how, and when to measure, to trend results, and optimize future improvement of their practice. Author's address: 934 Main Street, Grafton, OH 44044; e-mail: mheinke@vpmp.net.

1. Introduction

From the Merriam-Webster dictionary, a benchmark is defined as something that serves as a standard by which others may be measured or judged.[a] In business, benchmarking means the purposeful study and comparison against outside reference sources, such as industry-aggregated data or a competitor, to improve the performance of one's own company.

In small business, the number-one order of financial interpretation is to assure internally generated data is reliable, accurate, and consistent. To otherwise embark on benchmarking expeditions against outside data citations is a fool's journey. Until internal data accumulation is commandeered and practice results understood, an external benchmark endeavor is a waste of time and resources. First assure internal practice data trends are well understood and acted upon.

A good analogy can be made with the conduct of veterinary medical practice: the widely understood language of scientific nomenclature and medical terminology allows swift and accurate communication among veterinary medical professionals. Consistent ways of describing patient history, physical observations, and surgical and medical procedures increase practice quality and efficiency.

Similarly, understanding accounting and business intelligence terminology aids communication about the financial health of a veterinary practice in the same way. Wise use of technology further enhances financial data visualization and interpretation. The combination of affordable software, cognitive computing, accelerating application development, powerful personal computer processors, and cloud computing in the space of "big data" requires an even greater level of business intelligence sophistication in successful veterinary practices.

The basis of reliable financial and other essential practice data is a sound organized approach for methodic collection, recording, sorting, and summarization. In the case of operational and financial data, a reliable accounting system depends on accurate categorization of each practice's financial transaction by knowledgeable and trained personnel. Veterinary practice bookkeeping and accounting systems also require logical organization of data into reports that

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enhance management assessment of economic outcomes, including benchmarking activities.

2. Solutions and Discussion

System of Data Organization Required

Veterinary practice financial data organization requires a chart of accounts. In 2005, the author's firm expressly designed the Equine Veterinary Practice Chart of Accounts (EVPCOA), an organized list of all the asset, liability, equity, income, and expense accounts used in an equine veterinary practice for categorizing and recording each financial transaction.[1] In 2017, Veterinary Study Groups with American Animal Hospital Association (AAHA) and American Veterinary Medical Association (AVMA) published an updated version of a Chart of Accounts (COA) geared toward companion animal practices.

Because the author's firm was the primary author of this latter project, the EVPCOA and Companion Animal COA are not tremendously dissimilar. One or the other implemented by well-trained bookkeepers will put the practice's accounting house in order, leading to the consistent and efficient collection and aggregation of data that can be reasonably benchmarked against practice history, as well as the potential for comparison to other practices using similar business processes.

Foundational Work Leads to Practice Financial Health[2]

In the second of two conference papers[3] the importance of underlying practice principles to guide and drive success is discussed: Mission, Vision, Professional Ethics, and Core Values.

These critical elements lead directly to the specific measures of practice financial health. Consider them equally to that of establishing internal systems of accounting and measurement that allows practice leadership to optimize healthy financial performance over the long haul.

Methodical approaches to planning eventually illuminates the need for historical trends and understanding of current practice activities, that lead to established activities to drive future performance with predictability.

Avoiding Analysis Paralysis

With the proliferation of computer applications representing the new normal of business life, managers easily become overwhelmed with data and reports to the point that detail may obscure the overall practice situation. As the saying goes, the forest view is lost because of the trees.

Too much detail potentially causes inertia and confusion. More to the point, how can anyone find the time to sift through all this information, let alone act upon the information it conveys in the moment?

Thus, businesses emphasize real-time "bird's-eye" views of selected data, most often called KPIs. KPIs are presented in infinite varieties of interactive formats. While technology increasingly provides self-serve applications to achieve the 10,000-foot perspective, all share common elements:

- KPIs = mission-critical indices that give "at-a-glance" data points.
- Data trends = KPIs are followed over time and indicate and predict practice economic health.
- Reliable systems = KPIs and KPI trends are only as good as the data input, by trained personnel with attentive eyes to accuracy and consistency, and through appropriate oversight by administration, and using the veterinary practice COA.
- Timeliness = quick report turnaround is needed to guide practice decisions.
- Goal accountability = practice strategic planning and goal setting leads to methodic choice of key performance drivers, activities that encourage employee success in advancing selected objectives.

The foundation for operational KPIs and management reporting rests on consistent protocols for data collection. The typical baseline operational KPIs originate from both the financial accounting and veterinary practice information management software (VPIMS) reports.

Because data are plentiful and time is scant, a limited number of KPIs are usually chosen based on significance to sustaining practice profitability.

✓Profit is crucial to practice longevity.
✓Profit replenishes the supplies used.
✓Profit allows planning for contingencies.
✓Profit leads to adequate reserves when equipment suddenly breaks and must be replaced.
✓Profit allows more compensation for those deserving through their work ethic and effort.

Benchmarks of Success That Everyone Should Consider

1. Profitability
   a. What is it
   b. How is it measured
2. Cash flow is not profit
   a. Where to find it: statement of cash flows
   b. Financial statement showing sources and uses of cash
3. Budgets and budget variances
   a. Improve profitability and cash flow by planning for it, and
   b. Measuring results against the plan
   c. Plan borrowing and debt service, capital reinvestment: will debt promote growth?
4. Daily, weekly, monthly revenue breakeven monitoring
   a. Calculate revenue breakeven
   b. Refine for seasonality
5. Human capital performance
   a. Are they happy? Will they stay?
   b. Amount and cost of turnover

   c. Determine satisfaction
6. Client growth and retention
   a. Client retention rate
   b. Net promoter score
   c. Marketing outreach—social media goals

Desperately Seeking Causality

Ask any veterinary practice owner or consultant if they want to see benchmarks that imply causality to high profit. They will immediately lean in with rapt attention. Unfortunately, linking one piece of operational data to another does not necessarily provide the reasons for success or create a road map to improvement.

Unique, ambiguous, and perceived-as-unmeasurable characteristics are often considered possible correlating factors but are difficult to confirm or verify: a veterinarian's charismatic persona, positive team attitude, satisfied client perceptions, tidy practice appearance, and convenient location, and many more.

What performance characteristics lead to financial success that aren't measured? To a large extent, the missing components relate to lack of a clearly documented, contemporaneous understanding of what clients and employees think and feel. Why does one practice have high turnover and another doesn't? How do such factors impact each practice entity's profitability and ability to grow over time? Why do some hospitals successfully optimize client attendance and referrals and others fail?

Connecting the X's and O's

These squishy questions relate to what is now called *experiential data*, otherwise called X-data. This is a different kind of data that gains practice insight into why operational data (O-data) show what it does on an historical basis. By contemporaneously collecting information and opinions, thoughts, and feelings from the people important to business success, practice stakeholders can increasingly understand where they can do better to improve operational data outcomes.

X-data provide important, missing insight into business challenges faced in a new virtual world full of social media influence, information overload, and competition that spans far beyond local colleagues. It is easy to relate to massive business environment changes when a veterinary practice management team experiences the horror of an angry client opining untruths on Facebook or through a Yelp review. Businesses of all kinds are punished by an upset client when employee experience is not up to par.

Veterinary managers and practice owners have long intuited that there must be missing components that can be measured, correlated to profit, and managed, especially when they get very interested in analyzing operational data and then figuring out how can they make it better. The missing components are measurements of the human experience, and the gaps between what managers think is happening, what the client feels, and what actual measurements might show.

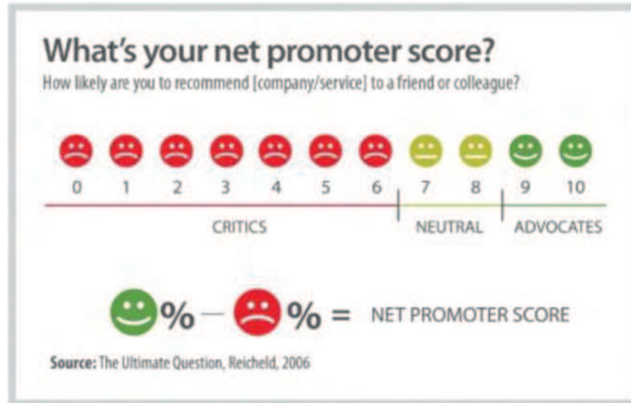

Fig. 1. The net promoter score is the number one key performance indicator.

Artificial intelligence and machine learning allow powerful and capable collection and interpretation of data, including experiential. In business, four foundational aspects of X-data have been described: Brand, Product, Client, and Employee. Each of these arenas is of intense artificial intelligence developmental interest: robust applications can curate surveyed opinions and perspectives and exploit the results to identify gaps that a business can narrow to gain competitive advantage.

Net Promoter Score

A good example of the new business world, where companies increasingly seek shortcut approaches to assessing experiential data is the Net Promoter Score (NPS; Fig. 1). NPS is a simple pulse survey method that attempts to measure client loyalty to a company or brand. Introduced by a 2003 Harvard Business Review article ("The One Number You Need to Grow"), NPS has evolved into the most commonly used measure of purported customer satisfaction and revenue growth correlation.

NPS is measured by a one- or two-question survey. The first, and sometimes only, question asks "On a scale of 0 to 10, how likely are you to recommend our practice to a friend?" The second optional follow-up question seeks client explanation of the rating.

As for any data point that is measured and monitored, the regularly tracked NPS trend for a practice may be the most important benchmarking factor. An internet search for veterinary NPS data, turned up a 2019 reference citing an average of 30, with a score of 55 correlated with clients who feel highly empowered about care of their pets.[b] An older 2012 article based on "hundreds" of UK practices, yielded a NPS of 75.8 (promoters of 81.3% and detractors of 5.5), while a survey across 15 European countries via an online pet forum with 304 respondents scored 55.[c]

In a June 21, 2018 blog, the author explained his practice's score was 84%, and mentioned an overall

Profit Margin Computation	
Tax Return - Taxable Income or Loss	
(Or bottom line BEFORE INCOME TAXES from Profit and Loss Report)	$ 20,000
Add Back:	
Interest Expense	15,000
Loss on Disposal of Assets	1,000
Depreciation and Amortization Expense	75,000
Owner Salaries, Wages, and Bonuses (Gross)	165,000
Estimated Owner Payroll Taxes (Employer Portion Only)	14,025
Guess at 8.5% Of Prior Line, if you don't know	
Owner Related Retirement Contributions and Insur. Benefits	42,000
(Practice/Employer portion only, not withholdings from wages)	
Rent (if not "arms-length")	72,000
Subtract:	
Gain on Disposal of Assets	(2,020)
Rental Revenues	-
Interest Revenues	(1,200)
Misc. Other Revenues Unrelated to Veterinary Operations	-
Estimated Normal Depreciation	(24,375)
Use 1.5% of Gross Income	
Estimated Normal Compensation for Owner	(105,000)
DVMS - Production Portion	
Estimated Normal Owner Compensation for Management Duties	(35,000)
5% of Gross Income is good starting estimate for total practice requirement; Keep in mind other staff providing management services - residual is left for owner compensation relative to management	
Payroll tax effect (estimate at 8.5% of Normal Owner Compensation)	(8,925)
Estimated Fair Value Rent Expense	(49,000)
Computed Net Profit	$ 227,505
Input Gross Income	$ 1,625,000
Net Profit Margin as Percent of Gross Income	14.0%

Fig. 2. Profit margin computation.

33% response rate to the NPS survey, that was far higher than previous response rates of 10% to other types of customer surveys.[d]

Profit is the ultimate KPI. Actually, profit will comprise TWO KPIs to manage: profit as a monetary amount and net profit as a percentage of gross income, otherwise called *profit margin*. Profit margin provides a better idea of practice financial strength than does profit. A veterinary practice can show some level of profit in dollars, but a low profit margin suggests a weak financial position.

There are many more metrics that include profit as a component of the calculation, but for the purposes of nearly all veterinary practices, managers follow and tend these two.

Very generally, profit is defined as revenues minus expenses. Yet profit is measured in different ways, with nuanced definitions. Here are just a few terms you will hear: EBITDA,[e] gross profit, net profit, taxable profit, and profit from business operations (operating profit). This last term, operating profit, is of most interest from a managerial perspective since it measures profit from the activities limited to veterinary practice. Operating profit equals operating revenue minus operating expenditures, and excludes taxes, interest expense, and interest income.

The unique aspects of each and every veterinary practice affects its operating profit and profit margin: location, local demographics and household income, species mix, competing service-provider options, pricing strategies, mix of service and product offerings, market presence, practice size (revenues and doctor numbers), and many more factors.

The industry range of veterinary practice operating profit margin is 1% to 25%, but most typically 5% to 20%. Excellent profit margin is generally considered 17% to 20% or more, good is 14% to 16%, fair is 11% to 13%, and underperforming 5% to 10%. Four percent or lower is cause for long-term survival concern, unless there are mitigating factors such as recent startup or transitioning into a significantly larger facility.

Even so, a practice generating $6 MM with steady annual growth, and operating profit margin of 8%

An Equine Practice, LLC FOR THE FISCAL YEAR ENDING DECEMBER 31ST	ACTUAL YEAR ENDING 2020 AMOUNT	% OF GROSS FEES	BUDGETED YEAR ENDING 2021 AMOUNT	% OF GROSS FEES	ACTUAL YEAR ENDING 2021 AMOUNT	% OF GROSS FEES	Variance Budget vs Actual 2021 AMOUNT	Variance %
EFFECTIVE GROWTH RATE TARGETED FOR DESIRED PROFIT MARGIN			8.00%					
GROSS FEES FROM PROFESSIONAL SERVICES	$1,522,000	100.00%	$1,643,760	100.00%	$1,625,670	100.00%	($18,090)	
OTHER INCOME:								
INTEREST INCOME	125	0.01%	135	0.01%	130	0.01%	(5)	0.00%
GAIN ON THE SALE OF ASSETS	1,674	0.11%	0	0.00%	0	0.00%	0	0.00%
MISCELLANEOUS INCOME	152	0.01%	0	0.00%	0	0.00%	0	0.00%
TOTAL OTHER INCOME	1,951	0.13%	135	0.01%	130	0.01%	0	0.00%
COST OF PROFESSIONAL SERVICES:								
DRUGS & PROFESSIONAL SUPPLIES	328,295	21.57%	345,190	21.00%	336,192	20.68%	(8,998)	-0.32%
LAB FEES & EXPENSES	33,636	2.21%	36,327	2.21%	37,257	2.29%	930	0.08%
GRAIN/HAY/BEDDING	10,045	0.66%	10,849	0.66%	11,522	0.71%	673	0.05%
MEDICAL WASTE DISPOSAL	7,914	0.52%	7,726	0.47%	7,854	0.48%	128	0.01%
MORTUARY SERVICES	9,284	0.61%	9,863	0.60%	10,101	0.62%	238	0.02%
Total Cost of Professional Services	389,175	25.57%	409,954	24.94%	402,926	24.79%	(7,028)	-0.15%
Variable Costs:								
Labor Related Costs								
COMPENSATION OF OFFICER DVM'S	262,849	17.27%	279,439	17.00%	282,000	17.35%	2,561	0.35%
COMPENSATION OF OTHER DVM'S	132,871	8.73%	147,938	9.00%	144,879	8.91%	(3,059)	-0.09%
Veterinary Wages and Salaries - Variable	395,720	26.00%	427,378	26.00%	426,879	26.26%	(499)	0.26%
COMPENSATION OF OFFICE MNGR/BOOKKEEPER	51,139	3.36%	53,422	3.25%	53,650	3.30%	228	0.05%
COMPENSATION OF TECHNICIANS	67,881	4.46%	69,860	4.25%	70,224	4.32%	364	0.07%
COMPENSATION OF RECEPTIONISTS	54,335	3.57%	57,532	3.50%	56,800	3.49%	(732)	-0.01%
COMPENSATION OF STABLE HANDS	34,397	2.26%	36,163	2.20%	34,500	2.12%	(1,663)	-0.08%
CASUAL LABOR	609	0.04%	329	0.02%	700	0.04%	371	0.02%
Support Personnel Wages and Salaries - Variable	208,362	13.69%	217,305	13.22%	215,874	13.28%	(1,431)	0.06%
EMPLOYER'S PORTION OF FICA	45,812	3.01%	48,029	2.92%	47,885	2.95%	(144)	0.02%
FEDERAL UNEMPLOYMENT	1,065	0.07%	1,151	0.07%	1,143	0.07%	(8)	0.00%
STATE UNEMPLOYMENT	6,849	0.45%	7,397	0.45%	7,512	0.46%	115	0.01%
WORKERS' COMPENSATION	9,436	0.62%	10,191	0.62%	9,977	0.61%	(214)	-0.01%
Payroll Tax Costs - Variable	63,163	4.15%	66,768	4.06%	66,517	4.09%	(251)	0.03%
RETIREMENT FUNDING	22,830	1.50%	24,656	1.50%	20,111	1.24%	(4,545)	-0.26%
EMPLOYEE BENEFIT PROGRAMS	26,483	1.74%	28,601	1.74%	29,500	1.81%	899	0.07%
PRACTICE VEHICLE/AUTO EXPENSES/VEH. INSUR/	41,094	2.70%	44,382	2.70%	39,637	2.44%	(4,745)	-0.26%
DUES & PUBLICATIONS	6,697	0.44%	7,233	0.44%	7,150	0.44%	(83)	0.00%
CONTINUING PROFESSIONAL EDUCATION	9,893	0.65%	10,684	0.65%	3,512	0.22%	(7,172)	-0.43%
TRAVEL	7,001	0.46%	7,561	0.46%	1,244	0.08%	(6,317)	-0.38%
MEALS & ENTERTAINMENT	2,435	0.16%	2,630	0.16%	344	0.02%	(2,286)	-0.14%
TELEPHONE/CELLULAR PHONES	17,503	1.15%	18,903	1.15%	18,734	1.15%	(169)	0.00%

Fig. 3. Sample practice budget.

(operating profit of $480,000), would be considered by many to be a superior practice to one with $1.5 MM of operating revenue and operating profit margin of 20% (operating profit of $300,000). Of course, numerous other factors would come to bear. Value is very much in the eye of the beholder.

Managers should know how to measure operating profit, even if it is just an approximation. In small, closely held businesses, interpreting profit usually requires a robust understanding of the elements of the financial statements, especially those of the profit and loss statement. The nature of small-business financial report preparation obscures results. Examples are listed below:

- Small-business bookkeeping fulfills dual purposes: annual tax reporting and management interpretation/decision making. Most all practices keep one set of books for both purposes.
- These two purposes conflict: taxpayers strive to defer tax payment to the extent possible through a variety of strategies that reduce taxable income. At the same time, practice owners wish to see profit trending at improved levels year over year and against industry benchmarks.

For advanced analysis of practice profit, engage experts for practice valuation services (also called

Breakeven Analysis For Daily Goal Achievement				
	Return on Capital (Interest Rate)	6.00%		
	Average Useful Life of Equipment (Years)	6		
	Target Annual Revenue	$1,643,760		Use revenue driven budget, pratice history, regression analysis, etc. In this example, from budget
Variable Costs To Be Covered (Refer to 12 Month Budget)				
	1. COPS	$ 409,954	24.94%	Normal expected percentage of gross income for your practice
	2. Administrative Expenses	$ 83,503	5.08%	
	3. Compensation Support Staff	$ 217,305	13.22%	
	4. Veterinarians	$ 427,378	26.00%	
	5. Payroll Taxes	$ 66,768	4.06%	
	6. Retirement Funding and Plan Expense	$ 24,656	1.50%	
	7. Employee Benefit Program	$ 28,601	1.74%	
	8. Continuing Education, Travel, Meals	$ 28,108	1.71%	
	9. Vehicle Expenses Incl. Insurance	$ 44,382	2.70%	
	10. Telephone	$ 18,903	1.15%	
	11. Sinking Fund for Minor Equipment Replace	$ 16,438	1.00%	Do not include in fixed cost section
	Total Variable Costs	1,365,996	83.10%	
Fixed Costs To Be Covered				
	1. Return on Professional Equipment			
	Assumed Useful Life	6		Years
	Obsolescence Factor at	16.67%		Of Total Equipment Cost
	Plus Return on Capital Invested	6.00%		Of Total Equipment Cost
	Total Required Return per Year	22.67%		Of Total Equipment Cost
	Total Equipment As Quoted or Purchased	$ 175,000.00		Includes Shipping and Handling and Install
	Sales Tax Rate	6%		IT, DR, Endoscopes, US
	Total Equipment Cost	$ 185,500.00		
	Total Required Annual $ Return On Purchased Equipment	$ 42,046.67	2.56%	
	2. Facility - Rent	$ 49,000	2.98%	If self rented, could be mortgage payment on building,
	3. Real Estate and Personal Property Taxes	$ 10,425	0.63%	or percentage of fair value; otherwise - contracted lease
	4. Maintenance, Repairs, Janitorial	$ 21,750	1.32%	
	5. Service Contracts	$ 5,500	0.33%	
	6. Business Casualty Overhead Insurance	$ 9,500	0.58%	
	7. Utilities/Trash	$ 15,050	0.92%	
	8. Equipment Rental/Leases	$ 3,350	0.20%	
	9. Licenses	$ 1,375	0.08%	
	10. Other Debt Payments -	$ -	$ -	Monthly payment - principal and interest
	11. Other Debt Payments -	$ -	$ -	
	12. Other Debt Payments -	$ -	$ -	
	Total Other Fixed Costs	$ 115,950	7.05%	
	Total Fixed and Debt Service Costs Per Year	$ 157,997		
Assumptions:				
	Total Target Annual Revenues	$1,643,760		
	Total Fixed Costs	$157,997		
	Total Variable Costs	$1,365,996	83.10%	
	Total Costs Estimated	$1,523,992	92.71%	
	Estimated Net Operating Profit		7.29%	
	Days open	306		
Calculation of Break-Even WITHOUT PROFIT				
	R(BE)	=	$\frac{F}{1-V}$	
	Where: R(BE) = Breakeven Point In Total Sales Revenues; F = Total Fixed Costs; V = Variable Costs as Percentage			
	Breakeven Point is then	**$ 934,996**		
	And the revenue per day to reach breakeven is	**$ 3,056**		
Goal	**Target Cost Coverage per Day is**	**$ 4,980**		Based on budgeted/projected target revenues stated first above
Goal	**Target Revenue per Day is**	**$ 5,372**		Based on budgeted/projected target revenues stated first above

Fig. 4. Example of budget variance tracking and breakeven analysis.

	EQUINE AMB W/HOSP NORMAL % OF GROSS INCOME	EQUINE AMBULATORY ONLY NORMAL % OF GROSS INCOME
COST OF PROFESSIONAL SERVICES		
DRUGS AND PROFESSIONAL SUPPLIES		
Drugs & Medical Supplies		
Hospital Supplies		
Anesthesia Costs		
Dentistry Costs		
Surgery Costs		
Other Ancillary Service Costs		
Purchase Discounts Taken		
TOTAL DRUGS AND PROFESSIONAL SUPPLIES	19.00%	24.00%
Laboratory Costs		
In House Lab Supplies		
Outside Lab Fees		
Radiology Costs		
Other Imaging Costs		
US/Radiology Reading Fees		
LABORATORY & IMAGING COSTS	3.00%	3.00%
Bedding Costs		
Grain Costs		
Hay Costs		
Biosecurity Costs		
ANIMAL HOUSING/HUSBANDRY COSTS	1.50%	1.50%
Mortuary Expense	0.50%	0.50%
Medical Waste Disposal	0.25%	0.25%
TOTAL COST OF PROFESSIONAL SERVICES	24.25%	29.25%
GROSS PROFIT	75.75%	70.75%

	NORMAL % OF GROSS INCOME	NORMAL % OF GROSS INCOME
PAYROLL & EMPLOYEE COSTS		
Veterinarians (Owners, Associates, Relief, Specialists)	22.00%	28.00%
Veterinary Technicians	4.00%	4.00%
Technician's Assistants	3.50%	2.00%
Receptionists	4.00%	2.00%
Practice and Office Managers	3.00%	2.00%
Barn Workers	2.00%	0.00%
Employer FICA	3.50%	3.50%
Payroll-Employer FUTA	0.10%	0.10%
Payroll-Employer SUTA	0.20%	0.20%
Worker's Compensation Insurance	0.50%	0.50%
Employee Benefit Programs	2.50%	2.50%
Employer P/S Contribution	0.50%	0.50%
Continuing Education	0.40%	0.40%
Bus. & Prof. Books, Journals, etc.	0.20%	0.20%
Travel & Lodging	0.35%	0.35%
Business Meals & Entertainment	0.25%	0.25%
Staff Parties/Recreational Events	0.10%	0.10%
Laundry & Uniforms	0.10%	0.10%
SUBTOTAL PAYROLL & EMPLOYEE COSTS	47.20%	46.70%
ADMINISTRATIVE EXPENSES		
Licenses & Permits	0.35%	0.35%
Veterinary; Business & Prof Dues	0.25%	0.25%
Advertising & Promo Expense	0.60%	0.60%
Business Gifts & Flowers	0.01%	0.01%
Computer Supplies	0.15%	0.15%
Office Supplies	0.60%	0.60%
Postage Expense	0.45%	0.45%
Printing Expense	0.20%	0.20%
Accounting Expense	0.80%	0.80%
Payroll Service Expense	0.20%	0.20%
Exp for Admin. of P/S Plan	0.10%	0.10%
Legal Services	0.15%	0.15%
Business Consult for Practice	0.50%	0.50%
TOTAL ADMINISTRATIVE EXPENSES	4.36%	4.36%

Fig. 5. Common ranges of equine practice operating expenses compared to operating revenues.

	NORMAL % OF GROSS INCOME	NORMAL % OF GROSS INCOME
FEE INCOME COLLECTION COSTS		
Bank and Credit Card Charges	0.80%	0.80%
Collection Expense	0.20%	0.20%
Returned Checks	0.10%	0.10%
Client Refunds	0.10%	0.10%
TOTAL FEE INCOME COLLECTION COSTS	1.20%	1.20%
FACILITY & EQUIPMENT COSTS		
Rent on Practice Real Estate	6.50%	1.50%
Rent/Lease on Business Equipment	0.50%	0.50%
Maintenance Expense	1.00%	0.20%
Maintenance & Service Contracts	0.10%	0.10%
Housekeeping & Janitorial Expense	0.20%	0.00%
Repairs	0.25%	0.15%
Practice Vehicle Expense	1.00%	3.00%
Property, Casual, Liability Insurance	0.65%	0.50%
Real Estate Tax	0.40%	0.00%
Utilities	0.80%	0.01%
Telephone	0.70%	0.70%
Trash Disposal Expense	0.10%	0.01%
SUBTOTAL FACILITY & EQUIPMENT COSTS	12.20%	6.67%
DEPRECIATION & AMORTIZATION EXPENSE		
Depreciation Expense	1.50%	1.50%
Amor. Exp. Computer Software	0.25%	0.25%
SUBTOTAL DEPRECIATION COSTS	1.75%	1.75%
NET INCOME FROM OPERATIONS	9.04%	10.08%

Fig. 5. Continued

business valuation.) Otherwise, professionals (CPAs, valuation experts) can perform lower-level profitability analytics that are extraordinarily helpful for strategic planning, budgets, and financial projections. Good financial management requires annual assessment of practice operating profit trends.

As for all KPIs, the starting point of operating profit measurement is reliable data availed through the annual profit and loss reports. Because this financial statement is primarily structured for tax reporting purposes, one can expect the strategies used to reduce taxable profit and taxes will cloud operational profits and practice financial performance. The strategies used often depend on the chosen type of legal entity: proprietorship, partnership, corporation.

Taxable profit for income tax reporting purposes usually approximates the bottom line of the small business profit and loss statement. Each legal entity type determines the required bottom-line adjustments to estimate operational profit. For most veterinary practices, the required adjustments include the following:

- Restating owner (and owner family member) compensation and benefit expenses to amounts that reflect owner value to the practice as employees, providing services in exchange for payment. Compensation and benefits should be comparable to what the practice would normally pay a non-owner employee for similar expertise and duties.
- If one or more practice owners also own the practice real estate, restate rent expenditures to the amount that reflects fair rental cost for the use of the real estate by the veterinary practice occupant.
- Depreciation and amortization expense must be adjusted to reflect a reasonable estimate of annual wear, tear, and obsolescence of medical equipment, and other tangible capital assets/property (called "economic decline").
- Any expensed equipment costs should be added back.
- Any lease payments for equipment that will eventually be owned (*purchase-lease* or *capital-lease*) should be added back.
- Any extraordinary expenditures deducted in a single year should be adjusted. For example, a major website overhaul or significant maintenance or repair expenditures hitting all in 1 year.
- Interest income and other non-operational sources of revenues are excluded.
- Interest expense and non-operating expenses are excluded.
- Corporate income taxes are added back (if any).

Fig. 2 shows a profit margin calculation applied to typical veterinary practice profit and loss report or tax return.

Practice Budgets—The Foundation for Operational Objective Measurement

A crucial element of business scorecard and KPI use is the art of projecting the practice's financial results through annual budgets. Financial budgets and plans are important to strategic planning in two main ways: 1) budgeting measures progress toward goals, and 2) good planning and budgeting are needed to fund each part of the strategic plan.

The minimum level of serious financial management is traditional budget preparation. Since recent financial history is a general predictor of expected practice performance in the coming 12-month cycle, traditional budgeting starts with the most recent 2 to 3 years of profit and loss reports, in computer spreadsheet format.

Operating revenues and expenses, as well as percentages of gross income, are projected forward, using documented assumptions such as the rate of practice income growth, client numbers, fee adjustments, vendor pricing changes, and employee compensation requirements.

Spreadsheets allow easy manipulation of budget data, computed in different and often complex ways that aid "what-if analysis." What-if analysis is a powerful scenario-planning process using spreadsheet models, where different numbers are applied to key variables to see what the overall effect will be on projected results. For example, "What if Cost of Professional Services is reduced by 2 percentage points? What resulting net profit result could be expected?"

Well-designed and maintained practice budget spreadsheets become powerful tools over future periods, as they are carried forward, modified, and adapted to new assumptions and current situations. With increasing levels of expertise, spreadsheet users will keep projections updated with monthly operational results, comparing them to previously predicted targets and revising the 12-month forecast so that it is regularly rolled forward with new targets established.

During this process, budget variances are identified. Budget variances are the gaps between projected targets established in the budget process and the actual results achieved as time progresses.

Variances are most often displayed in dollar amount differences, the percentage increase or decrease, and the differences in each monetary line item expressed as a percentage of gross income. Selected variances become important KPIs in their own rights, that will be important to track.

Fig. 3 shows the initial page of a practice budget depicts how arranged columns display actual results and budgeted amounts and the resulting variances, highlighting practice performance for each metric. Please note that not all pages of the budget are shown.

Breakeven analysis also derives from financial result measurement. Like budgeting, breakeven analysis can be adapted for different, important areas of practice planning.

- Daily break-even targets
- Breakeven analysis of pharmaceutical sales in concert with employee commissions, to determine appropriate pricing
- Breakeven analysis of equipment investment and use, to assist in procedure pricing and daily or weekly use targets

Primary goals of budget variance tracking and breakeven analysis are to:

- Support targeted practice profitability
- Use predictive analysis to identify gaps in real time, allowing timely prescriptive action
- Inspire and challenge leaders to improve practice financial health through actionable insight

Successful strategy implementation requires financial plans created through budgets and breakeven calculations, because it often takes money to bring tactical and operational plans to fruition. Managers must be able to predict expenditures with some semblance of reality. Resource allocation to implement a strategic plan typically includes outlays for equipment, payroll, supplies, and contracted services, in addition to deciding pricing and fee assignment (Fig. 4).

An interesting application of daily breakeven revenue targets involves posting the targets by day on a monthly calendar. Daily comparison results are posted for employee visualization, in green or red or any other simple way to illuminate accomplishment or deficiency (arrow up/down).

Daily breakeven revenues and client activity can be projected in real time, once the data is drilled with A.I. applications. With seasonality and desire to plan staffing levels, past history and trends can be used to plot forward to the exactness of day and hour practice activity. Since payroll and related human capital expenses are the largest part of the cost pie for most every veterinary practice, any tools an human resources (HR) manager can leverage become extremely valuable for creating efficiency and elevating profit.

Operating Expense KPIs

The final KPI graphic to share is that presently common ranges of equine practice operating expenses compared with operating revenues (Fig. 5). Surprisingly, these have changed little over the last 3 decades, although some new accounts have been added to the COA listing, such as for internet pharmacy revenues and costs of website and social media marketing.

Acknowledgments

Declaration of Ethics

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References and Footnotes

1. Heinke ML. The equine veterinary practice chart of accounts: Financial cornerstone of successful practice accounting and bookkeeping systems. Phoenix, AZ: Milburn Equine; 2006.
2. Heinke ML. Practice made perfect: A complete guide to veterinary practice management. 2nd ed. Lakewood, CO: AAHA Press; 2012.
3. Heinke ML. Strategies for improving financial health using practice key performance indicator benchmarking, in *Proceedings*. Am Assoc Equine Pract 2020;66:355–359.

[a]Merriam Webster Dictionary. www.meriam-webster.com/dictionary.

[b]Today's Veterinary Business, "A Balance of Power." Kimberly Ness and Kim Cameron, PhD. December 2019. Available from: https://todaysveterinarybusiness.com/access-and-pet-owners/. Accessed 6/3/2020.

[c]WSAVA/FECAVA/BSAVA World Congress 2012 as published in VIN, "the Role of Net Promoter Score: What It Is and Why It Can Work." Alison Lambert, BVSc, MMRS, MRCVS. Available from: https://www.vin.com/apputil/content/defaultadv1.aspx?pId=11349&catId=34781&id=5347223. Accessed 6/3/2020.

[d]Canadian Vet Magazine, "Using the Net Promoter Score to Measure Veterinary Client Loyalty", Mike Pownall, DVM, MBA. June 2018. Available from: http://www.veterinarybusinessmatters.com/2018/06/21/using-the-net-promoter-score-to-measure-veterinary-client-loyalty/. Accessed 6/3/2020.

[e]EBITDA is a Wall Street acronym for Earnings Before Interest, Taxes, Depreciation, and Amortization. While EBITDA has been used erroneously and loosely to describe operating profit in the veterinary profession, the calculation itself as defined will give misleading results for most small businesses since it does not adjust for key factors disguising economic profit.

Strategies for Improving Financial Health Using Practice Key Performance Indicator Benchmarking

Marsha L. Heinke, DVM, EA, CPA, CVPM

Business performance improvement requires a disciplined methodology for developing, selecting, and using Key Performance Indicators that support long-term strategic objectives for veterinary practices. This session provides well-documented, step-wise approaches for developing and using metrics for continual improvement. Author's address: 934 Main Street, Grafton, OH 44044; e-mail: mheinke@vpmp.net.

1. Introduction

How does a veterinarian know a horse's long-term response to their comprehensive laminitis management protocols unless they track its health progress with uniform measurement? How does a practice manager determine that implementation of fee increases resulted in projected financial outcomes? What metrics does an administrator purposefully design to ascertain client satisfaction and employee engagement?

Each of these questions highlights the veterinary business need to strategically plan and measure selected data that does more than document historical results. Businesses must choose data collection and reporting wisely, preferably actionable data that drive continual improvement. Data are plentiful and time is scant; successful business strategy requires an intelligent selection of relevant metrics.

Before assessing a practice's financial health, first ensure the practice uses tools and procedures to maintain accurate records.[1] Reliable internal data allow a reasonable evaluation of performance. Too many practices have not invested in dependable systems that allow nuanced interpretation.

Strategic execution requires fact-based information. To gain competitive advantage, make continuous effort toward data quality improvement via internal processes and policies, use technology and machine learning, and explore new options to streamline data collection and interpretation time.

In veterinary practice financial management, the prime requirement for benchmarking is the practice itself: how does it currently compare to the baseline financial health of last month or last year? Second, well-curated data ideally allow a manager to compare the practice to others of a similar "breed," such as to other equine ambulatory or referral hospital practices.

Everyone wants benchmarks, and yet, aggregated industry data can mislead. Does a comparison of any particular practice's financial health to published benchmarks have meaning? Is a practice owner or manager able to make that determination? In the end, managers are best served understanding

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the practice's internal analytics, being comfortable with their interpretation, and maintaining balanced skepticism of external benchmarks.

Solution and Discussion

A discussion of practice financial health betterment can only begin by enumerating certain principles. These essential principles underlie everything a manager will undertake with data mining, application selection, industry benchmarking, and executive decision-making. Long-term, sustainable financial health has the following characteristics:

- A defined business purpose.
- Stakeholder core values and vision.
- Veterinary professional ethical guidelines.

Retained and reinforced in institutional memory, these factors form the foundation of a practice's mission and vision statements. From these two statements, business strategy will flow, with a cascade of stated strategic objectives propagated throughout the organization.

Strategic objectives define the data selected for collection, measurement, comparison, and dissemination through various reporting mechanisms. Measurable data allow an understanding of where the practice has been and where it is going.

Good practice management decisions are founded in facts. Facts are derived from observations of day-to-day occurrences; yet, it is impossible to remember everything that has occurred without systems of documentation and measurement. Even a good manager cannot be everywhere at once. Concurrently, data exponentially increase. Paucity of data is not the challenge. The struggle is wrangling data into manageable, timely, and usable chunks.

A significant practice-managed duty is that of monitoring data trends as well as directing day-to-day activities in accord with the overall practice strategy. Data wrangling historically demanded (and still does) much labor to isolate raw data points, compute them into desired key performance indicators (KPIs), compile them, and trend them. Despite what feels like an overwhelming sea of data, managing a veterinary practice by the numbers is becoming easier because of increasingly seamless applications to sort and present information in easily consumable visualizations.

Influence of Cognitive Computing and Business Intelligence in Practice Management

Cognitive computing is the assimilation of massive volumes of structured and unstructured data into manageable content. Business intelligence (BI) uses tools and techniques to deliver relevant, reliable, and real-time information with the goal of making better decisions faster. BI takes a vast amount of practice data and presents the information in meaningful, actionable ways. BI applications include employee performance management, customer experience feedback, operational analytics, data and text mining, predictive and prescriptive process modeling, and much more.

With an increasingly nuanced ability to self-serve and visualize real-time data, managers should seek advantage through applications that allow systematic data collection and reporting. The valuable time saved from manipulating data into usable formats can instead be used to strategize operational improvement and the employee training required to enable it. Employees likewise gain timely feedback on the results of their work efforts through mobile applications.

Organizational Framework for Selecting Actionable Data[2]

Business intelligence tools and design are based in well-known and established models. An especially useful model for veterinary practice management is the balanced score card.

In the early 1990s, Dr. Robert Kaplan[a] and Dr. David Norton at Harvard Business School published a model for innovative strategic planning and performance management: the balanced scorecard. The model organizes a business into four equally important themes. Each focused area is defined by specific critical success factors that are distilled into measurable targets and become the basis for actionable data in the form of KPIs.

The balanced scorecard helps leadership clarify the practice's vision and strategy (which are often rather abstract) and translate them into defined, measurable activities that guide progress in creating value through investment in patients, clients, employees, suppliers, processes, and technology.

The author's firm modified Kaplan's model for veterinary practice implementation, calling it the Veterinary Practice Scorecard (VPS) and used it to design and plan specific tactics in each of the four aspects of business focus:

- The patient care/internal processes perspective.
- The client perspective.
- The employee growth, learning and innovation perspective.
- The financial perspective.

To maintain a healthy balance in leadership and managerial effort, each perspective receives equal attention and weight in the analysis. State objectives for each aspect and determine metrics that will most effectively measure progress and drive behavior leading to successful accomplishment of the objectives. Consider the questions posed for each perspective that drive objective development (Fig. 1).

Figure 2 shows an example of a balanced score card, demonstrating objectives, KPI choices and measurement, targets, target gaps, and estimates of target achievement.

In a real-time digital environment (think Smart phone), the user would be able to click through on any current KPI measurements to observe its trend

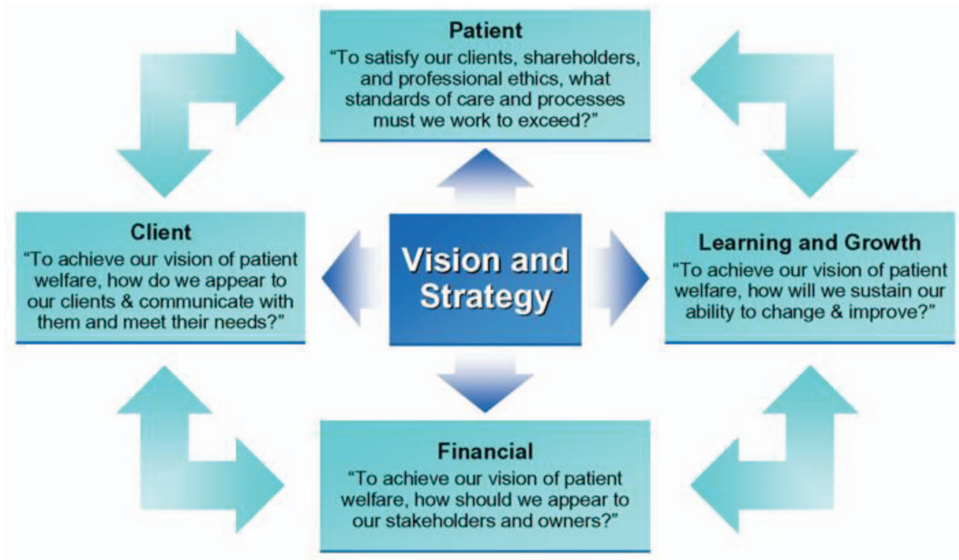

Fig. 1. Veterinary Balanced Score Card Model.

over any period of time and obtain a comparison with any prior selected period or date range. Self-serve options are useful when seasonal practice activity is a complicating factor to baseline comparison, and alternate date ranges can clarify interpretation.

The following examples of KPI trends use Excel spreadsheet models, updated by month, and include a moving trailing 12-month total (TTT). The TTT trendline is extremely helpful for visualizing practice improvement or adverse changes that should be quickly addressed (Fig. 3).

Many available business intelligence applications are built on balanced scorecard modeling. The forward thrust of these apps is to extract and combine data from multiple databases within the business. The apps knit the results together into effective data visualization through virtual dashboards. Any

BALANCED SCORE CARD

Current Date Range of KPI measurements: January 1 to September 25, 20xx   *Target Date:* December 31, 20xx

Patient/Internal Processes Perspective
How will we look to our patients?
Objectives: Improve efficiency of care delivery, improve care outcomes, improve care consistency

Key Performance Indicators	Target	Current	To Target
Documented SOAP, each patient examined	100%	81%	-19%
Core vaccinations up to date, each patient seen	100%	77%	-23%
Pet/Equine insurance discussed, new patient appts.	100%	90%	-10%
Pain assessment and management protocols in surgery, dentistry, OA, and cancer cases	100%	62%	-38%
Client question/phone call ---> appointment	90%	87%	-3%

Growth, Innovation & Learning Perspective
How will we look to our employees?
Objectives: Improve employee engagement, reduce turnover, improve training and mentoring consistency

Key Performance Indicators	Target	Current	To Target
Standardized onboarding protocols achieved each new employee	100%	80%	-20%
Mentor reviews 8/10 or better	100%	90%	-10%
Target CE hours per quarter	4	3.3	(0.7)
Decreasing employee turnover rates per year	15%	20%	5%
Employee Pulse Surveys Completed	100%	90%	-10%

Client Perspective
How will we look to our clients?
Objectives: Improve client awareness of services and products, improve client satisfaction, improve client adherence to recommendations

Key Performance Indicators	Target	Current	To Target
Net Promoter Score	55	58	3
Percentage of Clients Responding with NPS	75%	56%	-19%
Care estimates within 10% of actual invoice	100%	50%	-50%
Clients called within 2 hours of any inpatient procedure	100%	95%	-5%
Increase Active Client Numbers	6,500	5,800	(700)

Financial Perspective
How will we look to our practice owners/investors?
Objectives: Improve practice value, improve dividend yield, improve capital reinvestment

Key Performance Indicators	Target	Current	To Target
Increase net profit	$ 350,000	$ 300,000	$ (50,000)
increase profit margin	19.0%	16.5%	-2.5%
Increase total revenue (12 months)	$1,850,000	$ 1,818,182	$ (31,818)
Increase ACT (average client transaction)	$ 185.00	$ 155.00	$ (30.00)
Reduce COPS % of gross revenue	18.0%	21.5%	3.5%

Likelihood of reaching target: very likely | likely | indeterminable | unlikely | very unlikely

Fig. 2. Example of a Balanced Score Card Dashboard Design and Results.

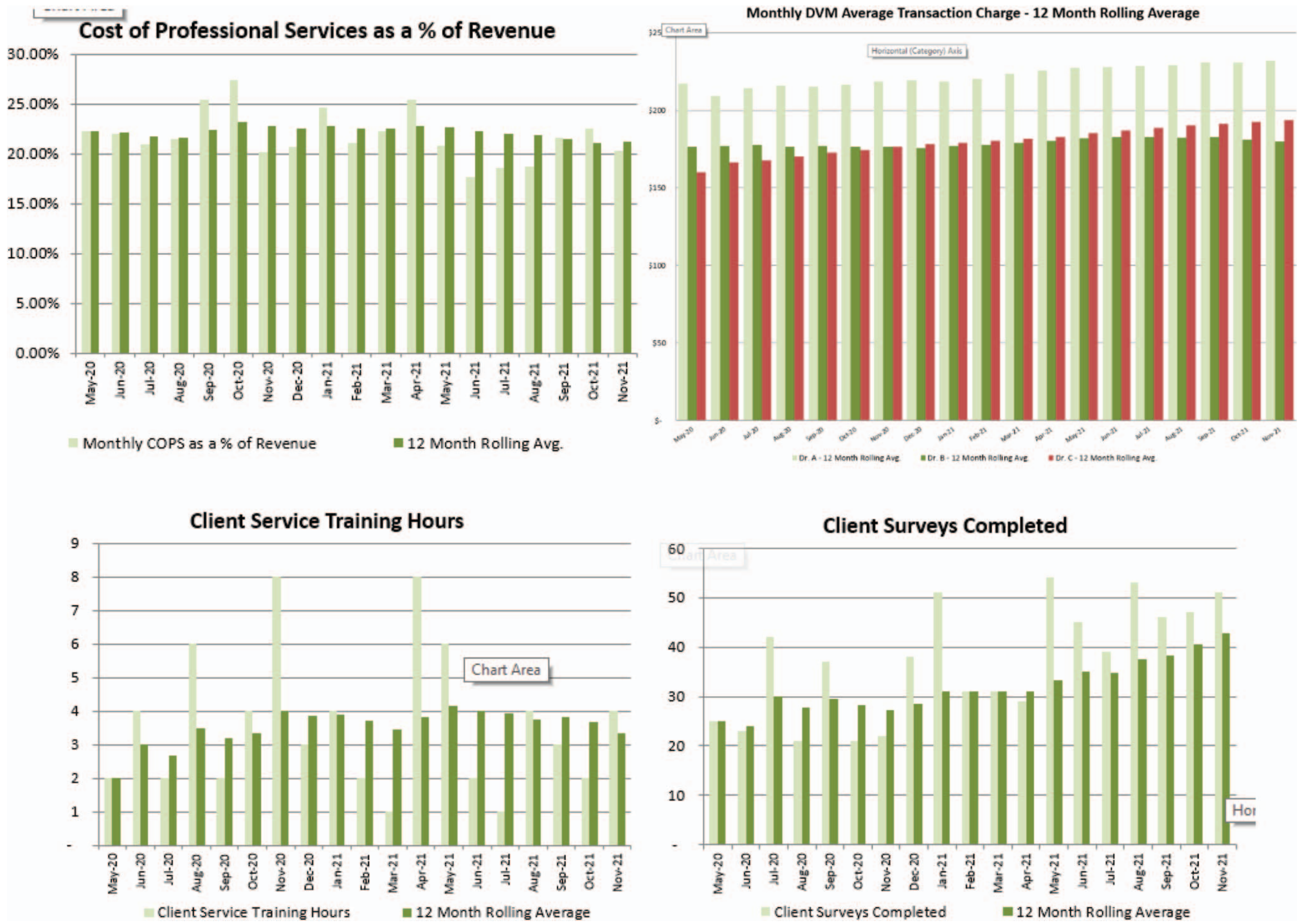

Fig. 3. Examples of Trailing-Twelve Month-Total (TTT) KP trend analysis.

data relationship can be presented in various effective visual graphics, including shapes and colors, that inform the user, who can also drill down to underlying data with a click of the mouse. Nothing is static; the aggregated data are real time.

The data dashboards integrate into the scorecard presentations often in a simplified manner. Figure 4 shows an example of effective data visualization, using a single KPI data point with its trend.

Moving from KPIs to Key Performance Drivers

Measurement is an ever present and important fundamental of practice financial health, but only some measurements mean much. The measurements most important to organizational progress are called KPIs.

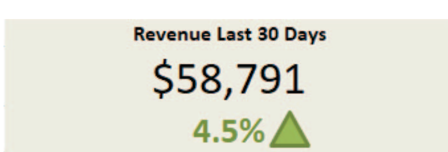

Fig. 4. Example of effective KPI visualization.

To see how a veterinary practice is evolving, measurements, trends, correlations, and comparisons are needed. KPIs that provide actionable insights in real time are the lifeblood of business intelligence.

KPIs can be lagging, giving an historical perspective, and providing a reasonable prediction of future activity. Forward-looking KPIs that prompt desirable employee behaviors and thus cause performance change are called key performance drivers (KPDs). These metrics shape desired activity to

Table 1. Examples of KPDs Affecting KPI Change

KPI Examples	KPD Examples
Appointment numbers	Client contact info collection
No show rate	Text/email reminder & confirmation completion
Employee turnover	Number of employee relationship-building events
Conversion rate website inquiries	Time to respond to website inquiries
Workers' comp claims	Number of safety training hours
% Lab tests charged/lab tests run	Number of lab procedure training hours
% Insured horses	% of clients receiving information/assistance with signup

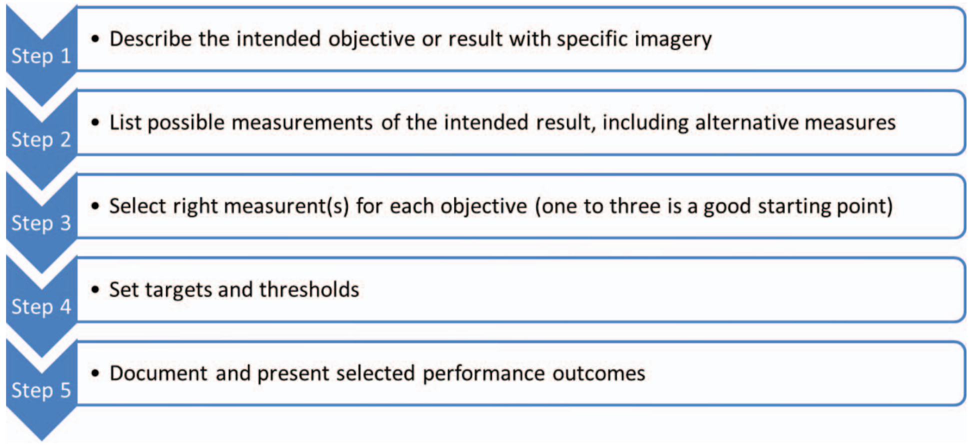

Fig. 5. KPI development process.

attain objectives. A well-designed balance of KPIs and KPDs support management guru Peter Drucker's famous quote, "what gets measured, gets done."

Use KPDs to improve behavior to hit pre-determined targets and the desired level of performance.

Some examples of KPIs and correlating KPDs can be found in Table 1.

Obstacles to KPI Use in Managing a Practice

The primary reason for KPI problems and analysis paralysis is a failure to use a disciplined methodology, such as balance score card modeling and setting defined strategic objectives that form the basis for the KPIs your practice uses. Simply measuring the data you always have or because it is easiest to obtain results in underperformance. Likewise, brainstorming KPIs without a purposeful vision is a problem.

Successfully developing and implementing KPIs is a disciplined process. Achieving any successful business intelligence methodology for improvement over time uses the defined process, such as the stepwise KPI development graphic (Fig. 5).

Given that the long-term sustainability of KPI implementation requires discipline, the critical factors for success are as follows:

1. Engaged practice leadership that is committed to the process.
2. Effective change management through leadership's concerted support of change, including clear team communications of clearly identified key steps.
3. Healthy practice culture using fact-based decision making (rather than dependence on gut instinct).
4. Intentional culture shift through learning to use performance measurement methods appropriately.
5. Strong project management skills for improved execution of KPI implementation and use.
6. Employees supporting team focus on continuous process improvement.
7. Long-term commitment to using KPIs to manage the practice.[a,b]

To gain competitive advantage, practice leaders and managers should make continuous effort toward data quality improvement via internal processes and policies, use technology and machine learning, and explore new options to streamline data collection and interpretation time.

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References and Footnotes

1. The Equine Veterinary Practice Chart of Accounts: Financial Cornerstone of Successful Practice Accounting and Bookkeeping Systems, 2006, Marsha L. Heinke, DVM, EA, CPA, CVPM.
2. Heinke ML. AAHA Press: https://ams.aaha.org/eweb/DynamicPage.aspx?site=store&Action=Add&ObjectKeyFrom=1A83491A-9853-4C87-86A4-F7D95601C2E2&WebCode=ProdDetailAdd&DoNotSave=yes&ParentObject=CentralizedOrderEntry&ParentDataObject=Invoice%20Detail&ivd_formkey=69202792-63d7-4ba2-bf4e-a0da41270555&ivd_cst_key=00000000-0000-0000-0000-000000000000&ivd_cst_ship_key=00000000-0000-0000-0000-000000000000&ivd_prc_prd_key=46D42EC7-D86D-4E2C-BE4A-3602D26C2901.

[a]Conceptual Foundation of the Balanced Scorecard, Robert S. Kaplan, 2010 https://www.hbs.edu/faculty/Publication%20Files/10-074_0bf3c151-f82b-4592-b885-cdde7f5d97a6.pdf.

[b]Balanced Score Card Institute, KPI.org.

Staying Safe and Comfortable in Practice During Pregnancy

Amy L. Grice, VMD, MBA

There are a number of hazards to pregnant women that are unique to veterinary medicine along with some that are common to all workplaces. Awareness will assist you in staying safe and comfortable during your pregnancy. Pre-planning for your absence from the workplace and education about your rights will help both you and your practice during this time. Author's address: PO Box 192, Virginia City, MT 59755; e-mail: amyvmdmba@gmail.com.

1. Introduction

Once you are trying to become pregnant or have confirmation that you are, you must take precautions for your developing child. Working in a physically strenuous job during pregnancy creates a higher risk profile, though it can also have benefits. An overview of general risks and common issues will provide a basis of awareness that can assist in maximizing the safety of your developing child and increasing your comfort.

2. Discussion

General Risks

Each woman is an individual, and some will have a higher risk tolerance than others, and each pregnancy will be different. Flexibility and good communication will go a long way toward having a smooth experience. All workplaces, including those outside of veterinary medicine, can affect your safety, even when you are not pregnant. Slipping on a wet floor, tripping on a cord, lifting something heavy, reaching overhead, using a stool or ladder, and climbing stairs are all hazards that can cause injury in most workplaces. Being pregnant exacerbates those general risks due to changes in balance and hormonal softening of ligaments.

Traumatic Injuries

Ambulatory equine practitioners often drive 30,000 to 50,000 miles each year, increasing their risk of an auto accident. Even those with less mileage often multitask while driving, which increases the risk of inattention to the road. Those veterinarians who work in large-animal practice are also at risk for injury simply from the size of the animals they treat. Taking normal precautions may be inadequate, as a pregnant woman has a changed balance and body shape. Do not hesitate to utilize sedation and ask for help in restraining animals for treatment.

"Various anatomic and physiologic changes of pregnancy may alter the type of injury experienced by pregnant women. These changes may also alter the manifestations of given injuries and the treatment required to re-establish maternal-fetal hemostasis."[1] Trauma in pregnancy remains one of the major contributors to maternal and fetal morbidity and mortality. Potential complications include maternal injury or death, shock, internal hemorrhage, intrauterine fetal demise, direct fetal injury, abrup-

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tio placentae, and uterine rupture. The leading causes of obstetric trauma in the general population are motor vehicle accidents, falls, assaults, and gunshots. These injuries are classified as blunt abdominal trauma, pelvic fractures, or penetrating trauma.[2] Unique to equine and bovine work are kicks, strikes, and crushing by patients.

Lifting, Standing, and Long Shifts

According to the National Institute for Occupational Safety and Health, heavy lifting, standing for long periods of time, or bending a lot during pregnancy can increase your chances of miscarriage, pre-term birth, or injury during pregnancy.[3] Consult with your obstetrician about appropriate restrictions, if any. Jobs involving high physical demands, such as bending at the waist more than 20 times per day or lifting objects more than once every 5 minutes, may increase risks for adverse birth outcomes. Pregnant women are at higher risk of an injury while lifting due to differences in posture, balance, and an inability to hold things close to the body because of changing abdominal size. In addition, changes in a pregnant woman's hormones have an effect on ligaments and joints in the spine. These changes make a pregnant woman more prone to injury from lifting heavy equipment or strenuous work with patients.[3]

Generally, 25 pounds is the limit for lifting in most healthy pregnancies, and past 20 weeks, this amount decreases. Specific recommendations can be found for recommended weight limits in early and late pregnancy for 3 lift frequency patterns.[4] In all types of lifting, proper form is essential. Bend at your knees, not your waist, keep the load close to your body, and lift with your legs, not your back. Avoid twisting your body while lifting. In the practice, use your assistant or a client to carry heavy equipment, and be cautious with holding up hooves. In the small-animal hospital, don't try to lift heavier patients by yourself.

Equine practitioners are generally moving around frequently all day, which can ease muscle tension and help prevent fluid buildup in legs and feet. Elevate your legs whenever possible if you are experiencing swelling. If you must be on your feet for long periods of time, rest one foot alternatively with the other on a stool or other slightly elevated platform, wear comfortable shoes with good arch support, and take breaks to sit down. You might also consider wearing compression socks and loose clothing.[5]

Nausea and Other Discomforts

Being pregnant can present additional physical challenges at the workplace. To stay productive at work, you must try to alleviate common pregnancy discomforts. One of the most distressing of symptoms can be nausea and vomiting. It may be called "morning" sickness, but it can hit at any time. Studies have shown that women with nausea and vomiting during the first trimester have a lower risk of miscarriage than do women without these symptoms.[6] Morning sickness affects around 80% of all pregnant females.[7] To ease nausea at work, avoid your triggers as much as possible. Some odors in veterinary medicine may be particularly difficult to tolerate, and these differ from woman to woman. Increase ventilation and avoid smelly things like anaerobic abscesses, anal sacs, and parvo or rotaviral diarrhea. It may help to snack often on crackers and other bland foods, or drink ginger ale or ginger tea. If you are vomiting, you will need to maintain your hydration. If you are queasy, you may want to prepare your client before you have the need to rush out of the stall or exam room.

Handling the fatigue of pregnancy can be tough. It might help to eat foods rich in iron and protein, because fatigue can be a symptom of iron deficiency anemia. Take short, frequent breaks if you can. Getting up and moving around for a few minutes outside may reinvigorate you. Or if you are on your feet continually, spending a few minutes with your eyes closed and your feet up also can help you recharge. If you are an ambulatory equine practitioner, pull your truck over for a 5-minute catnap. Don't neglect to drink plenty of water. Cutting back on activities that are not essential can help you get more rest when your workday ends. Consider hiring someone for domestic tasks or simply lower your standards. Go to bed early in order to get at least 8 hours of sleep every night. If you're repeatedly feeling depleted, listen to your body and consider cutting back on your work hours or the time you spend standing. If you are still in an emergency on-call rotation and are exhausted, consider stopping until you return from your maternity leave.

Stress

Veterinarians are often perfectionists and feel they should be able to perform at their peak at all things at all times. This can result in feeling like you are failing to be your best at anything you do. In order to keep stress under control, be kind to yourself. Growing a baby is hard work! Prioritize your tasks by making daily to-do lists and consider what you could delegate or eliminate. Maintain supportive relationships and share your fears and frustrations. Find some time for deliberate relaxation, even if it is just 5 minutes of meditation and focused breathing. Consider a prenatal yoga class, if your health care provider feels you are physically able. Rest. Many studies have shown the negative effects of stress on your health.

Your Rights as a Pregnant Worker

Title VII of the Civil Rights Act forbids employers with 15 or more workers on their payroll from refusing to hire, discharging, or otherwise discriminating against any person because of that person's gender. However, the Supreme Court ruled in a mid-1970s case that discrimination based on pregnancy was not the same as discrimination based on sex. As a result, the Pregnancy Discrimination Act of 1978 was passed, which explicitly requires that all employers treat pregnant and non-pregnant employees equivalently, both in terms of benefits received and all other respects. This act requires employers to treat a pregnant employee the same as any other temporarily disabled worker, if she is unable to perform her work because of her pregnancy. Since the Americans with Disabilities Act was passed in 1990, accommodation of employees with disabilities has been a standard feature of antidiscrimination law for US employers having 15 or more employees. Some state disability laws are applicable to businesses with just a few employees. Links to these state laws are available at https://www.workplacefairness.org/disability-discrimination-state-law.

Maternity Leave

Most veterinary practices do not offer paid maternity leave. In fact, in the United States, 88% of women do not receive any paid time off after giving birth, and 25% return to work within 2 weeks of giving birth.[8] The disability after a vaginal birth is considered to be 6 weeks, and a C-section, 8 weeks. There is an increased risk of injury when returning to work before this time.

You may wish to take out a short-term disability insurance policy if you plan to become pregnant in the future and are not covered under your employer's policy. Pregnancy, as well as the postpartum period, is one of the most commonly covered "disabilities" that prevent an employee from working. Carefully evaluate the coverage you are purchasing to be sure it fulfills your needs. Typically, short-term disability leave policies cover 6 weeks of pay at some percentage (up to 100% depending on your policy) for a vaginal birth and 8 weeks of pay for a Caesarean birth.

Inquire of your practice owner whether you can accumulate unused vacation time from the previous year to use in the current year for a maternity leave. If not, at least try to save all your paid time off for your leave. Begin saving some of each paycheck for a year before your delivery. Just $50 a week will add up to $2600 in a year. Every little bit will help. Consider your budget for each month's expenses and make a financial plan for your anticipated length of maternity leave. Because you can't be certain whether health issues for you or your baby will arise, try to be generous in your planning.

With the current difficulty that practices are having in finding and keeping veterinarians, leave policies may change in the veterinary industry. If you expect to have a family, inquire about maternity leave policies before accepting a position. If you are currently working at a practice with no paid maternity leave, consider negotiating for some. Remaining healthy with minimal injuries will allow you to stay in the career for the long haul.

Planning Your Return to Work

Because you cannot anticipate how you or your baby will fare after birth, keep all discussions about the length of your maternity leave tentative. Be honest about your intention to return in a certain time frame but be clear that this could be limited by health concerns. If it is your health that is impaired, and your doctor has not cleared you to return to work, you will be considered disabled. Then you must be treated as any other disabled employee would be treated. If your baby has health concerns, perhaps you can return to work on a modified schedule or delay your return. The individual circumstances of the practice will dictate what is possible.

If at all possible, plan to return part-time at first for at least a few weeks, to allow both you and the baby to adjust. You are much more likely to be injured or have an auto accident when you are sleep deprived. If you are generally in the on-call schedule, see if you can return to it just 1 night a week at first. But remember, your team members have probably been picking up extra shifts in your absence, and their patience may be wearing thin. Practices with many childless employees are often less willing to accommodate the inconvenience of a maternity leave with grace. Express your appreciation for their sacrifice. Even though they may be drawing more pay for more work, there's a good chance they would rather have the time off. Remember this as you adjust to your new life with a child and try to express your respect for their need for time away from the practice, giving it equal weight to the time you need for your family.

3. Conclusion

Educate yourself about the risks in your workday and the common hardships of pregnancy. Determine what areas concern you most. Most employers will be understanding, but not all. The practice will be affected for about a year with each pregnancy, and as the child grows, the company may be affected further with childhood illnesses, doctor's appointments and school events. Some family-oriented practices celebrate those parts of life, and others don't. Remember that you have many choices. It is your responsibility to shape the life you want to lead.

Acknowledgments

Declaration of Ethics

The Author has adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Author has no conflicts of interest.

References

1. Lavin JP Jr, Polsky SS. Abdominal trauma during pregnancy. *Clin Perinatol* 1983;10:423–38.
2. Mirza FG, Devine PC, Gaddipati S. Trauma in pregnancy: a systematic approach. *Am J Perinatol* 2010;27:579–586.
3. Reproductive health and the workplace. Available from: https://www.cdc.gov/niosh/topics/repro/physicaldemands.html. Accessed March 4, 2020.
4. MacDonald LA, Waters TR, Napolitano PG, et al. Clinical guidelines for occupational lifting in pregnancy: evidence summary and provisional recommendations. *Am J Obstet Gynecol* 2013;209:80–88.
5. Tobah YB. What causes ankle swelling during pregnancy—And what can I do about it? Available from: https://www.mayoclinic.org/healthy-lifestyle/pregnancy-week-by-week/expert-answers/swelling-during-pregnancy/faq-20058467. Accessed March 4, 2020.
6. Marnach M. Is nausea during pregnancy a good sign? Available from: https://www.mayoclinic.org/healthy-lifestyle/pregnancy-week-by-week/expert-answers/nausea-during-pregnancy/faq-20057917. Accessed March 5, 2020.
7. Novakovic A. What is morning sickness and how can I treat it? Available from: https://www.medicalnewstoday.com/articles/179633. Accessed March 5, 2020.
8. Froese M. Maternity leave in the United States: facts you need to know. Available from: https://www.healthline.com/health/pregnancy/united-states-maternity-leave-facts. Accessed March 5, 2020.

Veterinary-Specific Risks in Practice for Pregnant Women

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There are a number of hazards to pregnant women that are unique to veterinary medicine along with some that are common to all workplaces. Awareness will assist women working in veterinary medicine to stay safe during pregnancy, and help their employers mitigate unsafe working conditions for pregnant team members. Author's address: PO Box 192, Virginia City, MT 59755; e-mail: amyvmdmba@gmail.com.

1. Introduction

Whether you are an associate, an owner, or a staff member at a veterinary hospital, once you are trying to become pregnant or have confirmation that you are, you must take precautions for your developing child. Working in veterinary medicine increases your risks due to possible exposure to radiation, anesthetic gases, pharmaceuticals, zoonotic diseases, and viruses or bacteria. An overview of veterinary specific risks will provide a basis of awareness that can assist in maximizing your safety and that of your developing child. In addition, employers with a thorough understanding of the risks veterinary medicine holds for the young women on their team can better navigate necessary accommodations.

2. Discussion

General Considerations

Since the first trimester is the time of the most crucial development, avoiding risks in pregnancy as soon as possible simply makes sense. In the veterinary field in particular, it's important to share the news of your pregnancy promptly to avoid exposure to many workplace hazards. When you decide to announce the news, make sure your boss is the first one to know; you want her (or him) to hear it straight from you, not through the office grapevine. Schedule an appointment to tell her that you're expecting and to let her know when your baby is due. Keep your tone positive and upbeat, and don't feel compelled to share any overly personal details. If you are the pregnant owner of a practice, it makes sense to share the news with your team fairly early for the same reasons. Generally, folks figure it out pretty quickly on their own anyway, if you change your work habits. While it may seem to be tempting fate to share this information so early, it's in your child's best interest. If you are an employer of women of reproductive age, it is recommended that your employee manual state that employees should report their pregnancy to their supervisor as soon as possible, in order that information about possible hazards can be shared.

Current occupational exposure limits were set based on studies of non-pregnant adults. What is considered safe for you may not be safe for your unborn baby. A fetus may be more vulnerable to

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some chemicals because of its rapid growth and development, particularly early in pregnancy when its organs are developing. Changes in your metabolism also may increase how quickly you absorb some substances. When pregnant, changes in your immune system, lung capacity, and even ligaments can increase your risk of injury or illness. In addition, because of physical changes, the personal protective equipment that you could wear correctly before pregnancy, such as a lab coat or lead apron, may now not fit properly.

It is important to discuss possible job hazards with your physician. Although most women are able to safely do their job throughout pregnancy, sometimes they must adjust their job duties temporarily, or take extra steps to protect themselves and their babies. Your ability to continue working through your pregnancy depends on your overall health, the health of the fetus, and what sort of work you do. Many aspects of your job may be safe to continue through the entire pregnancy. Others may be fine at the beginning of pregnancy, but untenable near the end. Later in pregnancy, some duties may need to be changed or stopped. Sometimes your schedule or hours may need to be changed. As you continue working, the goal is to stay safe and comfortable.

Specific Risks in Veterinary Medicine

Radiation

While taking radiographs, you may be exposed to small amounts of radiation. If you work in a mixed practice, exposure can also occur with use of radioactive iodine treatment for hyperthyroid cats or in a hospital setting with the use of fluoroscopy. You may decide to try to eliminate the risk during your pregnancy by avoiding these duties, but for equine practitioners, especially in smaller practices, this may be impossible. If you choose to ask other staff members to pick up your radiology duties, it makes sense to discuss with your boss if there are other ways that you can still be productive by picking up other tasks. If you are the practice owner, don't expect others to work longer and harder to do these tasks for you without some compensatory action. This could be monetary, extra time off, or by you performing some of their usual tasks.

For those who cannot avoid taking radiographs, take steps to reduce the risk. Radiation exposure during your entire gestation should not exceed 500 mrem. The most dangerous time for radiation exposure is following conception (pre-implantation) up to the eighth week of pregnancy.[1] Many pregnant women wear the same protective equipment while taking radiographs as they normally do, including an apron, thyroid shield, and lead gloves. However, because of changes in body shape, a wrap-around lead apron may be better suited. In addition, wearing an additional dosimeter badge at the level of your uterus can provide more specific measurements of exposure to the fetus. If you will be taking radiographs while pregnant, review the reports from your dosimeter badge for the last year to ensure that your equipment and radiation safety techniques are protecting you from excessive exposure. As always, keep the time of exposure as short as possible, maximize your distance behind the generator, or in hospital settings, be out of the room or behind appropriate shielding.

In some equine practices, nuclear scintigraphy is used for diagnostics because of its sensitivity and noninvasive nature. A ^{99m}Tc labeled radiopharmaceutical is injected intravenously into the horse and images are acquired immediately post-injection and several hours later. Staff members are often in the room with the horse during the acquisition process. If you must be involved, avoid additional radiation exposure in a clinic with this diagnostic modality by wearing all recommended protective gear, and minimizing contact with the patient and patient's waste for 48 hours after the procedure.

Waste Anesthetic Gases

Waste anesthetic gas (WAG) exposure concerns many pregnant health care workers in human as well as veterinary medicine. Although a recent meta-analysis concluded that occupational exposure to WAG is associated with increased risk of spontaneous abortion, most of the studies included in the meta-analysis were conducted before WAG scavenging had become a legal requirement, and none of the studies attempted to establish a relationship between amount of exposure and magnitude of risk of spontaneous abortion. The meta-analysis included 19 studies of various designs with anesthetists, operating room physicians and nurses, dental assistants, operating-room workers, hospital workers, health workers, and veterinarians and veterinary assistants as subjects.[2] More recent studies have demonstrated that "rates of spontaneous abortion and low birth weight infants were statistically similar among female veterinarians and lawyers,"[2] leading one to conclude that WAG is being effectively scavenged in most settings.

However, if you can smell anesthetic gas, the level is entirely too high for safe exposure, whether you are pregnant or not. Appropriate operating procedures for safe anesthesia include always checking the machine for leaks before use, ensuring the scavenging system is connected and operational, and using a cuffed and properly inflated endotracheal tube. The most dangerous times for exposure are during induction and recovery. In order to allow time for the system to be flushed through the scavenging system, once the procedure is complete, the anesthetic gas should be turned off and the patient maintained on high oxygen flow. This will help to minimize exhaled WAG after the patient is disconnected from the anesthesia machine. Vapor respirators can also be purchased and worn as an extra barrier. If possible, swapping with a coworker during the recovery period can decrease your risk of inadvertently being exposed by horses exhaling anesthetic gases on the way to or while in the recovery stall. Because of the much greater risk of exposure with mask and box inductions, pregnant employees in mixed practices who utilize these methods should avoid these entirely.

Bone Cement

Bone cement is the common term for the chemical substance methyl methacrylate (MMA) (also known as polymethyl methacrylate). Bone cement may be used in various orthopedic procedures, particularly in orthopedic or neurology specialty practices. Bone cement is a clear liquid with a very identifiable sharp and fruity odor. It can be easily detected at levels far below those considered to be harmful to human health. In equine practice it is commonly used as a component of an adhesive for gluing on shoes, adding to the bottom of a cast, or repairing hoof cracks.

Toxicity studies performed on animals have had mixed results. Some studies have shown no serious adverse effects to the fetus. Other studies have found that pregnant animals exposed to very high levels of MMA experienced fetal abnormalities. These abnormalities included birth defects, issues with bone growth, and an overall decline in fetal weight. Because MMA carries a potential risk of harm to a human fetus, it is commonly advised that pregnant women avoid direct contact with MMA and inhalation of MMA fumes.[3]

Pharmaceuticals

Some drugs prescribed to veterinary patients are dangerous for pregnant women to handle. Common examples are diethylstilbestrol, chloramphenicol, misoprostol, cyclosporine, altrenogest[a], and dinoprost tromethamine.[b]

Diethylstilbestrol is a synthetic female hormone that is used to treat urinary incontinence in spayed female dogs and was widely prescribed for pregnant women from the 1930s to 1960s but was later found to increase cancer risk in babies that were exposed.[4]

While there are few literature reports linking the use of chloramphenicol in pregnancy to birth defects, it has been associated with adverse effects in the neonate as well as heritable genetic damage and cancer.[5] In addition, serious and fatal blood dyscrasias (aplastic anemia, hypoplastic anemia, thrombocytopenia, granulocytopenia) can occur after short-term or prolonged therapy. Chloramphenicol-associated aplastic anemia terminating in leukemia has also been reported.[6]

Misoprostol may cause adverse effects on the developing fetus, miscarriage, uterine rupture, bleeding, and death.[7]

Cyclosporine is an immunomodulatory drug used to treat an increasing spectrum of diseases in dogs. It is associated with premature delivery and low birth weight in human infants.[8]

Altrenogest is an oral progestin used to suppress estrus or as an adjunct to help maintain pregnancy in mares. Skin contact must be avoided as altrenogest is readily absorbed through unbroken skin. The product label warns that pregnant women or women who suspect they are pregnant should not handle this product, as accidental absorption could lead to prolongation of pregnancy.[9]

Dinoprost tromethamine is used for estrus induction and synchronization in farm animals and horses. It is readily absorbed through the skin and can cause abortion in pregnant women.[10]

These are not the only pharmaceuticals that can cause harm. Use care, read labels, and avoid handling hazardous substances as much as possible. If you do handle these drugs while pregnant, use double gloves or consider wearing thicker chemotherapy gloves. Wash your hands thoroughly and consider wearing a mask if handling tablets that could result in dust inhalation.

Chemotherapy

Chemotherapy is designed to fight cancer by killing fast-growing cells. Hence, these cytotoxic drugs are very harmful to the fetus's fast-growing cells. Ideally, pregnant women shouldn't interact with patients receiving chemotherapy or be involved in its administration. If there is no alternative, at least try to avoid the preparation of chemotherapy agents, the mixing of IV fluids containing chemotherapeutic agents and the injection or infiltration of tissues with these drugs, such as the injection of an equine sarcoid with cisplatin. Wear a gown and mask, as well as double chemotherapy gloves when performing treatments, if you must perform this service.

The waste of patients receiving chemotherapy is often toxic for a period of time as it is eliminated from the body. To the extent possible, let others perform clean-up of these patients' cages or stalls. Because certain chemotherapeutic agents are more dangerous than others, it is prudent to learn as much as you can about these drugs before handling them, if you're pregnant.

Formaldehyde and Formalin

Formalin is the name for saturated (37%) formaldehyde solution. Study results vary with regard to the degree of risk that formaldehyde can pose for pregnant women, but it is known to be a carcinogen, and is linked to spontaneous abortion, congenital malformations, and premature birth. Pregnancy is a particularly vulnerable time for exposure to indoor air pollutants such as formaldehyde. Avoiding contact with formaldehyde and formalin is wise during pregnancy.

Toxoplasmosis

Most pregnant women are aware of the dangers of toxoplasmosis. The feces of cats may contain a parasite called *Toxoplasma gondii*, which can cause the rare but serious blood infection. Toxoplasmosis can also be contracted by eating infected, undercooked meat or by eating contaminated fruit or vegetables. Interestingly, the most frequent exposure to toxoplasmosis is by eating undercooked pork.

If you have lived with cats for some length of time, work in a small animal practice, or have eaten undercooked pork, you may have already been exposed to toxoplasmosis and developed immunity to it. Pregnant employees may choose to be serologically tested, because with a seropositive result, they are not at risk of contracting the protozoa. For women who are not immune to toxoplasmosis, exposure to this parasite just prior to or during pregnancy may cause the fetus to be infected. According to the Organization of Teratology Information Services, when infection occurs between weeks 10 to 24, the risk for severe problems in the newborn is about 5% to 6%. Effects on the baby include premature birth, low birth weight, fever, jaundice, abnormalities of the retina, mental retardation, abnormal head size, convulsions, and brain calcification. During the third trimester, a fetus has an increased risk of becoming infected, but the risk of damage to the fetus is decreased since most of the important development has already occurred.[11]

During pregnancy, if you do not have immunity, allow other people to clean litter boxes. It is always wise to take sanitary precautions when handling litter boxes, even if you aren't pregnant. In addition, washing your hands thoroughly between handling patients (as you probably already do) is simply good biosecurity and good personal hygiene.

Other Zoonotic or Infectious Diseases

Exposure to or infection with diseases like rabies, tetanus, *C. difficile* diarrhea, listeriosis, salmonellosis, cryptosporidiosis, plague, sporotrichosis, methicillin-resistant *Staphylococcus aureus* infection, psittacosis, dermatophytosis, leptospirosis, bartonellosis, and Q fever have all been documented in veterinary workers. Pregnant women are more susceptible to certain zoonotic infections owing to physiologic suppression of cell-mediated immunity. Conditions to which pregnant women are more susceptible include toxoplasmosis, lymphocytic choriomeningitis, brucellosis, listeriosis, and psittacosis. Vertical transmission of certain zoonotic agents may result in miscarriage, stillbirth, premature birth, or fetal congenital anomalies. The NASPHV Compendium of Veterinary Standard Precautions is recommended as a resource to minimize these hazards.[12] In addition, the University of Wisconsin has a Web page devoted to zoonoses and pregnancy.[13]

3. Summary

Educate yourself about the specific risks in your workplace. Discuss these risks with your obstetrician and your concerns with the practice owner soon after you find out you're pregnant. There will be many decisions to make, some of which will be difficult, but the detrimental effect of failing to take precautions could cause a lifetime of difficulty for your child. Together with your employer and physician, you can decide whether you need to take special precautions or modify your work duties during your pregnancy. You need to feel comfortable with your choices.

Acknowledgments

Declaration of Ethics

The Author has adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Author has no conflicts of interest.

References and Footnotes

1. Occupational hazards of the female orthopaedic surgeon. Available from: https://www.medscape.org/viewarticle/420417. Accessed March 4, 2020.
2. Shuhaiber S, Koren G. Occupational exposure to inhaled anesthetic. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2145015/pdf/canfamphys00034-0033.pdf. Accessed March 5, 2020.
3. Kakazu C, Lippmann M, Karnwal A. Hazards of bone cement: For patient and operating theatre personnel. *Brit J Anaesth* 2015;114:168–169.
4. DES exposure: questions & answers. Available from: https://www.cancer.org/cancer/cancer-causes/medical-treatments/des-exposure.html. Accessed August 27, 2019.
5. Safety data sheet—Chloramphenicol. Available from: https://www.caymanchem.com/msdss/14334m.pdf. Accessed August 27, 2019.
6. Chloramphenicol. Available from: https://www.drugs.com/monograph/chloramphenicol.html. Accessed March 4, 2020.
7. Safety data sheet—Misoprostol. Available from: https://www.pfizer.com/sites/default/files/products/material_safety_data/misoprostol_tablets_1-Oct-2018.pdf. Accessed August 27, 2019.
8. Cyclosporine use during pregnancy. Available from: https://www.ncbi.nlm.nih.gov/pubmed/23516008. Accessed August 27, 2019.
9. ReguMate® product information sheet. Available from: https://www.merck-animal-health-usa.com/pdfs/equine/Regu-Mate%20-Fact%20Sheet%20-%20Merck%20Animal%20Health.pdf. Accessed August 27, 2019.
10. Safety data sheet—Lutalyse. Available from: https://www.zoetisus.com/contact/pages/product_information/msds_pi/msds/Lutalyse.pdf. Accessed August 27, 2019.
11. Toxoplasmosis. Available from: https://americanpregnancy.org/pregnancy-complications/toxoplasmosis/. Accessed August 27, 2019.
12. National Association of State Public Health Veterinarians. Compendium of veterinary standard precautions for zoonotic disease prevention in veterinary personnel. *J Am Vet Med Assoc* 2015;247:1254–1276.
13. Zoonotic disease and pregnancy. Available from: https://ehs.wisc.edu/zoonotic-diseases-and-pregnancy/. Accessed August 27, 2019.

[a]ReguMate®, Merck Animal Health, Madison, NJ 07940.
[b]Lutalyse®, Zoetis, Kalamazoo, MI 49007.

Overview of Racehorse Medications

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The use of therapeutic substances is necessary to effectively treat equine athletes; however, these compounds must be used judiciously to ensure the welfare of the horse and integrity of horseracing. Regulatory recommendations for drugs commonly administered to racehorses have been established to help practitioners achieve this goal. Author's address: K.L. Maddy Equine Analytical Pharmacology Lab, School of Veterinary Medicine, University of California–Davis, Davis, CA 95616; e-mail: hkknych@ucdavis.edu.

1. Introduction

While the administration of therapeutic substances is necessary for effective treatment of equine athletes, equally as important is ensuring the safety and welfare of the horse. This includes assuring that injuries, which would otherwise keep a horse from racing, are not "masked" by the administration of drugs. To that end, the use of therapeutic compounds in racehorses is tightly regulated. While the oversight bodies differ depending on the discipline, the goal of medication monitoring and anti-doping programs remain the same. First, these programs are meant to ensure the safety and welfare of the horse and jockey; second, to ensure a fair and level playing field/maintain the integrity of the industry and third, in the case of horseracing, to safeguard the public where pari-mutuel wagering exists. In horse racing, many racing jurisdictions in North America have adopted the National Uniform Medication Program (NUMP) recommendations, a set of regulatory recommendations (thresholds and withdrawal times) for therapeutic medications meant to encourage uniformity throughout the industry. These recommendations are made by the Racing Medication and Testing Consortium (RMTC) to the Association of Racing Commissioners International (RCI) who then votes to incorporate them into the NUMP. In 2015, the American Association of Equine Practitioners (AAEP) announced that the organization fully supports the adoption and implantation of NUMP in all racing jurisdictions as part of the AAEP's Prescription for Racing Reform.[1] As discussed in more detail below for specific classes of therapeutic medications, recently some racing jurisdictions within the United States have begun to adopt/implement stricter medication regulations that are more in line with international standards.

2. Therapeutic Medications Used in Racehorses

While certainly not an all-inclusive list, what follows is a discussion of a few of the more commonly used therapeutic substances in racehorses, including those that have been of concern as of late.

Non-Steroidal Anti-Inflammatory Drugs

Non-Steroidal Anti-Inflammatory Drugs (NSAIDs) remain the mainstay of treatment for horses with musculoskeletal pain and inflammation and as such are arguably the most commonly prescribed medication in racetrack practice. These drugs are potent anti-inflammatory drugs by virtue of their ability to

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decrease the production of inflammatory eicosanoids (prostaglandins and leukotrienes), through inhibition of cyclooxygenase (COX-1 and COX-2) enzymes. Compounds that have a greater selectivity for COX-2, which is oftentimes associated with the signs of inflammation, relative to COX-1, the so-called housekeeping enzyme, are considered to have a better safety profile. There are currently six US Food and Drug Administration (FDA)–approved NSAIDs labeled for use in the horse, including flunixin meglumine, phenylbutazone (PBZ), ketoprofen, diclofenac, meclofenamic acid, and firocoxib. While all are effective anti-inflammatory agents, they vary with respect to their COX-1:COX-2 selectivity, as well as pharmacokinetics properties.

While the use of this class of drugs is unarguably imperative in veterinary medicine for the effective treatment of pain and inflammation in equine patients, it is important that they be used judiciously in racehorses. As a result of their potential to mask injuries during racing or interfere with detection of lameness during pre-competition fitness and lameness examinations, the use of NSAIDs is highly regulated in racehorses. With respect to pre-racing lameness evaluations, the examination may occur as many as 14 hours prior to post time and therefore concerns have been raised with respect to the regulatory examining veterinarian's ability to effectively conduct an examination if PBZ is administered at 24 hours prior to racing (the current recommendation under the NUMP). In 2015, the AAEP recommended to the RMTC, a 48-hour restricted administration time for NSAIDs as part of NUMP, citing research supporting anti-inflammatory effects lasting beyond 24-hours and emphasizing the need to evaluate horses without the effect of anti-inflammatory drugs effecting this decision. Although not yet part of NUMP, within the last year, select racing jurisdictions have adopted a 48-hour stand-down time for NSAIDs.

"Stacking" of NSAIDs is a practice employed by some racetrack practitioners. As only one NSAID is permitted within 24 hours under NUMP, in this scenario, a "secondary threshold" with a 48-hour withdrawal time exists for the second NSAID. Administration of multiple NSAIDs in close proximity does appear to prolong the inflammatory effect in an *ex vivo* model, assessing the effects of administration of multiple NSAIDs, specifically flunixin meglumine and PBZ on the production of inflammatory mediators in lipopolysaccharide (LPS) stimulated blood.[a] Aside from the prolonged anti-inflammatory effects, from an animal welfare standpoint, it should also be noted that multiple NSAIDs may increase the risk of and/or compound the adverse effects (i.e., gastric ulcers) associated with administration of drugs in this class. In keeping with stricter regulations on the administration of NSAIDs in horseracing, the RMTC has recently recommended eliminating the secondary threshold to help end the practice of "stacking" of NSAIDs and this recommendation has already been adopted by some racing jurisdiction.

Corticosteroids

Similar to NSAIDs, the effectiveness of corticosteroids in the treatment of musculoskeletal and joint pain and inflammation make them particularly useful in racetrack practice. These extremely potent anti-inflammatory agents are administered by both intra-articular and systemic (IV, IM, and PO) routes of administration. Intra-articular corticosteroids are oftentimes formulated as esters (i.e., acetate, acetonide), prolonging the residence time in the joint. In order for the drug to elicit its pharmacologic effect, the corticosteroid must be liberated from the ester by enzymes present within the joint. As this process takes time, formulating these drugs as esters, gives them the properties of a "slow-release" formulation. Similarly, in order for the drug to leave the joint and enter the systemic circulation, it must be free from the ester group. With respect to exiting the joint, the corticosteroid leaves very slowly, resulting in a disproportionately high concentration of drug in the joint compared to what is detected in the blood. This suggests that the pharmacologic effect in the joint is also prolonged and the low to non-detectable levels of corticosteroid in the blood are not a good indicator of what is occurring in the joint. In one study with methylprednisolone acetate, concentrations of drug in the joint were detected for 70–77 days post administration, long after drug concentrations were below detectable levels in the blood.[2] This finding supports previous research, which demonstrates prolonged therapeutic effects for most of the commonly used intra-articular corticosteroids.[3]

Corticosteroid administration, both intra-articular and systemic, are tightly regulated in horseracing. Current recommendations under the NUMP is that triamcinolone acetonide, isoflupredone acetate and betamethasone be administered a minimum of 7 days prior to racing and methylprednisolone acetate at 21 days. Some racing jurisdictions, at the recommendation of the RMTC have extended the intra-articular administration time for triamcinolone acetonide, isoflupredone acetate, and betamethasone to a 14-day stand-down period. Additionally, the RMTC recommends prohibition of corticosteroid stacking, whereby the presence of more than one corticosteroid would be considered a violation.

Furosemide

Perhaps one of the most controversial topics in horse racing, both nationally and internationally, is the use of race day furosemide. Furosemide is administered to decrease the severity of bleeding associated with exercise-induced pulmonary hemorrhage (EIPH), which has a reported incidence of 43% to 75% in Thoroughbred horses when examined within 2 hours of racing.[4–7]

Studies of pharmacological interventions for EIPH have focused primarily on decreasing the severity of hemorrhage and to date, the only pharmacologic intervention that attenuates the bleeding associated with EIPH is furosemide.[8] While the mechanism of action is still unclear, furosemide has been shown to attenuate the increases in pulmonary pressures associated with strenuous exercise, thus decreasing the severity or incidence of EIPH.[8,9]

Due to the high incidence of EIPH in racehorses and the potential impact in the short term on athletic performance and over the long term on the animals' health, in many North American racing jurisdictions, furosemide administration is permitted as a preventative measure for EIPH up to 4 hours prior to post time, making furosemide the only permitted race-day medication. Recently, many racing jurisdictions are re-examining the allowance of race day furosemide. Two studies describing the effects of furosemide, administered 24 hours prior to race, on EIPH scores and red blood cell counts in bronchoalveolar lavage fluid had mixed results.[10,11] One study conducted at the racetrack using horses in active race training failed to demonstrate a significant difference in EIPH scores or red blood cell counts in bronchoalveolar lavage fluid when comparing furosemide administered at 24 hours and a saline control.[10] It should be noted that the EIPH history of horses enrolled in that study was unknown and the authors suggested perhaps the outcome would have been different had horses with a known history of EIPH been utilized.[10] In the second study, investigators assessed the effects of six different treatment protocols, including different doses of furosemide and with and without water restrictions, on the mitigation of EIPH in horses when the drug was administered 24 hours prior to treadmill and racetrack exercise.[11] Of the six treatment protocols, a combination of 0.5 mg/kg furosemide, administered at 24 hours prior to strenuous exercise in combination with water restriction (6 mL/kg at 20, 16, 12, and 8 hours prior to exercise) decreased the severity of EIPH.[11] It should be noted that the authors also recommended that a larger study is indicated to fully evaluate this protocol.

While currently, many racing jurisdictions do still permit race day (outside of 4 hours prior to post time) administration of furosemide, some have restricted its use starting with horses turning 2 years old in 2020. Additionally, the AAEP has supported investigation of alternative management strategies for EIPH with the intent of eliminating race-day administration of furosemide should a more efficacious strategy become apparent.

Bisphosphonates

Bisphosphonates are potent anti-resorptive agents that have been used for several years in human medicine to increase bone density and decrease fracture risk in individuals with osteoporosis.[12–15] In 2014, the FDA approved two bisphosphonate products for use in veterinary medicine, labeled for the treatment of navicular syndrome in horses greater than 4 years of age. Prior to this time, bisphosphonates were used in horses in an extra label fashion for conditions such as back soreness,[16] hock osteoarthritis,[17] and navicular disease.[18]

Despite the FDA's Center for Veterinary Medicine not recommending the use of bisphosphonates in horses less than 4 years of age,[19] anecdotal reports exist of its use in this age group. While there are no published reports describing the effects of bisphosphonates on the skeleton of growing horses because they are known to inhibit osteoclasts and osteoclasts play a role in bone development,[20] inhibition by bisphosphonates may have detrimental effects on normal bone development. Furthermore, as has been reported in young human athletes,[21] the adverse effects of bisphosphonates on bone in juvenile horses may be exacerbated if these young horses are undergoing high-impact exercise, such as race training.

The use of bisphosphonates in racehorses, regardless of age, is controversial.[22] One argument in favor of their use is that because bisphosphonates are known to inhibit the effects of osteoclasts, that administration may prevent weakening of bone and thus the occurrence of stress fractures.[22] However, in Thoroughbred racehorses microcracks are known to occur as part of high-intensity training,[23] and the first step in the healing process is resorption, which is mediated by osteoclasts.[24] It would then follow that bisphosphonates, through inhibition of bone resorption, may impair the normal healing process. An additional proposed mechanism of bisphosphonate activity is inhibition of osteocytes which play a role in osteoclast recruitment, further reducing the ability of the body to repair microcracks,[21,25] therefore adding to bone fragility. While not specifically related to the healing of microcracks, studies in mice and rats have demonstrated a delay in remodeling of the cartilaginous callus in fractures when animals were treated with bisphosphonates.[26–30]

It has been well established in humans that although BPs have a short residence (and detection) time in blood that they can remain in bone for months to years.[31] Recently, bisphosphonates were detected in bone and teeth from horses administered either clodronate or tiludronate at 4 and 30 days prior to collection of samples.[b] Using a liquid chromatography–tandem mass spectrometry assay, both bisphosphonates were detected in the right and left molar, right and left radius, right MC3 and right tuber coxae, providing the first evidence that similar to humans, BPs reside in horse bone for extended periods of time post administration potentially prolonging the duration of effect and inhibiting bone remodeling in young athletic animals.

Bisphosphonates also reportedly have analgesic effects. While the exact mechanism for this analgesic effect has not been definitely determined, some have theorized that it is due to either direct interaction with neurons[32] or inhibition of pain associated with active bone resorption.[25] One group of researchers have proposed that type 5 acid phosphatase (TRAcP5b), a marker of subchondral osteoclast activity,[33] may also be an indicator of bone pain associated with osteoclast behavior in individuals with osteoarthritis.[33] One study in humans demonstrated a significant decrease in serum TRAcP5b concentrations following administration of the bisphosphonate alendronate.[34] In horses, there are anecdotal reports of analgesic effects lasting up to 30 days. Both clodronate and etidronate have been shown to have analgesic effects in mice.[32]

Due to concerns regarding the use of bisphosphonates in young animals in active training, where bone development and remodeling are of great importance, some racing jurisdictions have adopted a policy prohibiting the use of this class of drugs in racehorses. Additional research on bisphosphonates in horses is needed to fully understand the effects on bone remodeling and development.

3. Concluding Remarks

Judicious use of therapeutic substances in racetrack practice is imperative to ensure the safety of equine athletes and regulatory recommendations are meant to aid the practitioner in this endeavor. Regulatory thresholds for therapeutic drugs are set at a concentration in which the drug has no or minimal pharmacologic effect and that which can be effectively regulated. In many North American racing jurisdictions, a pharmacokinetic study is conducted, and a statistical approach is then used to establish a withdrawal time that is representative of the time that drug concentrations will fall below the threshold value, plus a statistical margin of safety.[35] When utilizing these recommendations, it is important to note that they are based on a specific drug formulation, route of administration and dosage and therefore if treatment deviates, it may be necessary to extend the withdrawal time accordingly. It is also imperative that the treating veterinarian do his or her own risk assessment based on relevant clinical factors and that the regulatory recommendation be adjusted accordingly.

Lastly, the preceding discussion includes only a small subset of therapeutic drugs used in racetrack practice, and discussion of additional therapeutic medications, including regulatory recommendations, can be found elsewhere.

Acknowledgments

Declaration of Ethics

The Author has adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Author has no conflicts of interest.

References and Footnotes

1. https://aaep.org.
2. Knych HK, Harrison LM, Casbeer HC, et al. Disposition of methylprednisolone acetate in plasma, urine, and synovial fluid following intra-articular administration to exercised Thoroughbred horses. *Vet Pharmacol Ther* 2014;37:125–132.
3. McIlwraith CW. The use of intra-articular corticosteroids in the horse: What is known on a scientific basis? *Equine Vet J* 2010;42:563–571.
4. Pascoe JR, Ferraro GL, Cannon JH, et al. Exercise-induced pulmonary hemorrhage in racing Thoroughbreds: A preliminary study. *Am J Vet Res* 1981;42:703–707.
5. Raphel C, LR S. Exercise-induced pulmonary hemorrhage in Thoroughbreds after racing and breezing. *Am J Vet Res* 1982;43:1123–1127.
6. Hinchcliff KW, Jackson MA, Morley PS, et al. Association between exercise-induced pulmonary hemorrhage and performance in Thoroughbred racehorses. *J Am Vet Med Assoc* 2005;227:768–774.
7. Hinchcliff KW, Morley PS, Guthrie AJ. Efficacy of furosemide for prevention of exercise-induced pulmonary hemorrhage in Thoroughbred racehorses. *J Am Vet Med Assoc* 2009;235:76–82.
8. Hinchcliff KW, Couetil LL, Knight PK, et al. Exercise induced pulmonary hemorrhage in horses: American College of Veterinary Internal Medicine Consensus Statement. *J Vet Intern Med* 2015;29:743–758.
9. Sullivan SL, Whittem T, Morley PS, et al. A systematic review and meta-analysis of the efficacy of furosemide for exercise-induced pulmonary haemorrhage in Thoroughbred and Standardbred racehorses. *Equine Vet J* 2015;47:341–349.
10. Knych HK, Wilson WD, Vale A, et al. Effectiveness of furosemide in attenuating exercise-induced pulmonary haemorrhage in horses when administered at 4- and 24-h prior to high-speed training. *Equine Vet J* 2018;50:350–355.
11. Bayly W, Lopez C, Sides R, et al. Effect of different protocols on the mitigation of exercise-induced pulmonary hemorrhage in horses when administered 24 hours before strenuous exercise. *J Vet Intern Med* 2019;33:2319–2326.
12. Lai P, Nagammai T, Vethakkan S. A postmenopausal osteoporotic woman losing bone mineral density despite bisphosphonates. *Malaysian Fam physician* 2013;8:47–52.
13. Storm T, Thamsborg G, Steiniche T, et al. Effect of intermittent cyclical etidronate therapy on bone mass and fracture rate in women with postmenopausal osteoporosis. *N Engl J Med* 1990;322:1265–1271.
14. Uchida K, Nakajima H, Miyazaki T, et al. Effects of Alendronate on bone metabolism in glucocorticoid-induced osteoporosis measured by 18F-fluoride PET: A prospective study. *J Nucl Med* 2009;50:1808–1814.
15. Black DM, Cummings SR, Karpf DB, et al. Randomised trial of effect of alendronate on risk of fracture in women with existing vertebral fractures. Fracture Intervention Trial Research Group. *Lancet (London, England)* 1996;348:1535–1541.
16. Coudry V, Thibaud D, Riccio B, et al. Efficacy of tiludronate in the treatment of horses with signs of pain associated with osteoarthritic lesions of the thoracolumbar vertebral column. *Am J Vet Res* 2007;68:329–337.
17. Gough MR, Thibaud D, Smith RKW. Tiludronate infusion in the treatment of bone spavin: A double blind placebo-controlled trial. *Equine Vet J* 2010;42:381–387.
18. Denoix JM, Thibaud D, Riccio B. Tiludronate as a new therapeutic agent in the treatment of navicular disease: A double-blind placebo-controlled clinical trial. *Equine Vet J* 2003;35:407–413.
19. Clodronate sodium (Osphos) [package insert]. Staffordshire U. Dechra; 2014.
20. Li Z, Kong K, Qi W. Osteoclast and its roles in calcium metabolism and bone development and remodeling. *Biochem Biophys Res Commun* 2006;343:345–350.
21. Shima Y, Engebretsen L, Iwasa J, et al. Use of bisphosphonates for the treatment of stress fractures in athletes. *Knee Surg Sport Traumatol Arthrosc* 2009;17:542–550.

22. McLellan J. Science-in-brief: bisphosphonate use in the racehorse: Safe or unsafe? *Equine Vet J* 2017;49:404–407.
23. Ott SM. Long-term safety of bisphosphonates. *J Clin Endocrinol Metab* 2005;90:1897–1899.
24. Kidd LJ, Cowling NR, Wu ACK, et al. Bisphosphonate treatment delays stress fracture remodeling in the rat ulna. *J Orthop Res* 2011;29:1827–1833.
25. Marini JC. Do bisphosphonates make children's bones better or brittle? *N Engl J Med* 2003;349:423–426.
26. Li J, Mori S, Kaji Y, et al. Effect of bisphosphonate (incadronate) on fracture healing of long bones in rats. *J Bone Miner Res* 1999;14:969–979.
27. Fu L, Tang T, Hao Y, et al. Long-term effects of alendronate on fracture healing and bone remodeling of femoral shaft in ovariectomized rats. *Acta Pharmacol Sin* 2013;34:387–392.
28. Cao Y, Mori S, Mashiba T, et al. Raloxifene, estrogen, and alendronate affect the processes of fracture repair differently in ovariectomized rats. *J Bone Miner Res* 2002;17:2237–2246.
29. Gerstenfeld LC, Sacks DJ, Pelis M, et al. Comparison of effects of the bisphosphonate alendronate versus the RANKL inhibitor denosumab on murine fracture healing. *J Bone Miner Res* 2009;24:196–208.
30. McDonald MM, Dulai S, Godfrey C, et al. Bolus or weekly zoledronic acid administration does not delay endochondral fracture repair but weekly dosing enhances delays in hard callus remodeling. *Bone* 2008;43:653–662.
31. Drake MT, Clarke BL, Khosla S. Bisphosphonates: Mechanism of action and role in clinical practice. *Mayo Clin Proc* 2008;83:1032–1045.
32. Kim S, Seiryu M, Okada S, et al. Analgesic effects of the non-nitrogen-containing bisphosphonates etidronate and clodronate, independent of anti-resorptive effects on bone. *Eur J Pharmacol* 2013;699:14–22.
33. Nwosu LN, Allen M, Wyatt L, et al. Pain prediction by serum biomarkers of bone turnover in people with knee osteoarthritis: An observational study of TRAcP5b and cathepsin K in OA. *Osteoarthr Cartil* 2017;25:858–865.
34. Nenonen A, Cheng S, Ivaska KK, et al. Serum TRACP 5b is a useful marker for monitoring alendronate treatment: Comparison with other markers of bone turnover. *J Bone Miner Res* 2005;20:1804–1812.
35. European Agency For the Evaluation of Medicinal Products. 2000. Note for guidance for the determination of withdrawal periods for milk.

[a]Knych HK, Arthur RM, McKemie, et al. Pharmacokinetics and anti-inflammatory effects of flunixin meglumine as a sole agent and in combination with phenylbutazone in exercised Thoroughbred horses (submitted).

[b]Knych HK (manuscript in preparation).

Approaches for Equine Medication Control (Anti-Doping)

Scott D. Stanley, PhD

Equine anti-doping programs exist to protect the wagering public and serve as a strong deterrent for anyone considering using performance-enhancing drugs. The threat of new forms of doping have resulted in substantial changes over the past 3 decades. New technology has enabled racing chemists to detect drugs of abuse at lower concentrations. Author's address: Gluck Equine Research Center, University of Kentucky, Lexington, KY 40546; e-mail: scott.stanley2@uky.edu.

1. Introduction

In North America, professional horse racing is entirely regulated by the individual states. Each state has legal authority over pari-mutuel wagering, by which all bets of a certain category are placed together in a pool; excise taxes and the house share (i.e., margin) are deducted from the winning bets. The original intent of funds collected from pari-mutuel excise taxes were to support rural and agricultural economy. As a consequence, equine drug testing/anti-doping regulations are controlled through adopting Model Rules and by redrafting the rule language to ensure these are suitable for individual states. Each state has its own legislature, therefore each jurisdiction may have different requirements for changes to Model Rule language. For example, some state guidelines are statutes while other states use regulations. Statutes are laws made by the legislature and regulations/rules are adopted by Commissions/Boards to fill in the gaps of legislation. State codes are books where similar subjects (statutes/laws) are grouped together. Regardless, each process has unique requirements when notifying the public of any rule change; additionally, there are built-in timelines per state law for approving and enacting these changes. There are numerous examples where these different processes create delays in Model Rule implementation, and frequently there are unintended language discrepancies between states.

Currently, standardized methods for equine anti-doping laboratories do not exist. All Racing Medication and Testing Consortium–accredited laboratories perform the initial testing procedure or screening of performance-enhancing drugs using both gas chromatography and liquid chromatography, coupled with mass spectrometry. In general, these nontargeted techniques acquire the essential data to monitor large numbers of substances. In doing so, they provide coverage for nearly all prohibited pharmaceuticals. In most jurisdictions, urine and blood samples are analyzed using advanced LC-high-resolution accurate mass spectrometry, LC-HRMS,[a] to acquire the necessary data for small-molecule drug detection. LC-HRMS is now the most important screening technique used in equine anti-doping laboratories. Personnel training is critical as typical processing involves manual as-

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sessment of thousands of data files, requiring significant personnel time to review and evaluate individual chromatograms and spectra per file.

2. Define Roles of the Anti-Doping Laboratory

Horseracing anti-doping programs test for more substances and at lower limits of detection than any professional or amateur sport, including the Olympics. While racing establishments may logically consider the racing chemist only in relation to routine analysis of urine and blood samples, the impressive amount of research work also carried out each year should not be overlooked. It is true that the primary function of the racing laboratory is the routine testing of pre- and post-race samples. However, before this can be efficiently accomplished, many months of carefully organized research and validated work have to be completed by qualified scientists. Equine pharmacology is an underfunded discipline in veterinary medicine. Of late, resources previously dedicated to support exercised horses for targeted projects have been substantially decreased or eliminated entirely. The most productive research conducted in equine pharmacology involve well-designed studies, precise execution and comprehensive data analysis. The administration of drug targets to university-owned research horses is the foundation for obtaining accurate pharmacokinetic and pharmacodynamic information. Only then can research samples be effectively utilized for improving extraction methods, increasing sensitivity of techniques, developing methods for new drugs, and adapting new instruments to this highly specialized type of analysis.

Monitoring Medication Usage of Racing Population

Analytical Capabilities and When to Use the Most Sensitive Method

One of the primary responsibilities of racing officials charged with the regulation of racing is to ensure that the sport is conducted without any illegal external influence and with impartial judgment. This responsibility is shared to some degree by everyone involved in racing and all those interested in the continued well-being of racing as a sport and a business. Foremost among these responsibilities is the prevention of prohibited practices and the detection and punishment of those misguided persons whose decisions may compromise the sport's integrity. Few of these practices are more detrimental to racing in the eyes of the public than the use of a drug with the intention of altering the performance of a horse during a race. It follows that those concerned with the reputation of racing and with its honest conduct can leave no method, which offers promise of providing an effective weapon against those determined to cheat, unexplored.

The concept of threshold values for therapeutic substances was introduced in the early 1990s. The California Horse Racing Board authorized "decision levels" for 8 therapeutic medications. In the past 3 decades, racing authorities have employed different approaches to doping control of therapeutic medications. There are 4 basic ideological approaches; 1) zero tolerance, 2) permitted medication (thresholds), 3) screening limits, and 4) restricted administration time. Prior to development of thresholds for therapeutic medications, veterinarians and equine pharmacologists had their own opinions about agents and their effects on performance. Creating the concept and framework for evaluating therapeutic thresholds has provided a useful foundation for exchange of knowledge among experts, as well as valuable information for horsemen and regulators.

Zero tolerance, terminology often embraced by laymen, is an old approach used widely in Europe. This approach implies that the qualitative detection and confirmation of a prohibited substance would be all that is required to invoke the rule. In general, there is no reference to any quantifiable concentration, thereby making it immaterial if the substance is present in milligrams, nanograms, or femtograms per milliliter. The inherent problems are evident but not limited to the following: 1) naturally occurring substances (e.g., morphine and scopolamine), 2) prolonged elimination times for some therapeutic medications, 3) limited information regarding new therapeutic medications, and 4) variable methodologies/capabilities between laboratories. More recently, the majority of regulatory agencies have come to the realization that zero tolerance is scientifically and morally flawed with regard to many substances.

Permitted medications is often the term associated with therapeutic medications with a detection time exceeding the pharmacological effects most associated with a therapeutic dose. With this approach, the regulatory body establishes a "threshold" concentration, which is determined from pharmacokinetic studies. Concentrations in regulatory samples that exceed the threshold concentration would then be considered a violation.

The term, screening limit, is the concentration of a particular therapeutic substance in urine or plasma, above which the racing laboratory would report the sample as being positive. This ideology is used throughout the world but is particularly popular in Europe and Asia. This approach doesn't require the laboratory to report a measured concentration. The racing chemist would only need to establish that the sample contains a therapeutic substance above the screening limit prior to conducting final confirmatory analysis. The final confirmation does not require quantitation analysis.

Analytical chemists require guidance with respect to chemical agents with the potential for abuse and therefore that are of the highest priority for method development. In addition, the racing laboratories require guidance on establishing detection level (sometimes referred to as "threshold," "reporting limit," or "screening limit") necessary to control misuse of legitimate therapeutic drugs. With input from stakeholders and veterinary experts, the racing authorities establish the proper "limit" needed to prevent threats to racing that involve improper administration of drugs. Once the guidelines are issued, the laboratories are then responsible for selecting and applying the analytical method required to best verify compliance. In these cases, the labs use the fully validated quantitative methods reviewed and approved by an external accrediting organization.

Sample Analysis is a 2-Step Procedure

Initially, all samples undergo a multi-stage solid phase extraction procedure, followed by analysis using numerous screening methods. These screening methods most often employ chromatography separation coupled with mass-spectrometry detection. This combination affords simultaneous identification of thousands of compounds while providing limits of detection in the low parts-per-trillion concentration. These extraordinary sensitivities are advantageous for detecting prohibited substances which have no therapeutic purpose in horse racing. However, if interpreted incorrectly, such as in the case of therapeutic drugs, these highly sensitive tools can result in positive findings days to weeks beyond any pharmacological effect. To avoid irrelevant findings for therapeutic medications, comprehensive standard operating procedures and method validation must be routine in all racing chemistry laboratories. A properly defined workflow including sample preparation, sample analysis, and data processing to meet predefined criteria are a minimum requirement.

High-resolution accurate mass spectrometry is particularly important for biological samples that involve complex matrix (e.g., urine and blood). Full-scan approaches permit detection of unlimited numbers of analytes simultaneously. For a screening method aiming at detection of both target analytes and unknowns, high-resolution instrumentation is a distinct advantage.

Confirmation

The use of mass spectrometry for confirmatory analysis is mandatory in order to report a therapeutic excess or prohibited substance finding, in effect making this technique the gold standard for legally defensible data. The analytical technique of mass spectrometry is a measure of the mass-to-charge (m/z) ratio of ions, with the ratio of the analyte signal to the noise measured with a blank (background). Contemporary mass spectrometers can operate in modes that provide very low background noise and have the ability to detect individual ions, enabling the extreme lower limits of detection (femtograms $= 1 \times 10^{-15}$ grams).

Limit of Detection and Limit of Quantitation

The limit of detection for analytical procedures is the endpoint of achievable determination by statistical based measurement of the target analyte where the signal-to-noise is no less than 3:1. The limit of quantitation is the achievable determination by statistical-based measurement of the target analyte where the signal-to-noise is no less than 10:1. When samples are analyzed the resultant data must be evaluated to determine whether the therapeutic medication is found and if administered within the parameters set by the method validation studies.

Method Validation

In common with human testing laboratories, the racing industry requires quantitative methods to establish the concentration of an analyte relative to a scientifically determined threshold medication. These quantitative methods must be validated using predefined acceptance criteria to characterize and document performance limitations. Experimental data must be collected to evaluate for accuracy, limit of detection, limit of quantitation, linearity, precision, range, and specificity per US Food and Drug Administration–recommended guidelines. In addition, it is a requirement of all quantitative methods to estimate the measurement of uncertainty for the procedure at the threshold value. Measurement of uncertainty is used when reporting the range of possible values within which the true value of the measurement lies. Combining these validation steps enhances the integrity of the analytical processes and provides assurance to stakeholders regarding the reported findings.

3. New Emerging Trends/Threats

Proteins/Peptide

A wide range of unregulated peptide-based drugs are now available through the internet with numerous Web sites offering an infinite array of purported performance enhancing products (e.g., proteins–growth hormones [GH-somatotrophin], AOD9604, Thymosin β4, Actovegin, Cerebrolysin, Hexarelin, Dermorphin analogues, growth hormone-releasing hormone [GHRH] analogues, GRF analogues, anti-inflammatory peptides, etc.). In general, peptides make poor drugs but they theoretically can make good doping agents.

Peptides have poor bioavailability due to their low diffusion rate across cell membranes. They are rapidly degraded by endogenous proteases/peptidases, rapidly secreted by the kidneys and exhibit short half-lives after administration. All of these characteristics make peptides a challenge to detect in biological samples.

The bulk of these products are intended to stimulate cellular processes or mimic the effects of endogenous equine growth hormone, subsequently to build muscle, bone strength and speed recovery from injuries. The majority of the peptide products commercially available are untested but nonetheless endorsed through anecdotal statements posted online suggesting they have many different applications, including to increase muscle mass, decrease fat, decrease injury recovery time, restore structural maladies, stimulate glucose uptake, and treat acute/chronic illness. The ample supply of these compounds provides unrestricted access to anabolic peptides for abuse by dishonest trainers.

Biological emerging threats are listed below:

1. Equine somatotrophin—Elevate insulin-like growth factor (IGF)-1 and insulin-like growth factor binding protein 3 (IGFBP3) production.
2. GH-releasing hormones (GHRH)—elevate GH production.
3. GH-releasing peptides—Mimics GHRH production.

The ideal goal, to counter these illegal biological agents, would be to understand the specific cellular processes that are affected when the drugs are administered to the horses. To achieve this goal, the biology of the drug class needs to be understood. This is often done through the study of interaction networks. The studies to establish effect must be performed on a large cohort to evaluate each biomarker's specificity. Then, an initial screening method could be used to identify ideal biomarker candidates without having to know the specific drug (within a class) that was administered. The biomarker screening would include a specific panel of targets (proteins in known pathways) from the entire equine proteome and indicate critical changes by identifying up/down regulation from what is considered the baseline proteome.

Biotherapeutics

Over the past 15 to 20 years, biological therapeutics have become a large portion of the pharmaceutical and biotech drug development pipelines. The number and variety of new, large molecule therapeutics will continue to increase in the next decade. The human market has many biotherapeutics targeting arthritis, inflammation, and pain that are all local targets for equine biotherapeutic molecules. This expansion in the human field has led to a surge in therapeutics in specialized veterinary disciplines. Canine and feline oncology have already made progress with the introduction of numerous species-specific therapeutics. The market is much smaller, but the global players in equine healthcare are actively adding new drugs into their development pipeline.

Large molecules present unique challenges for anti-doping laboratories. Unlike the detection of small molecules, which are often based on their physical and chemical characteristics, biotherapeutics frequently require extensive clean-up procedures consisting of tryptic digestion and/or immunochemical methodologies, such as antibody purification. Further complicating matters, large-molecule therapeutics often have endogenous counterparts in matrix (e.g., erythropoietin). The size of the analytical molecule (molecular weight) alone presents an obstacle very different than small-molecule drugs. For example, some biologics are produced by cell culture, and each batch generates unique outcomes; therefore, individual production lots will vary slightly in terms of the molecular structure, which will affect the end products. Consequently, analytical method validation must be linked to reference materials prior to validation experiments, making the traceability of reference standards even more important.

Genetic Practices (Gene Editing/Gene Doping)

Gene editing is a type of gene engineering, whereby DNA is inserted, deleted, modified, or replaced within the genome of a living organism. Gene editing is most commonly considered within the realm of gene therapy research, with the aim of curing disease by altering malfunctional genes. To date, over 2300 gene therapy clinical trials have been completed in humans focused on the treatment of cancer and cardiovascular disease. However, like pharmacological therapies, gene therapy has the potential for misuse, specifically to enhance performance in athletes. This has been recognized as a risk to human sports for approximately the last 15 years. Gene doping poses a significant threat to the integrity of horseracing, and without the development of new methods, will go undetected. When viral vectors carrying genes encoding certain proteins are introduced into cells of the equine athlete, those cells will begin to produce these proteins. The cell will use endogenous components to produce these proteins, making the products virtually indistinguishable from their endogenous counterparts. The most frequently used technique is the so-called CRISPR/Cas9-system, which has fast tracked a wide variety of applications including basic biological research and the development of new therapeutics. Developing analytical methods to detect gene doping has been particularly slow and problematic since both the doping gene and the protein produced are likely highly homologous, if not identical, to their organically occurring counterparts. To overcome this imminent threat, novel methods must be developed, such as monitoring the number of copies of gene within the cell. Baseline data from genetically unmanipulated horses should be collected, and the "normal" number of copies for each gene of interest should be predetermined. Candidate genes that may be targeted would likely include those which 1) induce desirable changes in the muscle phenotype to increase strength and improve sprinting ability, 2) may increase oxygen delivery or blood flow to working muscles for enhanced capability, 3) alleviate pain to resist fatigue and improve post-race recovery, and 4) target mental aptitude, e.g., proopiomelanocortin (*POMC*) gene.

The real challenge is with the Biotech industry and their aggressive growth strategies to identify new gene targets. While only a small number of these molecules will become US Food and Drug Administration–approved drugs, the potential misuse of the remaining unapproved candidates presents a big challenge to the racing industry.

Phytotherapy (Herbal Medicine)

Phytotherapy is the use of plant extracts or preparations containing active drugs from plant origin (e.g., cannabidiol [CBD]). Approximately, between 40% to 50% of pharmaceuticals registered for human use are natural products or derived from a natural product. Well-known examples include aspirin, atropine, cocaine, digoxin morphine, and quinine. Racing laboratories recognized the need to determine a threshold for substances of dietary origin, even before thresholds were established for therapeutic medication.

The World Anti-Doping Agency (WADA) expert panel determined that CBD oil was not a cannabimimetic, and therefore is not prohibited under the WADA Code. Conversely, the following year, the United States Equestrian Federation (USEF) announced they would prohibit CBD and all related cannabinoids. They stated CBD and its active metabolites are likely to affect the performance of a horse due to their reported anxiolytic effects. They further noted that CBD is only one of 113 cannabinoid molecules that scientists have identified. Some estimate there could be a 100 or more undiscovered cannabinoids. USEF's position is that any horse competing under USEF rules found to have any form of a natural cannabinoid, synthetic cannabinoid and other cannabimimetic in their system at the time of competition will be in violation of their rules.

The use of herbal remedies (e.g., dietary supplements) is prevalent in humans, due in part to the prohibitive cost of many prescribed pharmaceuticals. Frequently referred to as "nutraceuticals," equine dietary supplements are widely used and often viewed as a required part of equine welfare. While these products are rarely harmful in their intended form, many people presume that supplements are safer than drugs. In spite of this belief, there have been numerous cases when wrongly formulated or contaminated supplements have caused positive drug tests in racehorses. Several findings of xanthine alkaloids (e.g., caffeine, theophylline, theobromine) have been reported and were attributed to nutritional supplements[b] or feed contamination (e.g., bakery biproducts). There have been numerous positive reports of ephedrine that were attributed to herbal products containing *Ephedra*. One product,[c] resulted in 9 positive cases in California. Other examples include the use of Chinese herbal remedies at racetracks. These products are not permitted since they are potential sources of drug violation largely because of the lack of regulation of the facilities used in the manufacturing process.

Implement Out-of-Competition Testing Protocol (Industry "Best Practices")

Various means have been proposed for the purpose of keeping a horse off the track that has been given a drug. Several approaches for out-of-competition testing prior to the race have been implemented in many states, many of which have been met with substantial resistance from horsemen's organizations. Any pre-race test of this sort, to be practical, must conform to certain requirements. First, since the results will be used to prevent horses from competing in races for which they have been entered, the test must be accurate, validated, and legally defendable. No innocent trainer will accept having their horse scratched because of the "possible" presence of a drug, and they would justifiably resent the implicit smear on their reputation and character. Therefore, any out-of-competition testing method resulting in regulatory action must be capable of detecting and identifying the drug beyond reproach. Trainers utilizing performance enhancing-substances to alter outcomes, create an unfair advantage and undermine the confidence in the competitors and the sport. The end goal is to protect horse racing events by creating the strongest possible deterrent to prevent competitors from any improper behavior.

4. Concluding Remarks

Medication Uniformity Throughout North America

The existing equine drug testing industry has struggled for many years to maintain effective anti-doping programs throughout the United States. The allocation of testing funds each state receives has been unchanged for many years. As a result, inflation results in rapidly declining relative funding. In addition, there has been no additional funding for most states' mandated testing or new testing technologies, and funding for research or quality improvement is inadequate. Consequently, several equine labs have not been able to invest in updated facilities or equipment, resulting in deficiencies reported by external auditors and delayed accreditation.

One mushrooming criticism of horse racing in the United States is that there is no centralized regulatory organization. As discussed previously, one argument is that since each state has control of its own medication regulations, uniformity for testing and enforcement will never occur, and therefore the only pathway to uniform rules would require federal legislation. As a result, there have been two national bills drafted and put in front of Congress, with the intent to create a level playing field and protect the welfare of equine athletes. If approved, these federal bills would strive to provide uniform anti-doping and medication control programs by establishing standards for the use of therapeutic medications and oversight through a single national authority.

Acknowledgments

Declaration of Ethics

The Author has adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Author has no conflicts of interest.

References and Footnotes

1. Bailly-Chouriberry L, Baudoin F, Cormant F, et al. RNA sample preparation applied to gene expression profiling for Horse Biological Passport. *Drug Test Anal* 2015;9:1448–1455.
2. Booth B, Stevenson L, Pillutla R, et al. 2019 White Paper On Recent Issues in Bioanalysis: FDA BMV Guidance, ICH M10 BMV Guideline and Regulatory Inputs (Part 2—Recommendations on 2018 FDA BMV Guidance, 2019 ICH M10 BMV Draft Guideline and Regulatory Agencies' Input on Bioanalysis, Biomarkers and Immunogenicity). *Bioanalysis* 2019;11:2099–2132.
3. Cawley A, Smart C, Greer C, et al. Detection of the selective androgen receptor modulator andarine (S-4) in a routine equine blood doping control sample. *Drug Test Anal* 2016;8:257–261.
4. Cawley A, Keledjian J. Intelligence-based anti-doping from an equine biological passport. *Drug Test Anal* 2017;9:1441–1447.
5. De la Torre B, Albericio F. The Pharmaceutical Industry in 2018. An analysis of FDA drug approval from the perspective of molecules. *Molecules* 2018;24:809.
6. Hansson A, Knych H, Stanley S, et al. Characterization of equine urinary metabolites of selective androgen receptor modular S1, S4 and S22 for doping control purposes. *Drug Test Anal* 2015;7:673–677.
7. Hansson A, Knych H, Stanley S, et al. Equine *in vivo*-derived metabolites of the SARM LGD-4033 and comparison with human and fungal metabolites J. *Chromat B* 2018;91:1074–1075.
8. Maple H, Scheibner O, Baumert M, et al. Application of the Exactive Plus EMR for automated protein-ligand screening by non-covalent mass spectrometry. *Rapid Commun Mass Spectrom* 2014;28:1561–1568.
9. Michely JA, Meyer MR, Maurer HH. Power of Orbitrap-based LC-high resolution-MS/MS for comprehensive drug testing in urine with or without conjugate cleavage or using dried urine spots after on-spot cleavage in comparison to established LC-MS (n) or GC-MS procedures. *Drug Test Anal* 2018;10:158–163.
10. Piccoli S, Mehta D, Vitaliti A, et al. 2019 White Paper on Recent Issues in Bioanalysis: FDA Immunogenicity Guidance, Gene Therapy, Critical Reagents, Biomarkers and Flow Cytometry Validation (Part 3—Recommendations on 2019 FDA Immunogenicity Guidance, Gene Therapy Bioanalytical Challenges, Strategies for Critical Reagent Management, Biomarker Assay Validation, Flow Cytometry Validation & CLSI H62). *Bioanalysis* 2019;11:2207–2244.
11. Timms M, Hall N, Levina V, et al. A high-throughput LC-MS/MS screen for GHRP in equine and human urine, featuring peptide derivatization for improved chromatography. *Drug Test Anal* 2014;6:985–995.
12. Toutain PL. Veterinary medicines and competition animals: The question of medication versus doping control. *Handb Exp Pharmacol* 2010;199:315–339.
13. Van Eenoo P, Van Renterghem P, Dimopoulou CH, et al. Estimating measurement uncertainty in quantitative methods not based on chromatography for doping control purposes. *Drug Test Anal* 2010;2:19–23.
14. Webbon P. Medication: A way forward from zero tolerance to irrelevant plasma concentrations. *Equine Vet J* 2002;34:220–221.

[a]Orbitrap™, Thermo Fisher Scientific, San Jose, CA 95134.
[b]Cytomax®, CytoSport, Inc., Benicia, CA 94510.
[c]Herbal Advantage, Herbal Advantage, Inc., Rogersville, MO 65742.

Responsible Use of Medication in Performance Horses/Racehorses

Jeff A. Blea, DVM

Regardless of discipline, a moral and ethical high ground must be considered when treating horses in a competitive environment. Knowing the right action is simple, following through on that action can be complicated and convoluted. The subsequent statement from over 3 decades ago remains quite relevant today and serves as a navigational tool when it comes to responsible use of medication in the performance horse or the racehorse. As an exercise, transpose the word veterinarian for organization, and these words will become very personal and compelling. *We must take care to maintain a high level of awareness of why we exist as an organization, lest we lose our bearings in the midst of the rapid pace at which things are changing and increasing in complexity.* Equine practitioners exist as an organization because of the horse and the medical and surgical needs particular to the species. Further, this consideration serves as a virtually infallible standard against which to consider all American Association of Equine Practitioners policy. If thought through to its ultimate conclusion, whenever a question is answered based upon the welfare of the horse, the human principles involved are also best served in the long run. We are here for the horse; to the extent that we are responsive to that concept, we will prosper both as individuals and as an organization. *Presidential Address, James Coffman, 1986*[a]. Author's address: Von Bluecher, Blea & Hunkin, Inc., 282 W Sierra Madre Blvd., Sierra Madre, CA, 91024-2312; e-mail: jbleadvm@gmail.com.

1. Introduction

Medication use in the equine industry is under considerable scrutiny by the general public, and in effect, is threatening the veterinary community's social operating license. The social license to operate has been defined as existing when an industry has the ongoing approval within the local community and other stakeholders, ongoing approval or broad social acceptance and, most importantly, ongoing acceptance. It is consequently granted by the community, hence, the social license to operate has to be earned and must be maintained. Where is the equine industry now and where does it need to be in the next 5 years relative to medication in the performance horse? Many believe that less is best. However, the question remains: while ensuring the survivability of the industry in which the horse competes, what is best for the horse? Stakeholders, including veterinarians, are recognizing that medication use in performance horses is no longer deemed universally acceptable, despite scientific evidence of benefit. Numerous industry attempts to educate the public on the difference between therapeutic medication versus performance enhancing medication have fallen in vain as permissive use of medication in equine sport is becoming less and less tolerated by society. The need to educate the public

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that therapeutic medication is necessary to maintain a healthy athlete is laudable yet it is becoming more difficult to obtain validation from a non-agrarian-based society. This is not a new frontier. However, in the public lens, responsible medication use in equine sport is becoming increasingly important and the equine veterinary community must adapt to a changing world if racing and performance horse sports are to remain viable and relevant.

Rest assured that the sky is not falling when it pertains to use of medication in performance horses. That said, equine veterinarians are a trusted resource, must remain so, and must be tolerant and accepting to public interest and concerns pertaining to medication in the competitive equine athlete. The focus of this presentation will be directed primarily to the racing industry and its stakeholders, whose utmost priority needs to be the safety and welfare of the horse. However, many of the same principles and concepts presented here can be applied to the majority of disciplines in the performance horse industry as well.

2. Discussion

Medication issues in equine sport have been at the forefront of veterinary medicine for many years. In fact, medication issues in racing have been a provocative issue since the inception of the American Association of Equine Practitioners (AAEP). A headline in the *Los Angeles Times* read, "Cops Ride with Vets" depicting the poor image of the racetrack practitioner, thus serving as the primary impetus of the founding members of the AAEP[b]. For the past 60 years, medication use in racing has been a recurrent topic of conversation and debate with the results sometimes coming full circle. For example, in 1965, the medication rule, which prohibited the use of specific medications 48 hours prior to a race, was abolished in California. Interestingly enough, in 2019 due to political pressure from animal rights activists, in conjunction with a media crisis surrounding fatalities at Santa Anita, a 48-hour medication rule was reinstated in California.

Throughout the years, and in large part due to the service of many equine practitioners, model rules and standards of practice were developed for competitive equine sports, specifically horse racing. The 1960 AAEP Guidelines contained the Policies Pertaining to Medication of Race Horses, essentially becoming the rules of racing at that time pertaining to medication. In 1963, the premise of medication uniformity and responsible use of medication had already been born. According to Dr. Jack Robbins, "If rules pertaining to medication could be more clearly defined and standardized, the practice of ethical veterinary medicine would be greatly simplified and facilitated"[c]. Today, racing industry struggles with the same issues as uniformity of 38 racing jurisdictions adopting different sections of the National Uniform Medication Program (NUMP) has been challenging. NUMP, developed through the work of the Racing Medication and Testing Consortium, is designed to provide unprecedented reform for horse racing in the areas of uniform medication rules, penalties, and testing guidelines. Much progress has been made, but because of differing issues among states, more work needs to be done to achieve medication uniformity in racing.

The horse show industry has not been exempt from the perception of illicit drug use in medication. As such, the first American Horse Show Association (AHSA) Drug and Medication Rules committee was formed in 1971 to address illicit drug use with medication. Over the years, governing bodies such as Fédération Equestre Internationale (FEI) and United State Equestrian Federation (USEF) have diligently attempted to provide medication guidelines that are responsible and in the best interest of the horse. They have for the most part been successful in establishing regulations in performance, while protecting the horse, and ensuring the integrity of fair competition. However, due to the shortcoming of inappropriate human competitiveness and the desire to prevail and gain monetarily, these organizations must remain steadfast in their regulatory efforts to maintain stakeholder confidence.

In racing, the Racing Medication and Testing Consortium, established by the AAEP in 2001, has been the most impactful and relevant organization relative to rules and regulations in the last several years. They have developed science-based industry standards pertaining to medication withdrawal times and laboratory standards. They serve as a resource to industry stakeholders, specifically veterinarians and horsemen, when applying rules of racing in a practical manner. The organization continues to be the most germane and progressive organization in racing as far as rules, regulation, and policy are concerned. Rules and regulation in sport are mandatory, and with the current sophisticated level of testing, they must remain practical and fluid. The management of the aforementioned aspects of fair competition in racing is dependent upon veterinary practitioners and organizations such as the AAEP.

Groups such as Racing Medication and Testing Consortium, which are veterinary centric, provide resources from veterinarians whereby the horse is the central focus. Veterinarians are regarded as the most trustworthy stewards regarding equine safety according to a 2019 survey[d]. Racetrack and performance horse veterinarians must engage professionally and politically to defend the horse. But equally important, is the need to continually manage the veterinary profession in performance horses, thus providing a means for social license to operate as a professional entity within the realm of competitive equine sports. The social license to operate is constantly evolving and based on public trust. If that trust is lost, veterinarians could potentially lose the ability to maintain leadership in the equine industry.

Social license to operate is a subjective concept, often used in the corporate world, and is essentially based on an industry's stakeholders, what they think of equine veterinarians, in addition to public perception of what veterinarians do. It is critically imperative to maintain a significantly impactful social operating license in the racing industry if veterinarians are to be at the stakeholder table to affect change. Veterinarians need to be involved in medication issues relative to the performance/racing industry. However, it is paramount to demonstrate a meaningful presence based on actions, thereby strengthening a position as advocates of the horse. In doing so, a social operating license becomes validated and significant within the industry.

This is accomplished by establishing a professional, ethical, and moral level of commitment to the welfare of the horse and the integrity of an entire industry. The legitimacy of equine practitioners in the racing or performance industry facilitates their credibility given by stakeholders and eventually evolves into public trust. Public trust is necessary for the racing industry and the performance industry to survive. In order to provide that trust and maintain a social license to operate as veterinary practitioners, practitioners must remain ethical and responsible in the use of medication, and at all costs, put the welfare of the horse first; above financial gain, recognition, and infamy.

Additionally, continual assessment of a social operating license as a veterinary profession must occur to ensure relevance to the horse and the industry that is served. It is a dynamic process, and as such, continual evaluation and measurement is needed to allow for change, acceptance, approval, and provide metrics of co-ownership of the veterinary social license to operate in the racing and performance industry.

So begs the question, how does the veterinary profession obtain and maintain social license to operate? Over the years, veterinarians have been regarded as a trusted resource. How do practitioners maintain that and continually develop that trust and acceptance from the public and stakeholders?

The solution is relatively simple; however, it requires change and continual evolvement in a world that is (was) constant and familiar. Racing, whether one recognizes it or not, will need a paradigm transformation in order to survive. Equine competition in general needs a cultural change if it is going to continue to exist and thrive. Most within the industry are reluctant to accept this. However, how is horse racing destined to exist, much less survive, in a world where horses die? Horse racing, a multi-billion-dollar industry, cannot survive in its current format.

Change needs to occur, and in an industry whereby change is hard, it needs to occur post haste to prevent a perilous outcome. Leadership, spurred by the veterinary community, must lead this charge based on science and fact, devoid of emotion where possible.

3. Conclusion

The equine veterinary profession can affect change, in essence a cultural change, in equine sport and establish responsible use of medication in racing/performance horse disciplines. As such, as a profession and an organization of equine practitioners, racetrack and performance horse veterinarians have a proven track record since 1954 of doing so. In order to facilitate the industry to survive and thrive, several important areas of interest need to be addressed and managed professionally by the veterinary community. They include, but are not limited to the following:

1. Ethics—As a profession, adherence to the professional conducts of ethical principles established by the American Veterinary Medical Association (AVMA) and the AAEP[e] is critical.
2. Integrity—Represent the profession and the industry with honesty and character.
3. Transparency—Maintaining and providing complete medical records detailing responsible treatment is in the best interest of the horse.
4. Accountability—Veterinarians must be accountable for their actions and must defend the reasoning for their actions.
5. Uniformity—Operating in a united manner is necessary for the sustainability of the industry.
6. Compassion—Review the veterinarian's oath that was sworn upon graduation and never lose focus on why veterinarians chose this profession in the first place.
7. Morals—This defines, in conjunction with ethical principles, the basis of the equine practitioner's social license to operate within the industry.
8. Trust—Validate by actions the role of the veterinarian as the steward for the horse.

As a profession, equine practitioners must prescribe, administer, and treat based upon an accurate diagnosis, with a valid veterinarian-client-patient relationship (VCPR) in order to do what is best for the horse. As veterinarians, it is imperative that actions and treatments are based on what is best for the horse. The sustainability of the industry is secured in that the welfare and safety of the horse is the guiding principle, and the profession must never abandon that principle. History has revealed that responsible medication use in competition by veterinarians, whether it be in performance horse disciplines or racing, has been a contentious and advancing issue in the public lens.

With the issues that occurred in racing in California in 2019, the industry stakeholders, including the veterinary community, are recognizing the need for urgent change to secure the sustainability of the racing industry in particular.

Change is often hard, but with change comes growth. Racing, the performance horse industry, and the equine veterinarian are in the midst of the greatest change, and perhaps the most profound growth that will ever be experienced in the equine industry. It will require the commitment and dedication of all industry stakeholders in order to be successful. At the end of the day, the beneficiary of this change and growth will be the horse. And isn't that what it's all about!

Acknowledgments

Declaration of Ethics

The Author has adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Author has no conflict of interest; however, he is on the Board of Directors of the Racing Medication and Testing Consortium.

References and Footnotes

1. Vail C. The History of the American Association of Equine Practitioners, The Second 2 Years 1980–2004. Lexington, KY: AAEP; 2004.
2. Lesser FR. Decisions that matter: The complementary roles of law, morals, and ethics in equine practice, in *Proceedings*. Am Assoc Equine Pract 2012;58:62–68.
3. Ramey DW. Ethics and equine medicine: Curse, pipedream, or opportunity? in *Proceedings*. Am Assoc Equine Pract 2013;59:1–8.
4. AAEP Prescription for Racing Reform: A 10-Point Plan for Action. 2016. Available from: https://aaep.org/sites/default/files/Guidelines/AAEP%20Prescription%20for%20Racing%20Reform%20Final.docx.
5. Equine Research and Safety Findings Survey, Glover Park Group, September 2019.
6. What is a Social License. 2018. Shinglespit Consultants, Inc. Available from: https://socialicense.com/definition.html.
7. Klein P. Three ways to secure your social license to operate in 2013. *Forbes*; December 2012. Available from: https://www.forbes.com/sites/csr/2012/12/28/three-ways-to-secure-your-social-license-to-operate-in-2013/#44eab81d48aa.
8. Kenton W. Social License to Operate (SLO). Investopedia. Available from: https://www.investopedia.com/terms/s/social-license-slo.asp.
9. Fiedler J. Sport horse welfare and social licence to operate: Informing communication strategies. Available from: https://www.researchgate.net/project/Sport-Horse-Welfare-and-Social-Licence-to-Operate-Informing-Communication-Strategies.
10. Principles of veterinary medical ethics of the AVMA. 2019. Available from: https://www.avma.org/policies/principles-veterinary-medical-ethics-avma.
11. Veterinarian's Oath. Available from: https://www.avma.org/policies/veterinarians-oath.

[a]Vail C. The History of the American Association of Equine Practitioners, The Second 25 Years: 1980–2004. Lexington, KY: AAEP, 2004;27.

[b]Vail C. The History of the American Association of Equine Practitioners, The Second 25 Years: 1980–2004. Lexington, KY: AAEP, 2004;127.

[c]Vail C. The History of the American Association of Equine Practitioners, The Second 25 Years: 1980–2004. Lexington, KY: AAEP, 2004;134.

[d]Equine Research and Safety Findings Survey, Glover Park Group, September 2019.

[e]Principles of veterinary medical ethics of the AVMA, HOD, 2019.

Role of the Veterinarian in Thoroughbred Racing Safety

George D. Mundy, DVM

Musculoskeletal injuries cause the majority of fatalities in Thoroughbred racing and training horses. Bone fracture is the most common fatal injury, with the fetlock joint accounting for 50–60% of all fractures. Safety efforts are focused on mitigating the occurrence of fatal fractures. The veterinarian is integrally involved in all aspects of these equine safety protocols as the attending veterinarian, race-day official, or regulatory veterinarian and association veterinarian. Author's address: Keeneland Association Inc., 4201 Versailles Road, Lexington, KY 40510; e-mail: gmundy@keeneland.com.

1. Introduction

Racing and training injuries have always been a concern and the focus of countless initiatives to improve safety of the participants. Much progress has been made in reducing injury rates; however, clusters or specific high-profile incidents continue to keep the issue of safety in the public conversation. Recently, the preponderance of social media and real-time fatality chronicling is challenging the industry to eliminate fatalities or face racings' extinction. In North America, equine safety protocols focused on reducing fatal fractures have been developed and implemented over the last 30 years, primarily from the epidemiological contributions of the California Postmortem Examination Program (1990) and the Equine Injury Database (EID) (2008).

Evolution of Thoroughbred Racing Safety Protocols

In 1990, the increasing incidence of Thoroughbred racing injuries resulted in the California legislature establishing the California Postmortem Examination Program. The program mandates the necropsy of all equine fatalities at state-licensed racing and training facilities. Early findings identified pre-existing bone conditions in horses with fatal fractures, leading to the implementation of nuclear scintigraphy imaging at Santa Anita racetrack.[1] An epidemiological cohort study, conducted in Kentucky and reported in 1996, validated the official veterinarians' role in identifying horses at higher risk of injury ("at risk horse") based on prerace physical inspection findings.[2–4] In 2008, the EID was established out of a proposal first put forth at the 2006 Welfare and Safety of the Racehorse Summit. Funded entirely by The Jockey Club and designed and developed through its commercial subsidiaries, along with leading regulatory veterinarians in the United States, the national database records injuries during racing and training, capturing 96% of annual race starts in North America. Data from the EID are instrumental for developing mitigation strategies for injury prevention.[5] For example, factors for horses at risk of fatal fracture are used by official veterinarians to identify "horses of interest" requiring extra scrutiny to determine soundness prior to high-speed exercise (timed "work out" or race).

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In 2012, the governor established The New York Task Force on Racehorse Health and Safety[6] in response to a cluster of 21 racing and training fatalities at the Aqueduct racetrack. The task force concluded New York should modify several existing critical protocols, including identification of pre-existing conditions, stand down period for intra-articular (IA) injections, restriction on other pre-race medications, criteria for attending veterinarian intervention, and the need for treatment records on all horses.

In early 2019, The Stronach Group (TSG), owner and operator of Santa Anita racetrack in California, introduced several "house rules" as part of the Enhanced Safety Procedures in response to a cluster of racing- and training-related fatalities.[7] These rules included mandatory examination by the attending veterinarian and intensified official veterinarian scrutiny of horses of interest prior to timed work outs and race entry. This represents the first time any organization has mandated that the attending veterinarian participate in assessing the horses' suitability to safely complete high-speed exercise (timed work out or race).

The California Horse Racing Board issued a report on 23 fatalities that occurred during the first 3 months of the Santa Anita race meet in 2019.[8] This report examined each of the fatalities and published key findings and recommendations in various areas, including track maintenance, management of the racing office, training practices, private veterinary practitioners and practices, horse safety and welfare, and regulatory veterinary procedures and practices. A number of factors combined as causative agents; however, 21 of the 22 fatal fracture cases exhibited signs of pre-existing pathology "presumed to be associated with high exercise intensity, which predisposed these horses to catastrophic injury." Furthermore, 19 of the 22 fatal fracture cases involved the proximal sesamoid bones of the metacarpophalangeal (fetlock) joint.[8]

2. Veterinary Safety Protocols—Identify Horses of Interest

I. Pre-Existing Pathology—Greater than 85% of fatal musculoskeletal injuries have pre-existing pathology at the site of fatal fracture,[9] and it is estimated that 40 to 60% of fatal fractures world wide involve the fetlock.[10,11] Multiple factors affect the accumulation of bone stress injury (BSI) or bone damage that result in fracture. These factors include the repetitive cycling nature of training (galloping), the speed of the horse during training and racing, and the distances that racehorses train and race. Repetitive high-magnitude loads incurred during training and racing exceed concurrent damage removal and replacement, resulting in transient periods of focal osteoporosis and bone weakening.[12] Strategies to identify horses with clinical signs or history of BSI, especially involving the fetlock joint include the following:
   a. Lameness—lameness associated with high-speed exercise (timed work out or race) may be indicative of BSI. The protocols inserting the attending veterinarian for mandatory pre-work/racehorse evaluation provides an opportunity for recognition and intervention in the BSI process. Fracture can be prevented by early diagnosis and adequate bone injury management.[12–15] The attending veterinarian (racetrack practitioner) is perfectly positioned as the primary diagnostician of lameness in these pre-exercise evaluations.
   b. Previous injury—horses with medical history of lameness within the preceding 3 months are at a higher risk of fatal fracture.[16] Fractures occur during high-risk periods caused by the events in the previous 2–3 months, although sometimes 6 months to years, preceding the acute fracture.[4,11] The attending veterinarian, as the primary care veterinarian, possesses the critical patient history and knowledge of prior medical procedures to best diagnose lameness and establish a critical pathway for resolution.
   c. IA Injections—there was medical history of IA therapy in 11 of the 22 fatal fractures at Santa Anita[8] and "…intra-articular corticosteroids may have impaired veterinarians and trainers from accurately assessing the horses' soundness leading up to a race" was a finding of the New York Task Force.[7]

II. Risk Modeling for Fatal Fracture—The EID annually publicizes statistical summaries of racing injuries and significant findings of ongoing epidemiological studies. To date, over 20 factors for horses of increased risk of fatal injury or fracture have been identified.[17] Examples of horse-level risk factors utilized to identify horses of interest include the following:
   a. 4-year-old or older non-starter
   b. 120-day lay-off
   c. Vet List appearance for "unsoundness"
   d. Previous EID injury
   e. Recent trainer change

3. Overview of the Veterinarian in Thoroughbred Racing Safety Protocols

Official Veterinarian

Equine Medical Director (State Regulatory Authority)

The equine medical director (EMD) is employed by the state, commonly with a university position or affiliation, serving as the chief veterinary steward for the racing authority (commonly known as "commission," "board," or "authority"). The EMD over-sees the equine drug testing program and provides veterinary oversight, scientific and clinical expertise, strategic planning, and recommendations to the regulatory authority. The EMD acts in a supervisory role to regulatory veterinarians performing drug testing, examinations to determine fitness for racing and training, and emergency care for racing horses.

Regulatory Veterinarian (State Regulatory Authority)

The regulatory veterinarian is employed by the State Regulatory Authority with duties to enforce the rules of racing. Regulatory veterinarians may not engage in the veterinary care of racehorses, horses in training, or any horses owned by individuals licensed by the regulatory authority beyond the scope of their duties. Specific duties include the following: direct and supervise the collection of pre- and post-race samples for the testing of horses for prohibited substances, inspect and record findings concerning racing soundness for horses entered, and maintain the official veterinarian's list ("Vet List") of horses that are ineligible to race because of sickness or unsoundness.

Association Veterinarian (Racing Association)

The association veterinarian is licensed by the State Regulatory Authority (as racing official) and is employed by the racetrack or entity that owns the racetrack. The association veterinarian enforces the rules of racing (State Regulations) where appropriate (as designee, and house rules as set forth by the racetrack. They are also known as the EMD, equine safety director, chief veterinary officer, or track veterinarian.

Attending Veterinarian (Racetrack Practitioner)

The attending veterinarian is licensed by the State Regulatory Authority (as practicing veterinarian) and is employed by the horse owner or trainer. All attending veterinarians administering drugs, medications, or other substances are responsible for ensuring that the drugs, medications, or other substances and the veterinary treatment of horses are administered in accordance with regulations, rules, and conditions for racing and training.

4. Safety Protocol Implementation—State Regulations, Rules, and Conditions for Racing and Training

I. State Rules and Regulations (Regulation)—Each state has an independent agency of state government charged with the responsibility of regulating the conduct of horse racing and pari-mutuel wagering on horse racing and related activities within the state. The agency (also known as commission, board, or authority) enforces statues (laws) and the regulations under these statutes. The agency creates, modifies, and amends regulations through the legislative process and employs staff to perform and/or oversee regulations. For example, most all states employ veterinarians to perform and oversee drug testing procedures. The legislative process of creating or amending regulations requires justification, the identification of funding sources, set timelines for debate, and public comment before becoming law. Therefore, the timeline for implementation of regulations can vary from months to years from state to state.

II. Rules and Conditions for Racing and Training (House Rule)—The racetrack association is the business entity holding a license from the State Regulatory Authority to conduct racing and/or pari-mutuel wagering. The association has inherent articles, policies, and procedures to conduct racing and pari-mutuel wagering. As a prerequisite for participation (compete in a sanctioned pari-mutuel race) or to have access to association stabling and training facilities, trainers agree to and enter by contract to abide by association rules and conditions for racing and training (commonly termed house rules). These contracts traditionally are included in the "entry document" (horse nominated or subscribed to participate in a pari-mutuel race) or the "stall application" that the trainer completes for the allocation of stabling at association facilities. By right of "exclusion," the act of preventing a person from participating, entering, or remaining on association grounds, the association enforces these rules and conditions. House rules can be implemented immediately at the discretion of the racetrack. The Enhanced Safety Procedures enacted at California racetracks in March 2019 in response to the cluster of fatalities at Santa Anita were implemented immediately by a combination of house rules and emergency regulation.[7]

5. Race-Entered Safety Protocols

Risk Assessment: Identify Horses of Interest

I. InCompass Solutions "Pre-Race Veterinary Exam" Software—InCompass Solutions, a commercial subsidiary of The Jockey Club, provides a central database that serves as a platform for several industry initiatives, including the EID and the Race Track Operations system. The Pre-Race Veterinary Exam module is designed for use by official veterinarians for the purposes of performing and maintaining a database associated with the pre-race and limb examinations performed daily at racetracks. The aim is to provide a history on each horse to enable official veterinarians to determine if an ailment is new and should be watched carefully or is an old injury that has had no ill effect on the racehorse in the past. Racing and work out history is also provided to assist in making race-day decisions on whether to allow a horse to race or not.

II. InCompass Solutions "Targeted Algorithms"—These custom daily reports are provided to official veterinarians using criteria pertinent to individual racetracks or jurisdictions. Each entered horses' racing data, contained in the Race Track Operations system database, is screened for EID markers of increased risk of injury, identifying horses of interest. Horse-level risk factors include previous EID injuries, appearance on the Vet List, and duration of time with same trainer.[18]

III. Mandatory Published Work Outs—Horses in EID categories of increased risk of injury, as a condition of race entry, require mandatory timed work outs with added requirements (i.e., official veterinarian pre-work examination, minimum distance and time, post-work testing, and others). These mandatory work outs are stipulated by regulation or house rules.

IV. Training Patterns and Published Work Outs—Individual horse racing and training (published work outs) history is reviewed for frequency, distances worked, and irregularities in work patterns indicating a potential issue requiring additional scrutiny.

Medical History: Identify Horses of Interest

I. Daily Treatment Records—In most jurisdictions, by regulation, Daily Treatment Records are confidential records of treatments and procedures performed by the attending veterinarian and are provided daily to the regulatory authority. Attending veterinarian medical records for individual entrants are reviewed for treatments, examinations, or diagnostics performed corresponding to training, and/or race pattern irregularities.

II. Lameness Examinations and Diagnostics—These procedures are documented in the required Daily Treatment Records. The trainer and/or attending veterinarian are required to produce individual medical records (e.g., dates, procedures, and results) for entrants when requested.

III. Intra-Articular Injections and Electric Shock Wave Therapy Treatments—By regulation, these procedures are reported with a mandatory stand down from racing, enforced by placement on the official Vet List.

Veterinary Examinations: Identify Horses of Interest

I. Attending Veterinarian Examination Within 3 Days of Entry—All potential entrants must be examined by the attending veterinarian for the express purpose of evaluating the horse's fitness to race as a condition of entry. The evaluation must include, at a minimum, watching the horse jog. The attending veterinarian records of the examination are documented on the Daily Treatment Records, or individual medical records are made available for review when requested.

II. Official Veterinarian Examination—Select horses of interest are subject to examination by the official veterinarian prior to race day. Examination findings are recorded in the InCompass Pre-Race Veterinary Exam module, enhancing the pertinent medical information available for future reference.

6. Training Population Safety Protocols

I. Observed/Monitored Training—Official veterinarian observation and monitoring of horses while training on association-provided surfaces has been a component of the Breeders' Cup Veterinary Inspection Panel and other selected events since 1993.[19] In early 2019, "Morning Training Oversight" by official veterinarians was instituted in response to a higher death rate experienced at Lone Star Racetrack in Texas[20] and as one of the Enhanced Safety Procedures at Santa Anita. Official veterinarians are present trackside during training hours to observe the population perform routine exercise sessions. Horses exhibiting unsoundness or obvious lameness are identified ("flagged"), and the connections are notified. Official veterinarians consult with the attending veterinarian regarding criteria for flagged horses to continue or return to training. In some cases, horses may be placed on the Vet List and subject to specific requirements for removal.

II. Mandatory Work Outs/Official Veterinarian Examinations—Horses with specific risk parameters for horses of interest are required to work out, with varied requirements dependent upon the risk parameter. For example, in California, unraced 4-year-olds are placed on the Vet List and must complete a Vet List-level work out (examination pre-work and post-work by official veterinarian, minimum 5 furlongs in sub 1:03 and post-work drug testing), in addition to other requirements for a first time starter.

III. Attending Veterinarian Examination within 5 Days of Work Out—Included in the California Enhanced Safety Procedures is a demonstration of the horses' fitness to work prior to speed exercise (published work out). The attending veterinarian performs and records the examination (the evaluation shall include, at a minimum, watching the horse jog) on the Daily Treatment Records or makes other medical records available for review when requested.

IV. Forty-Eight-Hour Work Out Notice—Notification of intent to work is a requirement of the California Enhanced Safety Procedures work monitoring program. Internal reviews of past performance data and all available information from the horses slated to work are used to identify individuals worthy of further scrutiny (horses of interest). The official veterinarian then works with all parties to determine if the horse is approved to work or whether another course of action is required.

V. Out of Competition Testing—The state regulatory body propagates regulations restricting or prohibiting the use and administration of drugs or stimulants or other improper acts to horses prior to the horse participating in a race. Any horse eligible to race is subject to testing without advance notice for specified substances. A horse shall be presumed eligible to race if (a) it is under the care, custody, or control of a licensed trainer; (b) it is owned by a licensed owner; (c) it is nominated to a race at a licensed association; (d) it has raced at a licensed association within the previous 12 calendar months; (e) it is stabled on the grounds of a licensed association or a training facility; or (f) it is nominated to participate in a specified race (i.e., Breeders' Cup). The definition encompasses the entire racing population regardless of current location.

7. Conclusion

More than 83% of racing and training fatalities are attributable to musculoskeletal injury.[21] An early finding of the California Post-Mortem Examination Program, which has been verified annually in the 30 years since the programs' inception, is evidence of pre-existing pathology in more than 85% of the fatal musculoskeletal injuries. The finding of prior pathology at the fracture site means most fatal injuries are preventable.

To date, the Thoroughbred industry approach has been to identify horses at a higher risk of injury prior to racing. In fact, this risk modeling developed through the EID has yielded a 20% reduction in the national fatal injury rate since the databases' inception in 2008. Horses of interest are scrutinized on race day to determine suitability to start, which is ultimately the decision of the official veterinarian. Practically, the question is "if this horse starts, will it end in fatal injury?" If the answer is "no" for every starter entered, then all horses would compete in the race. In these cases, the official veterinarian is correct 99.47% of the time (2019 EID national fatal injury rate was 1.53 per 1,000 starters).

The cluster of fatalities at the Santa Anita racetrack in early 2019 led to the implementation of house rules and Enhanced Safety Procedures. Particular procedures applied risk modeling by official veterinarians to the training population and mandated that attending veterinarians evaluate horses prior to high-speed exercise events (timed work outs and races). The Enhanced Safety Procedures yielded a 30% reduction in racing fatal injuries and a remarkable 50% reduction in training fatal injuries.[a]

Veterinarians implementing stringent safety protocols to the entire at-risk training and racing population have the greatest potential to decrease fatalities and improve the safety of racings' participants.

Acknowledgments

Declaration of Ethics

The Author has adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Author has no conflicts of interest.

References and Footnote

1. Stover SM, Murray A. The California Postmortem Program: leading the way. *Vet Clin North Am Equine Pract* 2008;24: 21–36.
2. Cohen ND, Peloso JG, Mundy GD, et al. Racing-related factors and results of prerace physical inspection and their association with musculoskeletal injuries incurred in thoroughbreds during races. *J Am Vet Med Assoc* 1997;211:454–463.
3. Cohen ND, Mundy GD, Peloso JG, et al. Results of physical inspection before races and race-related characteristics and their association with musculoskeletal injuries in Thoroughbreds during races. *J Am Vet Med Assoc* 1999;215:654–661.
4. Cohen ND, Berry SM, Peloso JG, et al. Association of high-speed exercise with racing injury in Thoroughbreds. *J Am Vet Med Assoc* 2000;216:1273–1278.
5. Arthur RM. 2018. ARCI Conference: Identifying horses at risk. Available from: https://www.youtube.com/watch?v=hykgWabeB3Q&list=PL9-HTzzk492yhg-isBrbKIwYDs7AcOiZY&index=3&t=0s.
6. New York Task Force on Racehorse Health and Safety. 2012. Official report. Available from: https://www.governor.ny.gov/sites/governor.ny.gov/files/archive/assets/documents/Report.pdf.
7. Santa Anita Park. 2019. California Enhanced Safety Procedures. Available from: https://www.santaanita.com/wp-content/uploads/2019/03/California_Enhanced_Procedures.pdf.
8. California Horse Racing Board. 2020. Report on fatalities at Santa Anita Park from 12/30/18 through 3/31/19.
9. Stover S. Using big data and artificial intelligence to detect pre-clinical lameness: Can it reduce the number of catastrophic injuries, in *Proceedings*. Am Assoc Equine Pract 2019; X–X.
10. Anthenill LA, Stover SM, Gardner IA, et al. Association between findings on palmarodorsal radiographic images and detection of a fracture in the proximal sesamoid bones of forelimbs obtained from cadavers of racing Thoroughbreds. *Am J Vet Res* 2006;67:858–868.
11. Estberg L, Stover SM, Gardner IA, et al. Fatal musculoskeletal injuries incurred during racing and training in Thoroughbreds. *J Am Vet Med Assoc* 1996;208:92–96.
12. Martig S, Chen W, Lee PV, et al. Bone fatigue and its implications for injuries in racehorses. *Equine Vet J* 2014; 46:408–415.

13. Stover S. Diagnostic workup of upper-limb stress fractures and proximal sesamoid bone stress fractures and proximal sesamoid bone stress remodeling, in *Proceedings*. Am Assoc Equine Pract 2013;59:427–435.
14. Mackey VS, Trout DR, Meagher D, et al. Stress fractures of the humerus, radius and tibia in horses: Clinical features and radiographic and/or scintigraphic appearance. *Vet Radiol Ultrasound* 1987;28:26–31.
15. Riggs CM. Fractures—a preventable hazard of racing Thoroughbreds? *Vet J* 2002;163:19–29.
16. Hitchens PL, Hill AE, Stover SM. Relationship between historical lameness, medication usage, surgery, and exercise with catastrophic musculoskeletal injury in racehorses. *Front Vet Sci* 2018;5:217.
17. Parkin T. Equine injury database—can we explain the significant drop in risk in 2015? Welfare and Safety of the Racehorse Summit VII. 2016.
18. Parkin T. Equine injury database update and call for more data. Welfare and Safety of the Racehorse Summit VIII. June 2018.
19. Mundy GD. Veterinary aspects of Breeders' Cup Championship Day, in *Proceedings.* Am Assoc Equine Pract 1994; 181–182.
20. Texas Racing Commission Monitor Training. 2019. Available from: http://www.txrc.texas.gov/agency/news/postings/TxRC_Morning_Training_Oversight_Notice%201.pdf.
21. Johnson BJ, Stover SM, Daft BM, et al. Causes of death in racehorses over a 2 year period. *Equine Vet J* 1994;26:327–330.

[a]Benson, D. Santa Anita Park, Arcadia, CA. (personal communication). Regulatory Vets CE Short Course, March 3–4, 2020.

Understanding the Principles of Using Radiographs for Pathological Trimming and Shoeing

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1. Introduction

Pathological shoeing and therapeutic shoeing are terms often used interchangeably to describe special shoeing required to address a variety of lower-limb and foot issues to career- and life-threatening injuries and disease. Pathological shoeing is a very serious process that demands the greatest respect of veterinarians and farriers. Obtaining success depends on adequate preparation, knowledge of the subject, strong principles, and skills of two highly respected professional fields of public service. Recognizing the gravity of the specific issues and being well prepared to think through the medical and mechanical requirements is paramount for success. These two highly respected professionals must share equal responsibility for the health of the foot, yet they do not have a common thread of education, knowledge, or skills required for collaborative efforts.[1]

There is a steep learning curve for the veterinarian/farrier team to shift from their routine daily task to using radiographs as a guide for mechanical solutions. The veterinarian must obtain working knowledge of the foot and a basic understanding of farrier principles and the farrier must become familiar with radiographic parameters and how they relate to the external landmarks of the foot. As farriers learn to read and interpret the radiographic information that relates specifically to the task and veterinarians develop working knowledge of how mechanics can offer medical benefits, the learning curve begins to flatten out. Additionally, high-level pathological shoeing requires considerably different farrier supplies and equipment than most farriers would normally have and a much larger time commitment from both professionals. Without a thorough understanding of the task at hand by either or both professionals, success is left to chance. This is the weakest link in pathological shoeing. When both the veterinarian and farrier understand the value of the mechanical thought process, the information offers predictability and improved success rates. The strategy for pathological shoeing based on radiographic information offers unlimited mechanical options that otherwise would not be available.

NOTES

The rationale for this how-to session is the challenge that faces veterinarians and farriers that are not accustomed to using radiographs to plan the mechanical strategy. The objective is to describe the basic methodology and consequences of using radiographic data as blueprints when pathological shoeing is required as a treatment for foot issues.

2. Visual Assessment and How It Relates to the Mechanical Thought Process

The exam should first start with evaluating the external characteristics of the foot and should be performed in a systematic fashion. The external hoof capsule and the sole should be cleaned of all debris to allow accurate evaluation. The evaluator should focus on the dorsal face of the hoof capsule, coronary band, ground surface, heel and heel bulbs, and pastern plane and digital alignment relative to planes of the foot. During the exam, it is important to realize that there is a range of normal for hoof characteristics that is dependent on the horse's age, breed, environment, use, and previous injury or disease. It is helpful to know what may be considered "normal" for that particular foot in order to identify subtle deviations from "normal" that are of clinical significance. The hoof profile and growth ring pattern can change every few millimeters and each alteration is there for a reason. Growth ring patterns, from toe-to-heel and medial-to-lateral and sole growth describe the response to the nutrient supply to the tubular and solar papillae. The horn growth centers are in turn influenced by the mechanical forces within the foot, thus giving meaning to the word, "mechanics".

The mechanical thought process is not well understood; therefore, success with pathological shoeing in the past was routinely thwarted by the lack of a means to develop a sound mechanical plan. Until more recently, shoeing recommendations were without a specific plan and as a rule were focused on trimming the capsule in a fashion to make it appear as if the ill effects of the issue suddenly were eliminated. Trimming and shoeing without regard to the mechanical imbalance of forces that oppose injured or diseased components can be counterproductive and result in escalation of further imbalance that can become a devastating vicious cycle. More recently, the perception of the foot as a mechanical model with suspension and complementary support components has made it possible to better understand the cause and effect of the internal forces on the healthy foot, as well as those with a variety of pathological issues (Fig. 1). Through this model, the distal phalanx is suspended within the hoof capsule by the laminae, and its direct antagonist, the deep digital flexor tendon (DDFT), whereby the DDFT provides lift or suspension to the caudal aspect of the distal phalanx. The author has theorized that the DDFT exerts considerable influence on the digital structure and function and is thus a key factor in many of the causes of pathological distortion of the hoof capsule.[2] This theory was derived from the author's years of clinical experience and is supported by gross exam, radiographic and venographic assessment, as well as monitoring clinical outcome. This work suggests that there is a consistent and direct correlation between the amount of tension in the DDFT and patency of dorsal lamellar and the circumflex vessels in both healthy feet and those with pathological issues. It was also concluded that mechanical manipulation could remarkably reduce DDFT tension and aid reperfusion to compromised components and horn growth centers, ultimately producing medical benefits. Scientific *in vivo* biomechanical research could further knowledge concerning the tendon theory. The mechanical approach has provided an array of efficient trimming and shoeing options that are designed to offset or attenuate the offending force of the DDFT as it opposes and/or influences the failing antagonist or adjacent components.

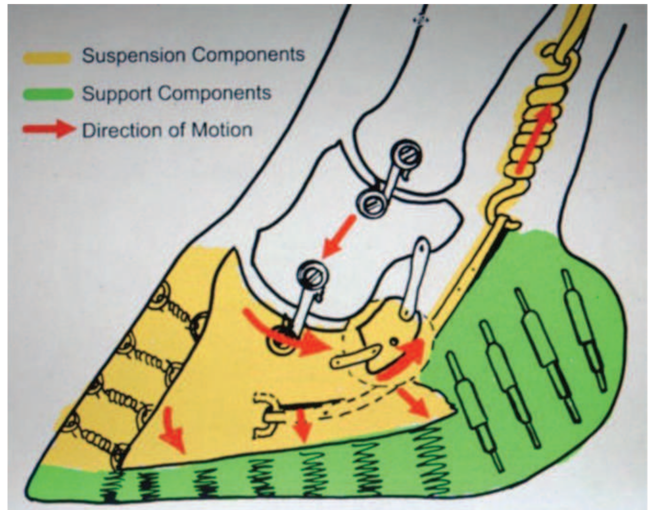

Fig. 1. This mechanical diagram is a very basic representation of the suspension and support components of the foot. When the foot is balanced, these components work in harmony and have the ability to have full recall.

3. The Value of Podiatry-Focused Radiographs

When used in combination with the external characteristics of the foot, radiographs further enhance and fine tune the clinician's ability to identify and monitor changes in the feet. Traditional foot radiographs are taken with the primary beam centered just below the coronary band with the purpose of identifying pathology in either the coffin joint or navicular apparatus. They fail, however, to provide information for the veterinarian-farrier team to confidently or correctly assess the relationship of the external landmarks (hoof capsule) relative to the internal structure (coffin bone). Obtaining consistent, podiatry-focused, "low-beam" lateral/medial (LM) and dorsal/palmar/plantar (DP) radiographic

Fig. 2. Diagram of the correct way to take a podiatry-focused LM radiograph. Note the limbs are placed on blocks of equal height in a natural stance relative to its toe-out conformation. Barium paste is placed along the dorsal hoof wall, the plate is placed adjacent to the foot, and the focal point of the generator is centered ½ inch proximal to the bearing surface of the foot.

images and a means to measure the soft-tissue parameters relative to the task to be undertaken are a required precursor to the mechanical planning stage of pathological shoeing.[3,4] Crucial details regarding the trim, shoe fabrication, and placement are based on pertinent radiographic information. The techniques for taking podiatry-focused radiographs have been previously described by the author and are represented in Fig. 2.[3–5] Podiatry-focused foot radiographs are typically taken with the shoes on as it is important to understand how the previous shoeing influenced the horn growth rate and pattern and how the current trim and shoe relates to the soft-tissue parameters and digital alignment. Understanding the sole depth prior to pulling shoes can help prevent unwarranted pain and further damage to feet with shallow and or convex soles and may help anticipate the need for the application of protective boots prior to putting the foot down. The views should be taken with both the front and hind feet on blocks of adequate and equal height, so that the cross hairs of the generator are at height of approximately ½ to ¾ inch (12–18 mm) higher than the height of the positioning blocks. This assures that the primary beam is aligned between the palmar rim and the ground surface of the barefoot or shoe, which should produce a radiograph with the branches of the shoe superimposed over each other. There are certain situations, which represent exceptions to this rule, where the shoe thickness, pads, or excessive sole depth raises the palmar rim height (sole depth) approximately 25 mm above the primary beam and requires the primary beam to be raised. In this scenario, the branches of the shoe will not be superimposed and so a second low-beam LM will need to be taken so the branches of the shoe are superimposed in order to accurately interpret ground palmar angle (palmar angle [PA]; see below) (Fig. 3) and digital breakover. Foot radiographs taken in this fashion offer a more accurate and consistent representation of the areas of interest than the traditionally recommended "high-beam"-orientated foot radiographs focused at the coffin joint and/or navicular apparatus. Radiographs, especially foot radiographs, should be taken with a specific goal in mind, and sometimes that may necessitate taking both high- and low-beam LM and DP images, each with their own purpose in mind.

There are several points that need to be addressed in order to enhance the quality of images to avoid misinterpretation of radiographic assessment secondary to radiographic artifacts such as distortion and magnification. First and foremost, the user should always seek to obtain radiographs on a flat, level surface with the horse standing as squarely as possible and the blocks positioned relative to any toe-in or toe-out conformation to assure the best representation of natural, static conformation, digital alignment, and joint surfaces. These tips additionally assure that the radiographic beam is oriented perpendicular to the cassette to minimize distortion. Magnification can be minimized by ensuring a consistent zero subject-film distance (plate touching the subject) and a consistent focal-film distance (24 to 28 inches). Magnification increases as the distance from the cassette to the subject increases or when the distance from the focal spot to the object decreases. Magnification cannot be avoided on the DP image due to interference with the fetlock unless a palmar-dorsal image is taken. Fortunately, measurements are not always required on the DP image, so these are usually taken out of convenience unless a specific reason arises. The majority of digital x-ray units do not have a calibration aid to compensate for the magnification of the parameters along the sagittal plane as the software is designed to measure distance at the level of the detector and are therefore not reliable. A known length of metal placed on the sagittal plane and another of identical length on the detector confirms the need for the calibration device. Radiographic markers should be applied to the dorsal hoof wall as even with advances of digital radiography, there is always some evidence of burnout (saturation artifact) of the dorsal lamellar wall. The author prefers to use a line of barium paste as it highlights the contour of the dorsal hoof wall more accurately than does a piece of wire or other metallic object. It should be applied along the dorsal hoof wall starting at the horn-coronary band junction; it can also be used to accurately measure the relationship between the coronary crest and the extensor process. Lastly, interpretation of radiographs should be made with the knowledge of the most recent trim or shoeing. A trim alone can initially change many of the soft tissue parameters; however, these parameters can slowly start to drift back to their original measurements within a matter of days. Radiographs from a horse that was recently trimmed

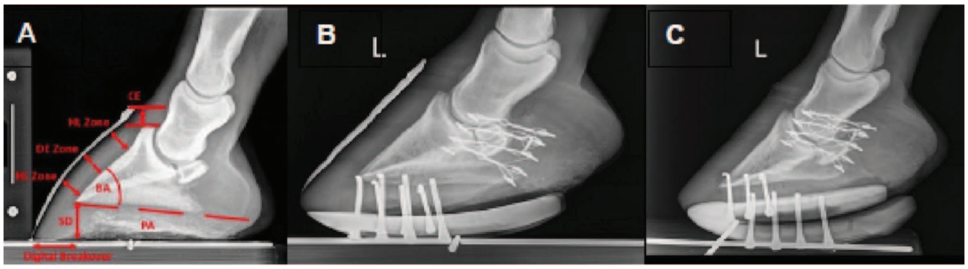

Fig. 3. A, LM image showing the relevant soft-tissue parameters: CE, coronary extensor process zone; HL Zone, hoof:lamellar zone; DE Zone, dermal/epidermal junction; BA, bone angle; SD, sole depth; PA, palmar angle; DB, digital breakover. The PA, SD, DB, and often the HL are altered with a typical trim. B, The low-beam LM reveals one branch of the shoe, two branches of the coffin bone that indicates medial listing in this case, and accurate sole depth. C, High-beam LM with the same foot as in panel B, revealing two distinct branches of the shoe that is superimposed over the sole and the wings are deceptively superimposed. A low-beam DP image would verify the presence of medial listing.

would have a completely different interpretation than a horse that was reset 6 weeks before and so it is important to know and record the last trim or reset.

4. Processing the Data

Obtaining the desired images is the first step toward planning the mechanical goals and options. When radiographs are obtained in a consistent fashion, the user can then precisely and repeatedly measure the soft-tissue parameters, identify the mechanical limitations, and formulate a treatment plan. Soft-tissue parameters that are of interest to the farrier include sole depth, PA, bone angle, horn-laminae zone, and digital breakover (Fig. 3). Medial-to-lateral balance is also a parameter that can be estimated from the LM image but best evaluated on the DP image. The data is only as valuable as one's ability to process it in a manner that offers realistic guidelines relative to the mechanical deficits as well as viable reversal treatment options. When used correctly and in conjunction with the external characteristics of the foot, these parameters can shed light on the mechanical deficit that often contributes to the seat of the problem (Fig. 4). Having a diagnosis is great as long as the mechanical requirements of restoring healthy horn and other suspension and support components are understood as the presumably primary issue is treated.[2]

Sole Depth

Sole depth is the distance measured from the solar margin at the apex of the third phalanx to the radiolucent border of the sole. This is typically a parameter that is routinely estimated by the farrier, but a relatively accurate interpretation of the sole depth can represent a challenge for even the most experienced farrier. It is quite easy to know if it is adequate, or in excess but knowing precisely the sole depth distal to the apex requires a proper lateral radiograph especially when it is extremely thin, 5 to 6 mm. Based on venographic studies, a sole depth of less than 15 mm is considered clinically significant. As the sole depth decreases, the solar papillae are usually bent, compressed, or absent, respectively. Inadequate solar papillae on venographic studies can translate to inadequate blood supply and in the author's experience, leads to poor sole growth and ultimately creates a vicious cycle of thin, tender soles. The lack of adequate foot mass occurs for reasons other than at the hands of farriers, therefore radiographic sole depth is an impor-

Fig. 4. A, Positive PA with sole depth equaling the HL zone plus equal amount of cup. Note the calibration tool, radiopaque paste, and the lucent zone between the paste and dorsal wall. B, Zero-to-one-degree PA, adequate sole depth, and cup of foot, slightly broken back axis and calcification within the navicular suspensory ligament (a mechanical consideration). C, Negative PA, combination of sole and cup is greater than the HL zone. Where are the most probable hot spots? Visualize the PA being dependent on the tension of the DDFT as it regulates the pitch of these feet. The hoof apparently grows subsequent to the capabilities of the solar and tubular papillae that are dependent on circulation.

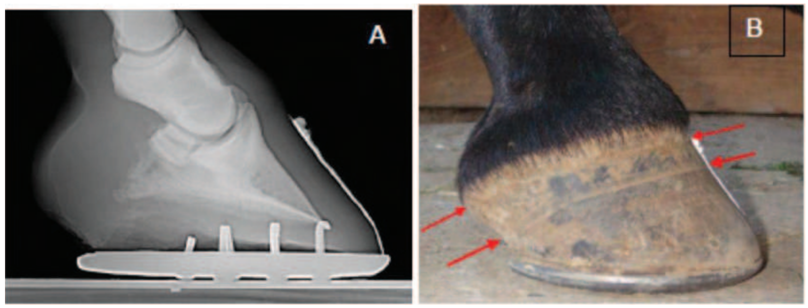

Fig. 5. A, Soft-tissue parameters reveal useful information for the veterinary/farrier team. Note the PA is quite similar to the angle between the diverging growth rings in panel B. B, The external characteristic describes the heel-to-toe ratio growth rate and is a helpful reference, especially toward the end of the reset schedule.

tant consideration before trim and equally important after the trim when there is a specific mechanical plan.

PA

The PA refers to the angle between the solar margin of the distal phalanx and the ground surface. The ground surface can either be defined as the ground surface of the hoof capsule or the ground itself and because of this there could be two separate PAs (capsule PA and ground PA, respectively) depending on the level of mechanics of the shoe. To obtain an accurate assessment, both branches of the shoe should be superimposed on the LM projection. The PA alludes to the function of the DDFT and is a very important consideration when designing mechanics. Increased suspension increases PA and equivalent heel growth. This is consistent with club feet that have a relatively healthy foot but increased DDFT tension relative to the increased contraction forces of the muscle belly (Fig. 5A). Chronic laminitis has an increasing PA as the DDFT challenges its direct antagonist, and the failing laminae anchor no longer resists the relentless imbalance of forces. In both of these conditions, there is too much suspension, leading to sole papillae that are compressed and not capable of growing adequate sole. Clinically, a growth ring pattern that has a remarkably wider distance between the adjacent rings at the heel than at the toe is an indication of increased suspension via the action of the DDFT (Fig. 5B). On the other end of the spectrum, a deficiency in the suspension components of the foot is apparent when the adjacent ring spaces are wider at the toe than heel. When this occurs, the heel papillae are compressed and not capable of growing adequate horn tubules. The dorsal tubular papillae remain uninhibited by load and subsequently grow excessive toe that is consistent with the crushed heel, negative PA foot (Fig. 6, A and B). Radiographic evidence consistently reveals the consequences of sagging or excessive suspension and gives support to the tendon theory.

The crushed heel, negative PA foot is one of the most common problems that farriers and veterinarians face and a study in mechanics. Farriers are often accused of removing too much heel creating the issue, radiographic evidence disconfirms this accusation. It has been thought in the past that the tension on the DDFT steadily increases as the heel is lowered. However, crushed heels and negative PA feet have various degrees of broken back digital alignment and when the pastern becomes more upright the distance from origin to insertion of the DDFT remarkably shortens. This results in further decreased tension and unrestricted blood flow to the productive solar papillae distal to the apex of

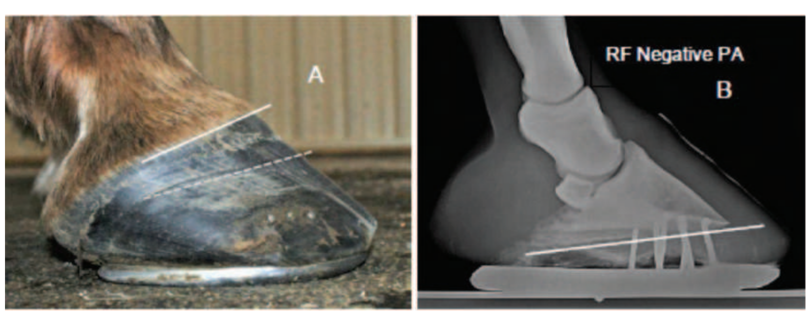

Fig. 6. A, Note that the toe grew approximately twice as much as the heel over the past 2 months, increasing sole depth. B, Note the similar negative angle, one branch of the shoe, and two wings of the coffin bone. Most often it will be the medial wing. A DP view is required to confirm.

Fig. 7. A, Yearling with a Grade 2 club, 55° bone angle that was 5° larger than the opposite foot and a 15° capsule PA. This could be a good candidate for the check desmotomy but will always have a slightly steeper foot than its opposite due to bone angle. B, This foot has a 45° bone angle and a positive capsule PA but appears as a long toe underrun heel foot. C, This weanling had a 60° bone angle, 10° greater than the opposite foot. HL zone, 15/10 mm and a 5° PA. The opposite foot had a 50° bone angle and zero PA and 15/10 HL zone. This was a 20° difference in hoof angles. This appearance would lead one to believe a check desmotomy was highly indicated. Unfortunately, that would only result in a 5° advantage due to the low PA still leaving a 15° difference in toe angles, therefore surgery would not be very beneficial both functionally and cosmetically.

the coffin bone. The lateral image consistently reveals an adequate sole along with a natural cup. The lateral image also reveals some degree of coffin joint luxation that supports inadequate tension of the DDFT as a possible contributing factor.

These mechanical alterations are only discernible with podiatry focused radiographs.

A helpful tip is that the frog trimmed to its natural base also lies along a very similar plane as the palmar rim of the third phalanx. The linear area of the deepest part of the sulci along the frog is quite close to the same plane as the palmar rim. Paste defining this area (sulci) on a lateral view can be a helpful teaching aid as it can help guide the trim plane that oftentimes is strikingly different than that of a routine trim. An imaginary line that connects a dot of paste placed at the skin frog junction and another at the apex of the frog also will be in a very similar plane as the palmar rim. Using these landmarks helps the farrier develop an eye for a more precise trim when specific goals are indicated.

Bone Angle

The bone angle is the angle made by the dorsal and solar surfaces of the coffin bone. Why is it important to measure bone angle? The answer is that bone angles typically differ between right and left and front and hind feet. Farriers are most often expected to match toe angles as it is assumed that all feet should match and be symmetrical. The old saying, “assumptions and expectations are different than fact,” is an understatement. Feet seldom if ever match and certainly are not symmetrical inside or out. The bone angle is approximately 50° in the majority of feet however it can vary 10° to 12° less or greater than 50°.

Exceptionally low bone angles are often the cause for low toe angles in spite of adequate PA and sole mass. The mismatched syndrome is prevalent in most all breeds and it is common to find mismatched bone angles, especially in the front feet that vary as much as 10° or 12°. When the bone angle is remarkably larger in one front foot than the other, trying to match toe angles with a rasp can be a futile attempt and go against the natural mechanical balance of the foot. It is not uncommon to find various grades of club feet with 5° to 10° greater bone angle than the opposing foot. Therefore, the commonly termed “high/low” horse can have matching PAs yet have toe angles that are 10° different. Attempts to match them without this radiographic evidence can be futile as well as detrimental. One should also be aware of the bone angle relative to the capsule PA when considering an inferior check ligament desmotomy as a high bone angle (60°) and a low PA (5°) will not offer favorable results due to the low PA (Fig. 7, A and C).

As a rule, the majority of light-boned breeds have a bone angle of 50° give or take a couple degrees, although, much lower bone angles are also relatively common (Fig. 7B).

Horn-Lamellar Zone

The horn-lamellar zone (HL) is defined as the distance between the dorsal surface of third phalanx and the outer surface of the dorsal hoof wall, measured perpendicular to the dorsal face of the third phalanx. It is commonly measured just distal to the extensor process and near the distal tip of the third phalanx. It consists of horn wall and the opaque dermal/epidermal zone that borders the horn and the laminae. Ranges of normal vary depending on type and size of the horse and so this measurement is best used when comparing serial radiographs over time. It is also important to measure both the horn (H) and lamellar (L) zone separately, as significant, life-threatening lamellar swelling can occur without rotation. One must also consider that the horn portion of the HL can be drastically altered by the farrier in an attempt to make the foot look normal and so measuring the HL by itself can be misleading unless used in conjunction with other soft tissue parameters.

In the past, "capsule rotation" was considered pathognomonic for laminitis; however, other common foot issues result in horn alterations that may resemble laminitis at first glance, yet not involve the laminae. For example, white-line disease frequently has capsule rotation radiographically but as a rule, the disease process is limited to the horn wall and the laminae only become altered to some degree in the ultra-chronic case. Clinically, white-line disease can resemble laminitis and require similar mechanical benefits as the wall is also an antagonist to the DDFT, and once it loses its natural function due to invading bacteria and fungi, the wall fails to resist the relentless pull of the tendon. Radiographically, the gas line is distinctly different from white-line disease as it is within the inner non-pigmented horn, starts at the ground surface and has an erratic pattern of destruction. The etiology of capsule rotation and lesion intensity sets the stage for specific shoeing recommendations and goals. The farrier should be involved with formulating the mechanical plan based on the radiographic data that relates specifically to the trim, shoe design, and application.

Digital Breakover

Digital breakover is the distance from a vertical line drawn at the tip of the coffin bone and 90° to the point of break-over or the most dorsal location of the solar aspect of the hoof or shoe that contacts the ground. The point of break-over can be variable based on whether or not the shoe is flat or has a radius (rocker-type shoe). It is common practice to back the toe up to enhance break-over and to make the low-profile foot with crushed heel appear to have a stronger toe angle. Unfortunately, it is not a problem with the toe but a stark loss of heel mass. The natural heel-to-toe ratio is out of balance and reducing the strategic strength of the dorsal wall for the sake of making the heel appear stronger can be counterproductive. This practice fails to remarkably improve mechanics and it can be counterproductive (Fig. 8).

Fig. 8. The lateral image reveals that the wall was backed up with a rasp along the distal 2/3 of the dorsal face. Note the location of the dermal/epidermal opaque line relative to what was removed. The dorsal wall is the thickest and apparently the most strategic part of the capsule and removing it has little if any benefit.

Medial/Lateral Balance

Balance is defined as even distribution of weight. This term is frequently used by farriers and vets with a wide range of interpretation based on a variety of external and radiographic reference points. Even though subjective and without regard to sole depth, bone asymmetry, and PA, it is commonly thought that radiographic medial/lateral imbalance of the solar rim of the coffin bone is the cause for unsoundness. Therefore, oftentimes the farrier is instructed or inclined to remove foot on the longer side and/or add shims to the lower side in an effort to leave the wings horizontal with the ground surface. Unfortunately, when the foot has less than adequate mass (depth of sole and heel) removing more sole that is the first line of defense for the underlying sensitive structures is counterproductive. Discretion is due as there are more points of interest to consider when assessing static radiographic balance. The DP view for podiatry issues requires astute attention to assure the horse is standing as square as possible, with each foot on a proper positioning block and with the head straight forward to assure the most accurate representation of rim and joint balance. The slightest shift of load will alter both rim and joint balance. Coffin bone asymmetry frequently occurs with toe out conformation. Often there is less sole depth medial versus lateral and the bone is remarkably smaller in the vertical and horizontal plane than the lateral half. A large majority of these will also have medial joint listing along the same plane as the solar rim. Despite the vertical bone asymmetry and/or medial listing, the joint space will often be uniform. This description of imbalance can be consistent with sound, top athletic horses provided they have adequate foot mass. A more descriptive term may be natural imbalance as it is apparent that it is the result of permanent congenital limb and hoof deformities that we aren't going to change but can manage the ill effects (Fig. 9 and Fig. 10).

The growth rings along the medial lateral quarter will also reflect a despairing rate of growth between them when load distribution is altered by undesirable limb conformation. The excessively loaded side will have less distance between the rings. This deficit in medial wall growth is consistent with the lighter breeds that have toe-out conformation due to a valgus carpus, outward rotation of the entire limb (extorsion), or both. When the conformation defect is more severe, a pushed up or displaced medial heel with this conformation can be seen as well. The pushed up or displaced heel is often erroneously referred to as a sheared heel. The pushed-up heel remains firmly attached to the opposing quarter, whereas the sheared heel no longer remains firmly attached to the adjoining heel bulb

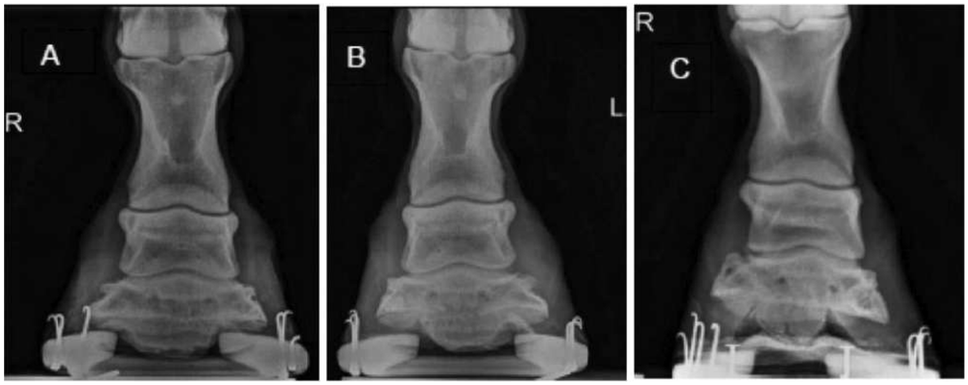

Fig. 9. A, Right front natural medial listing of the palmar rim, coffin, and pastern joints with even joint spaces. Note also that the metacarpophalangeal joint slopes medial to lateral. This is a distinguishing point of interest that confirms the left from the right foot unless the images are flipped, another valid reason to never flip images. B, The left foot of the same horse in panel A. This is the steeper foot of the mismatched pair; note the bone shape and the apex is remarkably lower than the wings, evidence of a higher PA. There is evidence of imbalance as the medial side of the coffin and pastern joint is narrower than the lateral side. To balance the coffin and pastern joints, the medial side of the foot should be lowered accordingly. C, This horse has an extensive medial listing of the pastern and coffin joints and palmar rim. However, this horse becomes sound when the lateral side of his foot is lowered just enough to balance the joints but not enough to make the palmar rim parallel with the sole. The external hoof characteristics offer no clue to this degree of congenital imbalance.

and can be quite easily manipulated proximately. It has long been assumed by horsemen, farriers, and veterinarians that the heel bulb is a reflection of medial/lateral wing balance and correcting it using the heel bulb length as reference requires lowering that side of the foot. However, a DP radiograph will reveal the opposite has occurred. The wing of P3 is already lower and lowering further is counterproductive. Radiographic information can be vital for success as relying on external landmarks alone can be misleading (Fig. 11). For example, the medial and lateral sulci can be valuable landmarks for the farrier as they attempt to balance the heels, but only if the coffin bone is symmetrical. The sulci are very close to the plane of the concave surface of the coffin bone, as well as the wings that form the palmar rim on radiographs.

5. Radiographs Are Not Just for Planning

Clients should be made aware of the value of radiographic assessment throughout the mechanical application as this information assures the detailed plan is followed as closely as possible. Radiographs before shoeing set the planning stage. Images produced during the trim and various stages in the application of the mechanical aid are often indicated even for the most experienced podiatrists. The images made of the final application are of utmost value as they either confirm or disconfirm that the plan was followed and offer baseline values for the next exam.

Comparative exams should be performed with each reset for the cases that remain in the healing and or rehab status. By comparing images taken

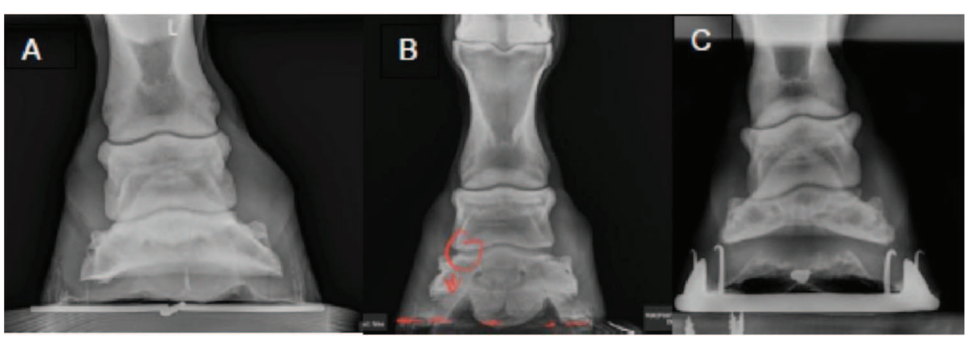

Fig. 10. A, Asymmetrical coffin bone likely secondary to load-induced changes to the medial side of the coffin bone secondary to a conformational wide stance. Note pastern angle and the symmetric joint spaces. B, The palmar rim is parallel with the ground but there is narrowing of the coffin joint (circled in red). C, Hind foot with plantar rim balance but an asymmetrical coffin bone and second phalanx. The above examples reveal the value of radiographic data when foot issues occur.

Fig. 11. A, Left fore DP image that is flipped to match the same perspective view of the photo in panel B. B, The pushed-up medial heel bulb deceptively suggests it needs lowering. However, the medial wing is already remarkably lower than the lateral and the palmar rim is in the same plane as the pastern joint. Therefore, further lowering the medial side exacerbates joint imbalance. C, Left fore DP image displayed as taken. In order to enhance the efficacy of the mechanical plan all images should be displayed as made. A builder would never attempt to work from flipped blueprints and for logical reasons.

at each reset it is possible to recognize where treatments have worked and also when there is digression or no response. This can be particularly beneficial in treatment of life-threatening syndromes. Radiographs used in this fashion for pathological shoeing provide a progressive learning curve for the veterinary/farrier team.

6. Conclusion

Career and life-threatening foot issues that require pathological trimming and shoeing continue to be a common occurrence in equine practice and requires the services of a farrier to apply the mechanical manipulation to the hoof via trim and/or shoe or mechanical aid in an effort to enhance the healing environment. Determining exactly what the farrier has to work with relative to goals and mechanical deficits of specific suspension and/or support components is critical to determining an appropriate treatment plan for the horse. Consistently measuring parameters as accurately as possible can help develop the eye for the slightest alteration from that of healthy feet of various ages and breeds. The goal of the team is to develop instinctive skills that correlate the internal parameters with external characteristics. Using the image as a guide for planning the trim lines and specifics of the shoe can reveal flaws in the plan as well as other options. Cellular phones that offer a pen are an asset for the team to sketch their plans over the digital radiographs. The farrier should understand the importance of processing the information to his or her hands and the rasp. It is one thing to observe proposed trim lines and a shoe superimposed over the lateral radiograph but quite another to fully understand that the trim should mimic the sketch. Taking lateral and DP views during the trim process helps adhere to the specifics of the plan and prevents over trimming that can drastically alter the plan as well as the outcome. Understanding how to think through the mechanical requirements and developing a realistic strategy is dependent on radiographs that are critical for both the veterinarian and farrier to know how to manage the case.

Acknowledgments

Declaration of Ethics

The Authors have adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Authors have no conflicts of interest.

References

1. Merriam JG. The role and importance of farriery in equine veterinary practice. *Vet Clin North Am Equine Pract* 2003; 19:273–284.
2. Redden RF. Hoof capsule distortion: understanding the mechanisms as a basis for rational management. *Vet Clin North Am Equine Pract* 2003;19:443–462.
3. Bras RJ, Redden R. Understanding the basic principles of podiatry. *Vet Clin North Am Equine Pract* 2018;34:391–407.
4. Redden RF. Clinical and radiographic examination of the equine foot, in *Proceedings*. Am Assoc Equine Prac 2003:49; 174–185.
5. Redden RF. Radiographic imaging of the equine foot. *Vet Clin North Am Equine Pract* 2003;19:379–392.

Life After Deep Digital Flexor Tenotomies

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1. Introduction

Despite significant research and recent findings over the past decade, a complete understanding of laminitis and its complex pathophysiological processes remain uncertain. Preventative measurements and strategies of this devastating disease remain largely empirical and anecdotal with little information from evidence-based medicine. Recent technological advances offer some promises towards the effective treatment or the rehabilitation process of the laminitic horse. Laminitis can be one of the most frustrating, but rewarding diseases to treat. Anyone interested in working with foot problems in the horse must have an effective strategy for treating the laminitic horse. It is these cases in particular which are in the most need of veterinary expertise. There are a few instances when there is the opportunity to dramatically improve the quality of an animal's life. With the appropriate treatment approach, a large proportion of laminitic horses can be rehabilitated to pasture soundness, light use, and even some degree of athletic performance.[1] However, some advanced cases cannot be rehabilitated to an acceptable level of comfort and therefore euthanasia is advised to prevent needless suffering.

If the distal phalanx continues to displace and/or if the foot fails to show continuous improvement defined as hoof growth with shoeing mechanics alone, oftentimes a deep digital flexor (DDF) tenotomy is warranted. A DDF tenotomy is the fastest way to counteract the forces at play and restore perfusion and tissue mass to the dorsal regions of the foot (Fig. 1). These feet generally respond with significant distal dorsal sole growth at the tip of the coffin bone over 4–6 weeks (Fig. 2).

One of the most significant developments not only in the evaluation and treatment of laminitis but also understanding the mechanics of the foot in general has been the venogram: a simple but technique sensitive procedure that allows visualization of the vascular tree of the foot.[2–4] The venogram has become an invaluable tool that also allows visualization of the effects of pathology and various treatment concepts, making it one of the most valuable tools for diagnosis and treatment strategy.[5] The venogram provides the first detectable evidence that confirms laminitis, clearly distinguishing it from other syndromes with similar clinical signs, and reveals the damaging effects of laminitis earlier in the syndrome than radiographs. Having this information at the time of first clinical signs or shortly thereafter allows a treatment window with the largest response, enhancing the ability to make more timely decisions concerning reversal therapy and also providing a baseline that facilitates monitoring the efficiency of the chosen treatment regimen. This can offer a much more favorable prognosis than wait-

NOTES

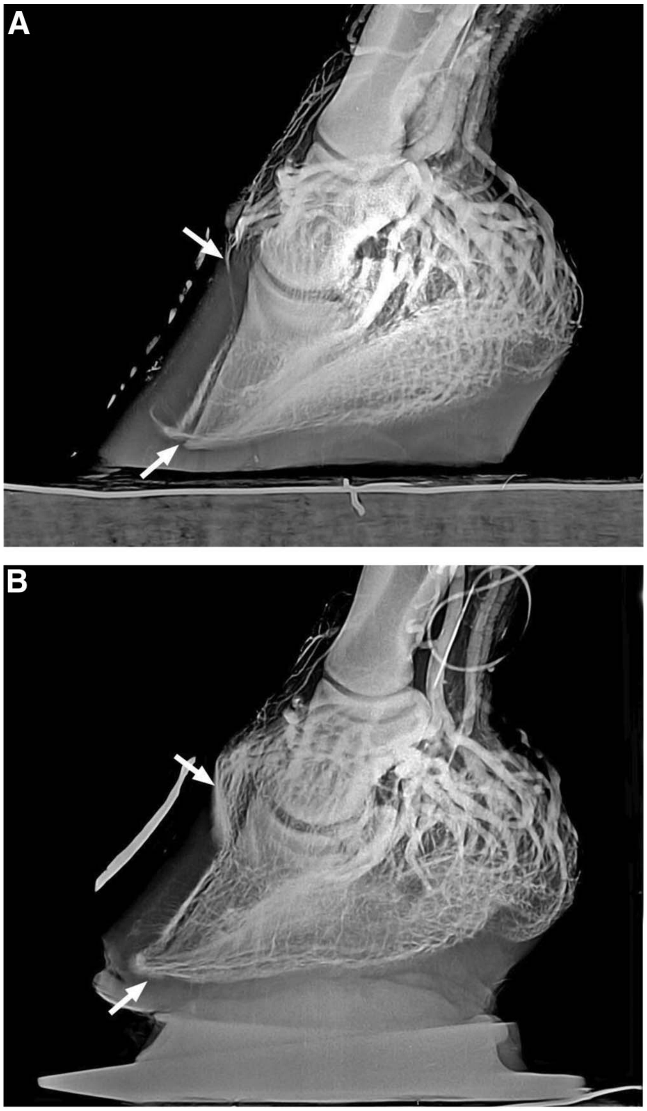

Fig. 1. A, Venogram study before DDF tenotomy with evidence of severe compromised blood supply. The distal phalanx apex has descended distal to the circumflex vessel (arrow) and contrast is absent distal to the apex identifying poor perfusion of the solar plexus and absent terminal papillae. The coronary plexus (arrow) is also compromised with poor perfusion and absent papillae. B, Venogram study 6 weeks post DDF tenotomy shows that contrast has returned to the coronary plexus, and papillae are evident (arrow). The distal phalanx apex and the lamellar-circumflex junction has returned to a normal orientation (arrow). Contrast is slightly reduced distal to the distal phalanx palmar processes. (Images courtesy of Dr. Amy Rucker.)

Fig. 2. A, Horse with derotation/re-alignment shoe and DDF tenotomy. B, Evidence of a positive response to DDF tenotomy 6 weeks later with significant sole growth. C, The ultimate goal has been achieved when health of the coffin bone and re-establishing normal coffin bone alignment with adequate sole depth has been maintained.

ing until radiographic evidence confirms that significant displacement has occurred.

By re-establishing vascular perfusion, the ultimate goal is to maintain health of the coffin bone and eventually re-establish normal coffin bone alignment and adequate sole depth. Transection of the DDF tendon allows immediate re-alignment of the coffin bone in relation to the ground surface. Timing of the DDF tenotomy and re-alignment shoeing procedure is critical. The procedure should be performed before the patient experiences advanced structural failure. The most important aspect of the procedure is management of the foot. Combination of surgery with the appropriate trim and therapeutic shoeing is imperative for long-term success. Performing the DDF tenotomy without realignment shoeing of the hoof capsule will have a short-term clinical improvement and most likely won't affect the survival rate.[1]

Transection of the DDF tendon is a controversial treatment for chronic laminitis largely because of the variation in personal experience with the procedure and the varying success rates reported in previously published data.[1] Differences in reported success rates are more likely because of the dissimilarities in foot pathology and the foot management associated with the procedure. Outcomes are determined based on the degree of bone disease, solar penetration, degrees of rotation, sinking (distal displacement of the coffin bone but no rotation), number of limbs involved, and front or hind feet affected. There are several issues to consider when making the decision to perform a DDF tenotomy: initial damage assessment, short- and long-term goals of the client, aftercare capabilities and responsibilities of the caretakers, mechanical knowledge, and skill level of the farrier and veterinarian relative to the patient, and financial impact. The DDF tenotomy has often been viewed merely as a salvage procedure. It is only considered late in case management and is often performed without considering the benefits of repositioning the palmar/plantar (herein referred to as palmar) and the articular surface of the coffin bone with healthy load zones. However, if performed early in case management, at the first indication that the vascular supply is not responding to optimum mechanics before permanent damage occurs, the DDF tenotomy can greatly enhance the prognosis by increasing the potential for rapid vascular reperfusion to severely compressed areas. This can preserve the integrity of the palmar rim and optimize solar and tubular papillae function, which accelerates sole and horn growth.

Transection of the DDF tendon as a treatment for chronic laminitis has been reported with variable success rates in the previously published data. Eastman et al[6] reported the results of 35 cases between 1988 and 1997. A total of 77% of the cases survived a minimum of 6 months, and 59% survived >2 years. Allen et al[7] reported on 13 cases. Five of these (39%) returned to limited athletic activity, six (46%) were pasture sound, and the remaining two cases (15%) improved initially but were eventually euthanized (one due to further deterioration after 9 months, and the other due to economic reasons). Hunt et al[8] reported the experience with 20 cases. In these cases, 55% survived less than 1 month, 30% survived longer than 6 months, 15% of these remained lame. None of the cases in that study returned to athletic performance. These studies had a large variation in case specifics and included the degree of coffin bone injury at presentation, chronicity, shoeing and/or trimming protocols at the time the DDF tenotomy was performed, and follow-up care. In Hunt's study, there were several cases which all received the same shoeing protocol and postsurgical foot management.

To better evaluate the efficacy of the tenotomy procedure, Morrison[9] subclassified 245 cases that received a DDF tenotomy into the following categories: degree of displacement of the coffin bone, coffin bone disease, medial, lateral, or vertical sinking of the coffin, and coffin bone that penetrated the sole.[5] Of the 245 cases, 51% were considered a success. Success was defined as survival for >1 year after surgery, maintaining good body condition, and an Obel lameness Grade of 2 or less (moving freely at the walk but possibly having a stiff gait, sore on turning, and able to pick up each foot when asked). Cases with no coffin bone disease and no signs of sinking or solar penetration had an 83% success rate. Cases with moderate coffin bone disease, and no sinking or solar penetration had a 93% success rate. Cases with severe coffin bone disease and no sinking or penetration had a 44% success rate. Cases with signs of sinking (medial, lateral, or vertical) had an overall success rate of 18%, while non-sinkers had a success rate of 71%. Cases with penetration and no sinking had an 88% success rate while cases with penetration and sinking had a 25% success rate. The number of limbs involved and their location was also associated with outcome: success rate for one limb was 52%; two limbs, 50%; four limbs, 50%; front limb, 51%; and hind limbs, 50%.

During laminitis and the rehabilitation process, it is important to minimize further damage to the foot. As a team, the veterinarian and farrier should have an understanding of the normal supporting structures of the digit, biomechanical forces on the foot, and the structural failure that results when these forces act on a diseased and damaged foot. In a healthy foot, the antagonistic forces between the laminae that support the coffin bone dorsally and the deep DDF tendon that pull palmarly are in balance. In the laminitic foot, these forces are out of balance due to the loss of dorsal laminar support. This allows the unopposed palmar force of the DDF tendon to pull the coffin bone away from the hoof capsule and creates instability. Venograms clearly outline the blood circulation in the foot, and perfusion deficits that are a consequence of laminitis. This is an invaluable diagnostic that could help with prognosis. The clinical information gained from a physical examination of the foot, venograms, and radiographs will dictate which treatment modalities need to be implemented. The multitude of prognostic factors that affect outcome in the horse with laminitis make treating these cases a challenge. Treating the horse with laminitis requires experience, expertise, realistic expectations, and a unified effort by the farrier, veterinarian, and owner.

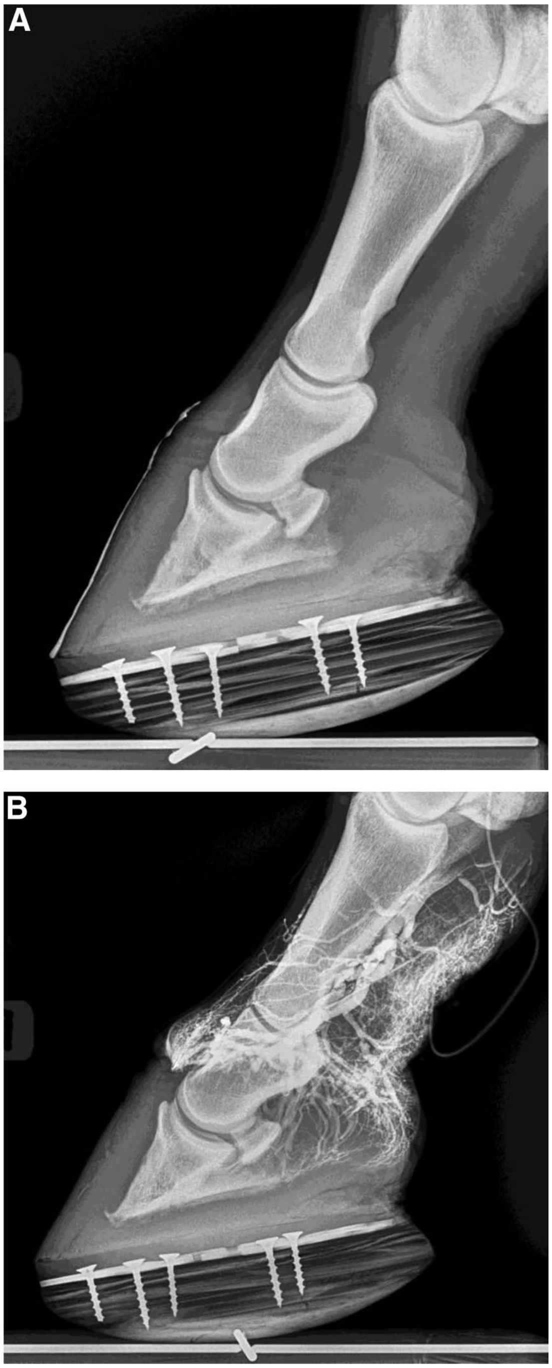

Fig. 3. A, Radiograph of a horse with acute laminitis with no improvement that was fitted with an optimum mechanical approach with no evidence of displacement of the coffin bone. B, Venogram that revealed clear evidence that the vascular damage (complete occlusion) exceeded the benefits of optimum mechanical treatment, which played a major role in the decision to perform a DDF tenotomy.

Serial venograms play a major role in the decision to perform a DDF tenotomy as it can reveal clear evidence that the vascular damage has progressed beyond the benefits of optimum mechanical treatment (Fig. 3). The information obtained will clearly distinguish the case that was fitted with an efficient mechanical aid at the onset of the syndrome from the case that was not. The value of frequent venograms to monitor the integrity of the blood supply, especially in the absence of remarkable growth, is the best way to detect the reason for horn growth deficit. Most cases with moderate to severe vascular damage will not have noticeable horn growth for the first 30 to 45 days even with mechanical aid, and will not have detectable rotation of the coffin bone. Without the diagnostic benefit of a venogram, essential information about perfusion will delay surgery by several weeks, causing the optimum treatment period to be missed. Waiting for the horse to develop complications such as seromas/abscesses due to the vascular damage, which occurs approximately 6 to 8 weeks from onset of clinical signs, to make surgical decisions can save lives for a while but significant irreversible damage sets the stage for ongoing complications and often euthanasia. When there is little if any growth 30 days post onset it is most probable that there is declining vascular supply in spite of the soundless level.[5] Do not rely on the pain scale to assess progress as it can be very deceptive.[5]

The role of the venogram is pivotal to proper case management and outcomes. Assessing internal damage with the venogram allows a better understanding of the correlation between the vascular pattern and healing response and how the mechanical component greatly influences both. Using sheer mechanics and shifting the load from the dorsal half of the foot palmarly to the heel proves to be the most reliable means of treating the laminitic horse. Doing so expeditiously, ideally before the destructive cycle to the blood supply has caused irreversible damage to soft tissue growth centers and the palmar rim including the respective terminal papillae, can produce favorable results in a large majority of cases.[10] Prognosis is related principally to vascular integrity and damage at the time of insult. Vascular compromise creates soft tissue damage, followed by mechanical disruption of the equilibrium between the supportive forces of the laminae and tensile force of the DDF tendon. Timing of treatment and a DDF tenectomy is essential for an optimal outcome by quickly re-establishing healthy vascular supply, which can prevent the mechanical phase from destroying the suspension network.

Realignment shoeing is also known as derotation shoeing[6] (Fig. 4). Transection of the DDF tendon allowed immediate realignment of the coffin bone relative to the ground surface. The goal for the realignment shoeing was to apply a tenotomy rail bar shoe[a] onto the foot to re-establish parallel alignment of the ground surface and the coffin bone. Additionally, the shoe should have a heel extension to prevent the distal interphalangeal joint from dorsi-flexing after transection of the tendon. The palmar extension of the shoe should be continued to a

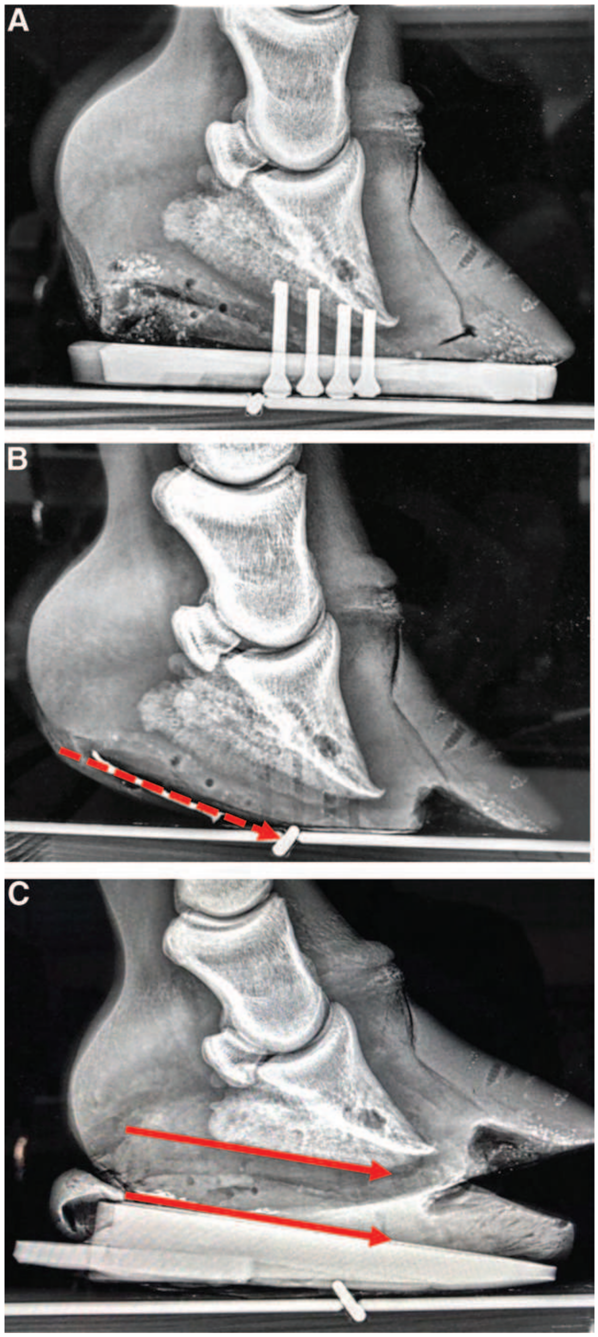

Fig. 4. Example of derotation/re-alignment shoeing. A, Radiograph with evidence of severe displacement of the coffin bone. B, Dotted red line-trimming only as needed to match the palmar angle of the coffin bone. C, Evidence of achieving a parallel level of the coffin bone with the derotation rail shoe after DDF tenotomy.

line dropped at a 90° angle from the proximal palmar aspect of the first phalanx to the ground with the horse standing squarely. The heel extension serves to improve sole mechanics by providing additional support to the palmar aspect of the foot. The sole support material[b] is then mixed and applied to the sole. The shoe is then firmly placed onto the foot at the same angle as the solar surface of P3 as viewed on the radiographs. At this point, the sole support material was often molded into a toe wedge to achieve proper shoe alignment. Once the proper angle is achieved, the shoe is glued in place using fiberglass cloth impregnated with the adhesive[c] leaving the toe open to minimize the chances for abscess formation which can be caused when the toe is covered with the adhesive material.

Successful management of the laminitic horse begins with the understanding of the normal supporting structures of the digit, the disease process, vascular compromise, and the structural failure that results in the laminitic foot. An early accurate diagnosis, and appropriate treatment are imperative for a successful outcome. Rehabilitation of the laminitic horse requires a dedicated team and cooperative efforts between the farrier, veterinarian, and owner. As with any surgical and therapeutic procedure, timing and proper case selection are essential for the best long-term outcome. The information presented here provides useful information that can assist the equine professionals in formulating a prognosis for laminitis cases requiring the DDF tenotomy and the realignment shoeing procedure. To be qualified as a competent equine podiatrist is one of the most rewarding and treasured credential that a pathological focused farrier or veterinarian could possess. Saving the career or life of a horse that is suffering from developmental complications can be one of the most gratifying experiences one could ever have.

Acknowledgments

Declaration of Ethics

The Author has adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Author has no conflicts of interest.

References and Footnotes

1. Morrison SE. Deep digital flexor tenotomy and realignment shoeing for chronic laminitis. 5th International Equine Conference on Laminitis and Diseases of the Foot, West Palm Beach, FL, November 5–8, 2009, pp. 50–1.
2. Redden RF. Clinical and radiographic examination of the equine foot, in *Proceedings*. Am Assoc Equine Pract 2003;49:320–327.
3. Rucker A, Redden RF, Arthur EG, et al. How to perform the digital venogram, in *Proceedings*. Am Assoc Equine Pract 2006;52:526–530.
4. D'Arpe L, Bernardini D, Coppola L. How to do a digital venography in the standing horse, in *Proceedings*. 10th International Congress of World Equine Veterinary Association 2008;529–530.
5. Redden RF. The use of venograms as a diagnostic tool, in *Proceedings*. Bluegrass Laminitis Symposium 1993;1–6.
6. Eastman TG, Honnas CM, Hague BA, et al. Deep digital flexor tenotomy as a treatment for chronic laminitis in horses: 35 cases (1988–1997). *J Am Vet Med Assoc* 1999;214:517–9.

7. Allen D Jr, White NA 2nd, Foerner JF, et al. Surgical management of chronic laminitis in horses: 13 cases (1983–1985). *J Am Vet Med Assoc* 1986;189:1604–6.
8. Hunt RJ, Allen D, Baxter GM, et al. Mid-metacarpal deep digital flexor tenotomy in the management of refractory laminitis in horses. *Vet Surg* 1991;20:15–20.
9. Morrison S. Long-term prognosis using deep digital flexor tenotomy and realignment shoeing for treatment of chronic laminitis. *J Equine Vet Sci* 2011;31:89–96.
10. Redden RF. Shoeing the laminitic horse, in *Proceedings*. Am Assoc Equine Pract 1997;43:356–359.

[a]Tenotomy rail bar shoe, Nanric, Inc., Versailles, KY 40383.
[b]Elastomer, Advanced Cushion Support, Nanric, Inc., Versailles, KY 40383.
[c]Equilox Adhesive System, Equilox International, Pine Island, MN 55963.

Shoeing Around the Coffin Joint

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1. Introduction

The distal interphalangeal joint (DIP) is the major articulation of the digit. It is the center of articulation about which many structures of the distal limb act upon during locomotion. The DIP joint is therefore considered a focal point of the digit and is a major landmark when assessing hoof form, function, and balance. The DIP joint, being the distal most joint of the limb, is most affected by asymmetrical loading patterns when ambulating on uneven terrain and is also greatly influenced by foot manipulations, such as trimming and shoeing. The range of motion is higher than the proximal interphalangeal (pastern) joint. At the trot, the range of motion of the coffin joint has been shown to be 47° and the pastern joint 35°.[1,2] The DIP joint is comprised of the articulations of the distal phalanx, distal end of the middle phalanx, and the two articular surfaces of the navicular bone (Figs. 1 and 2).

The joint is stabilized by soft-tissue structures: the common digital extensor tendon acts to extend the DIP joint as it courses down the dorsal pastern, combines with the extensor branches of the suspensory ligament, and inserts on to the extensor process of the distal phalanx. The extensor tendon has multiple attachments to the dorsal pastern and is adhered to the joint capsules of the pastern and DIP joint, and the ungual cartilages. The extensor tendon acts to stabilize the dorsal aspect of the joint and prevents dorsal luxation of the joint (Fig. 2). The palmar aspect of the joint is stabilized largely by the deep digital flexor tendon (Figs. 1, 3, and 4) and the impar ligament, which originates on the distal end of the navicular bone and inserts on the distal phalanx just proximal to the deep digital flexor tendon (DDFT) insertion on the semilunar crest. The suspensory ligaments of the navicular bone also aid in stabilizing the palmar/plantar aspect of the joint. The lateral and medial regions of the joint are stabilized primarily by the collateral ligaments (Fig. 5), and the chondrocoronal (attached collateral ligament to ungual cartilage). The joint capsule assists in stabilizing the entire joint (Fig. 4).

The DIP joint is primarily designed to move in flexion and extension; however, there are rotational/transverse plane and collateral /frontal plane movements as well. These planes of motion allow the joint to tolerate uneven ground. It is believed that excessive rotational and collateromotion are the cause of excessive wear and tear on the articular surfaces. To limit the stress on the joint and maximize foot function, maintaining a balanced foot proportioned around the center of rotation of the DIP is necessary.

Joints have a limited and slow rate of repair.[3] When joint damage accumulates and outpaces the repair process, clinical manifestations of joint disease arise. Gross and histological changes in os-

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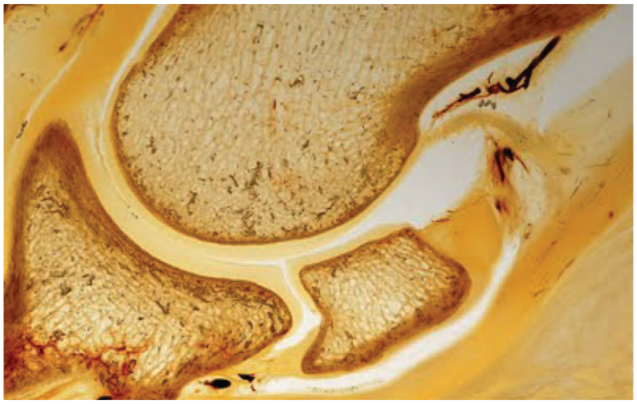

Fig. 1. Plastinated image showing the articulation of the distal interphalangeal joint. Photo courtesy of Christoph Von Horst.

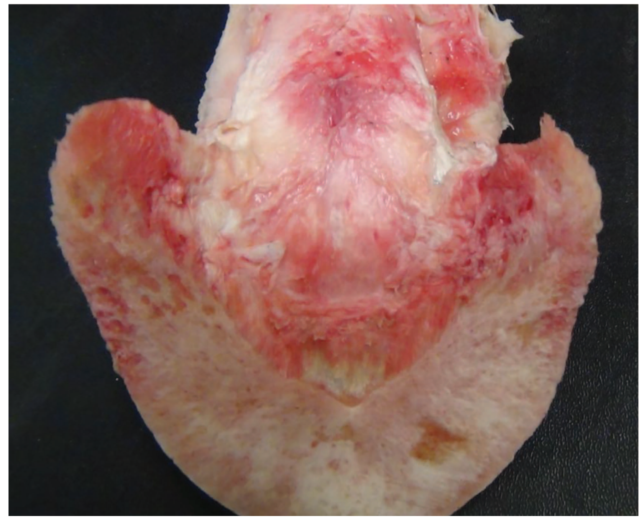

Fig. 3. Palmar view of the distal phalanx showing the insertion of the deep digital flexor tendon.

teoarthritis include cartilage degeneration, subchondral bone sclerosis, osteophytes, synovial inflammation, and periarticular fibrosis.[4] Fig. 6 shows a normal DIP joint on the left and an abnormal joint on the right, with cartilage erosions and an inflamed and thickened joint capsule.

Damage to the DIP joint can be caused by an acute injury to the joint or peri-articular supporting structures or can be from chronic wear and tear. Degrees of lameness can be variable depending on the nature and extent of the damage. Cases present with variable degrees of sensitivity over the frog region. Distension of the joint can usually be detected by palpation of the dorsal pouch just proximal to the coronary band. Palpable joint distension is not pathognomonic for DIP joint disease. Joint distension can occur secondary to any cause of foot inflammation. It is common to detect joint distension with foot abscesses, fractures, soft-tissue injuries, and severe bruising. Cases typically have a positive response to lower-limb flexion and are worse on hard surfaces. Diagnostic analgesia is required to accurately diagnose the DIP joint as a source of pain. The DIP joint blocks out with a palmar digital nerve (PDN) block (along with most of the structures of the foot[5]). Intrasynovial analgesia of the DIP joint will desensitize the joint, but over time will also desensitize the navicular apparatus and toe region of the sole. It is believed that a positive response to DIP joint analgesia within 5–10 minute is most likely the joint. After 10 minutes, diffusion of anesthetic will begin to desensitize other structures. Navicular bursa analgesia is difficult to perform in some cases, but is fairly specific for desensitizing the navicular apparatus without

Fig. 2. Dissected foot and pastern showing the insertion of the digital extensor tendon.

Fig. 4. Lateral view of the digit displaying the anatomical structures stabilizing the distal interphalangeal joint.

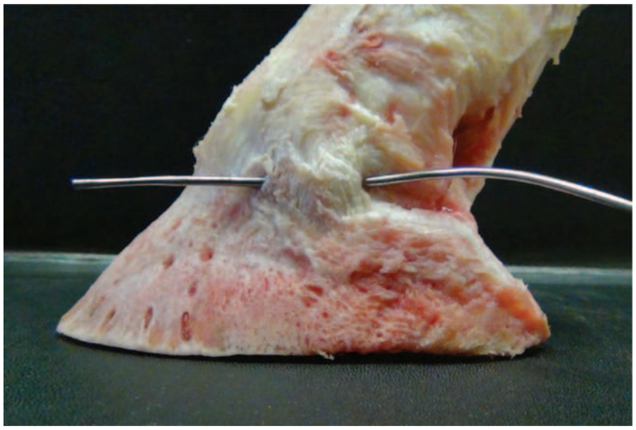

Fig. 5. Probe inserted into the collateral ligament of the distal interphalangeal joint.

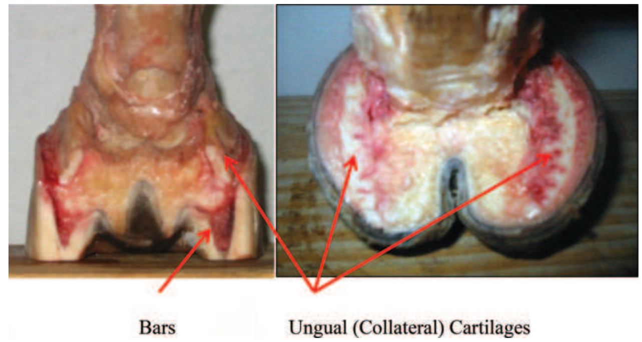

Fig. 7. Caudal view of the dissected foot revealing the digital cushion and collateral (ungual) cartilages.

desensitizing the DIP joint; therefore, a negative response to navicular bursa analgesia and a positive response to DIP joint analgesia is a strong indication that the DIP joint is the source of pain. Radiographs in acute cases rarely show much. In chronic cases, osteophytes, narrowed joint spaces, subchondral sclerosis, and enlarged synovial invaginations on distal border of navicular bone are all signs of joint disease. MRI is very helpful in evaluating the extent of the cartilage damage and peri-articular structures. MRI is also helpful in determining active inflammation and physiology of the adjacent bone.

Treatment of coffin joint disease involves managing the inflammation and its destructive action on the cartilage. Systemic and intra-articular anti-inflammatories, hyaluronic acid, and polysulfated glycosaminoglycan (PGAG)s are used.[6] Acute conditions require rest and rehabilitation whereas chronic conditions require a more long-term management program. Severe cases may require a decrease in performance level or retirement. Systemic or articular treatments with steroids, hyaluronic acid (HA), and PGAGs have been shown to be of clinical benefit in decreasing inflammation and maintaining joint health. Special attention to trimming and shoeing is most likely to have the biggest impact, especially in cases with poor conformation or foot-balance issues.

Trimming to establish even loading medial to lateral is the goal. Radiographs should be used in cases with a history of DIP disease, to help establish a balanced trim. Trimming perpendicular to the long axis of the pastern is recommended when radiographs are not available. When shoeing, preserving the natural function of the foot is the goal. Taking into consideration the shock absorbing mechanism and loading characteristics of a healthy barefoot.

There are several mechanisms in place to accommodate shock absorption: 1) hoof wall, 2) lamellar interface, 3) soft tissue (joint, joint capsule, sole corium, digital cushion, tendon/ligament, bone), and 4) movement of blood into and out of the foot. When the foot is loaded, the elastic hoof capsule deforms, soft tissue is compressed and stretched, and the elastic/pliable lamellar interface allows the bone column to displace slightly within the hoof capsule. A well-formed hoof capsule with proper mass, shape, and moisture content are the foundation for a well-functioning foot.

As the foot is loaded, the compression and tension within the foot squeezes the blood out of the foot and helps drive it up the limb through low-resistance vascular pathways in the collateral cartilages. The structure most responsible for transmitting external shock into movement of blood are the bars, digital cushion, and collateral cartilages. It has been hypothesized, by Dr. Rooney,[7] as the heels impact the ground, the bars receive vibrations and force, which then transmits it to the collateral cartilages, which lie just deep to the bars (Fig. 7). The collateral cartilages are rich in vasculature and contain a pool of blood, which receives these vibrations and converts it to the movement of fluid/blood up the limb. Basically, the collateral cartilage and its vasculature provide a low-resistance pathway for the rapid movement of blood out of the foot during ground impact, acting as a hydraulic shock absorber. Feet, which are efficient at shock absorption, have thick, robust collateral cartilages (with abundant

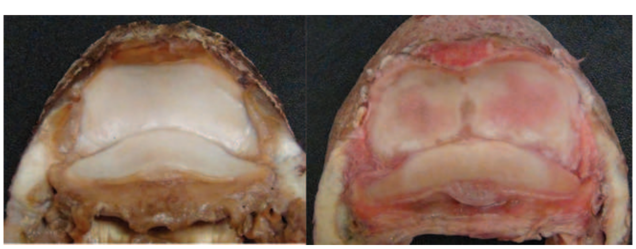

Fig. 6. Distal interphalangeal joint with the second phalanx removed showing the articular cartilage of the distal phalanx and navicular bone. A healthy joint is on the left and a degenerative joint is on the right with cartilage erosion.

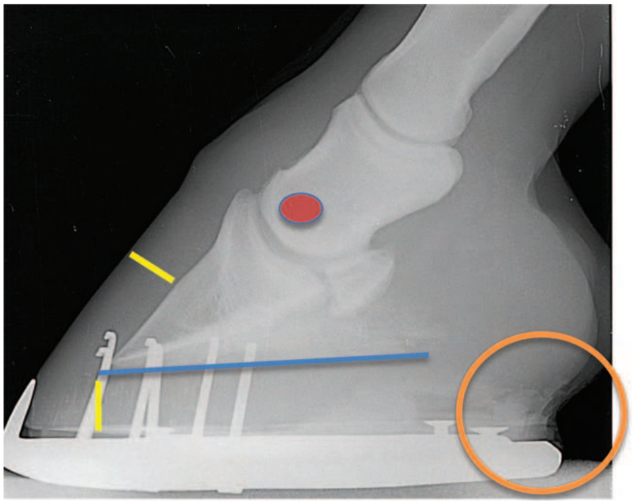

Fig. 8. Diagram illustrating and demarcating key areas to be evaluated when formulating a shoeing plan (sole depth, heel position, palmar/planter angle, and center of rotation).

vasculature), well-developed digital cushion, and strong, well-developed bars.

This is one example of why feet must have proper form to function. This simply means that the anatomical structures need to be of proper mass and spatial arrangement to execute the sequence of events needed to accommodate the dissipation of vibrations generated during ground impact and support the weight of the horse. There are several goals that should be achieved in order to promote a healthy and functioning hoof (Fig. 8): 1) The center of rotation (red dot) should be lined up with the center of the weight-bearing surface of the foot. The center of rotation can easily be identified on the foot, because it usually corresponds to the widest part of the sole. 2) A positive palmar/plantar angle (blue line), ideally between 2° and 5°. 3) Adequate sole depth, ideally the sole depth would equal the thickness of the Horn-Lamellar thickness (yellow lines). 4) Heel position should be at the widest part of the frog (orange circle). 5) The moment arm acting on the DIP joint needs to be appropriate. The moment arm is simply the length between the joint axis and the point of force, in this instance the ground surface of the shoe. This means they need to be long enough to provide support and stability but short enough to prevent excessive leverage and torque on the joint and supporting structures. The degree of leverage reduction combined with the pitch (how steep and elevated the angle of roll is on the shoe) dictate how much stress is reduced but also how unstable the foot functions as a platform or base of support. Fig. 9 shows shoes with medial/lateral leverage reduction, the image on the left is more suitable as a therapeutic shoe, whereas the image on the right would be more suitable as a performance shoe.

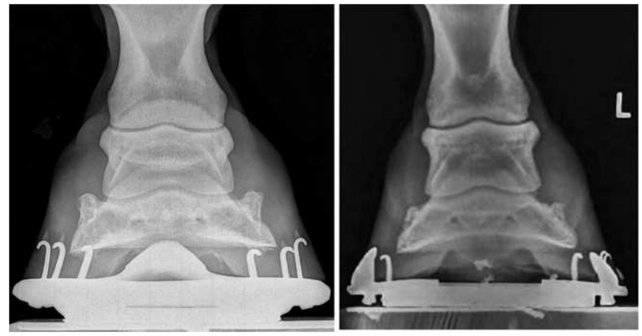

Fig. 9. Anterior-posterior radiographic view of two examples of shoes with medial/lateral leverage reduction.

Shoeing Around the Coffin Joint in the Sagittal Plane

An underrun heel, where the heels are migrated forward and consequently the entire foot including the toe also migrate forward. As a result, the foot becomes out of balance in the sagittal plane, meaning that the weight-bearing surface of the foot is no longer centered around the COR. This imbalance creates dysfunction in the shock absorbing and supporting roles of the foot. In this common scenario the bars and collateral cartilages are not lined up and cannot absorb shock as well as a foot with well-positioned heels that line up with the collateral cartilages (Fig. 10, A–C). When a foot has proper form, it is “balanced.” Fig 10A is an example of a well-balanced foot with ideal heel position and normal proportions to the weight bearing structures of the foot. Figs 10B and C are feet with under-run heels. The weight-bearing portion of the heels are migrated forward and no longer line up with the shock absorbing mechanism of the foot.

Causes of Under-Run Heels

Arches and straight lines are strong architectural shapes. Strong feet have a sole arch and straight walls. Sighting the foot from the coronary band, the walls should be straight without flares or dishes. When feet become weak and distorted the sole arch typically flattens and the walls bend, creating distortions. Hoof capsule distortion refers to misshapen/imbalanced hooves such as flares, cracks, under-run, collapsed, and sheared heels, all of which are a result of long-term abnormal weight distribution on the foot. Distortions affect function and have been shown to be correlated to musculoskeletal injuries and lameness.[8–11]

Distortions are a result of either overloading a healthy structure, causing it to collapse or bend, or can be the result of underloading a structure, such as the case of a contracted heel on a clubfoot. In this case the heel is underloaded and the toe is overloaded, causing the heel to contract and the toe to bend or dish. Distortions can also result from disease processes, such as laminitis, where the hoof wall in the toe region is separated, creating flares or

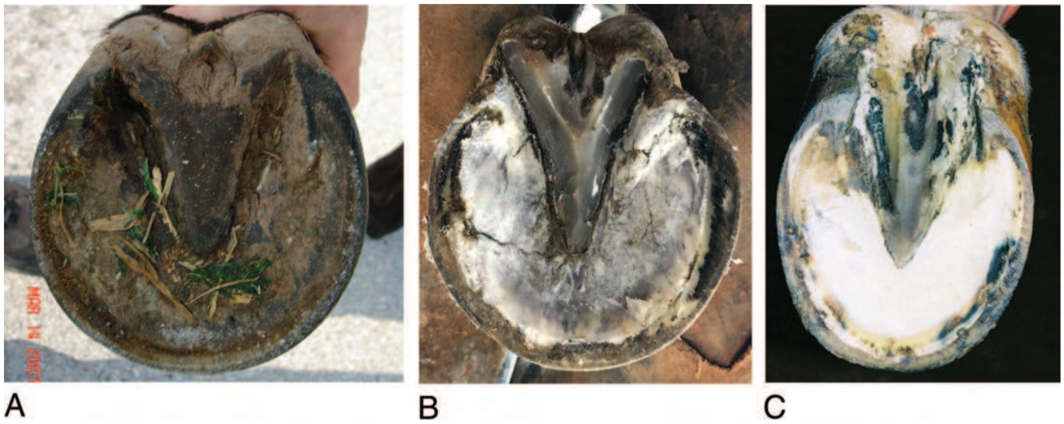

Fig. 10. Three different feet showing variations in heel contour (A is ideal, images B and C are under-run or forward migration of the heels).

dishes. Fungal infections or white-line disease can also cause weakening of the hoof and subsequent distortion. In the case of the Thoroughbred racehorse and other disciplines, a lot of stress is put on the hooves, therefore, it is necessary to have a healthy structure that is put under repetitive high loads. Speed training puts high force on the heels, which lowers the hoof angle over time. As the angle gets lower, more force is placed on the heel, creating a vicious cycle that can be difficult to correct. The combination of a lighter hoof with thinner hoof wall and sole depth combined with rigorous speed training makes the Thoroughbred hoof susceptible to distortions such as under-run heels, quarter cracks, crushed heels, and sheared/shunted heels (Fig. 11). The heel region of the hoof is softer and more pliable than the toe and is designed to dissipate shock. The heel houses such structures as the collateral cartilages, digital cushion, and an abundant vascular system, all designed to absorb shock. The toe is more rigid, designed to penetrate the ground to establish traction. Since the heel is more pliable and hits the ground first, hoof distortions typically present here first.

Fig. 11. Racehorse hooves showing a sheared or shunted heel on the photo to the left. The photo on the right shows a racehorse hoof with both heel bulbs shunted or pushed up from repetitive overload. Note the hairs on the heels are irritated and sticking up.

Many heel problems tend to be reoccurring. This is because the primary problem has not been effectively corrected. Having knowledge of the etiology of a foot problem will help formulate a successful treatment plan to heal the condition, prevent reoccurrence, and improve the longevity and wellbeing of the horse.

The most common hoof capsule distortion is the under-run heel. The horn tubules in the heel become bent forward, making the heel grow more forward at an acute angle rather than down. This hoof capsule distortion makes it particularly difficult to shoe around the center of articulation as the entire hoof migrates forward. It can be argued that the under-run heel is caused by the act of shoeing alone in which a normal hoof's natural wear is prevented. The hoof wall grows in length over the shoeing cycle, increasing toe length and decreasing hoof wall angle over time.[12] As the toe grows long, it pulls the heels forward. When due to be shod again, the foot is trimmed and rebalanced to start the entire process all over again. This continuous repetitive process trains the horn tubules to migrate forward. Other considerations with shoeing, is the alteration in the foot's loading pattern. In the unshod foot, load is distributed to the sole, bars, frog, and hoof wall, whereas the shod foot load is primarily concentrated on the hoof wall. Although when in soft footing the shod foot will incorporate the sole, bars, and frog into weight bearing.

Some may argue: since horses train on soft footing, which packs into the foot and loads the sole, bars, and frog, doesn't this offset the effect of the shoe overloading the hoof wall? Sport horses spend the majority of their time standing in a straw or dry-shavings bedded stall. It is during this period that the foot is mostly dependent on the architecture of the foot tissues for support. Long-term, low-magnitude loading creates distortion rather than short-term, high-magnitude force.[13] Horses standing in a

Fig. 12. Ten-day-old foal foot showing the typical under-run heel conformation of a newborn.

stall with little arch/sole support slowly fatigue the integrity of the capsule and propagate distortions. The arch of the sole slowly flattens, the heels become under-run, and perhaps a heel bulb becomes sheared or shunted proximally. The insidious nature of a hoof capsule distortion slowly compromises the foot, rendering it more susceptible to an acute injury.

The horse's foot is capable of handling huge impact forces without structurally collapsing. This is due to the fact that when a horse is traveling, the moving foot fills with blood during the swing phase. Probably from centrifugal force filling the non-weight-bearing tissue maximally with blood, creating turgor pressure. This fluid in closed spaces may help support the architecture of the foot during ground impact. It is with the help of this mechanism that the foot is able to withstand high-impact forces. Most hoof capsule deformities (under-run, collapsed heels) slowly develop over time. It is in the author's experience that most of these distortions occur while the foot is semi-static (while the horse is just standing around).

Prevention and Treatment of the Under-Run Heel

Prevention of a dysfunctional heel begins as a foal. The foal is born with a small, soft hoof. The solar surface is smaller in circumference than the coronary band. The soft, contracted hoof is a normal adaption to prevent injury to the mares' birth canal during the birthing process. If you look at a newborn foal's hoof you will see they are born with an under-run heel (Fig. 12). In nature, the newborn foal quickly becomes very mobile and the abrasive terrain quickly wears the horn away to achieve a normal heel position. The heel position should be trimmed back to the widest part of the frog at each trimming. Care should be taken not to trim the heel too low creating soreness and sole bruising. Ideally, the growing horse should remain barefoot as long as possible to encourage a strong well-adapted heel.

Fig. 13. Assessment of the plane of the frog in relation to the solar border of the wall. These photos show two examples of frogs that are "prolapsed" or that are breaking the solar plane and are closer to the ground than the ground surface of the hoof wall.

The most important element in preventing a compromised heel from occurring is maintaining ideal weight-bearing proportions to the weight-bearing surface of the foot. Recognizing a compromised heel and addressing it before it creates lameness issues is paramount to a successful foot-management program. The first morphological sign of an overloaded heel is a frog that begins to prolapse or break the plane of the solar surface of the hoof wall (Fig. 13). The wall in the heel region begins to collapse or recede as it is overloaded, and the frog plane becomes lower than the hoof wall. Another sign of excessive heel concussion are hairs that begin to raise and irritation/dermatitis of the heel bulbs (Fig. 11).

The most effective way to rehabilitate a weakened or compromised heel is to go barefoot for a period of time. The frog plane improves and the under-run heel position corrects quickly. Often, this is not possible and cases will need shoes to stay sound for training and competition. In this instance, shoeing modalities that mimic the barefoot condition are required to manage and rehabilitate the heel structures. Figure 14 shows a race filly's foot before and after going barefoot for 3 months. Notice the improved heel position, weight-bearing proportions, and overall shape of the foot. There are several features of the barefoot condition that can be simu-

Fig. 14. Solar view of the foot of a race filly before and after going barefoot for three months. Note the improved heel position and the difference in shape/dimensions of the foot.

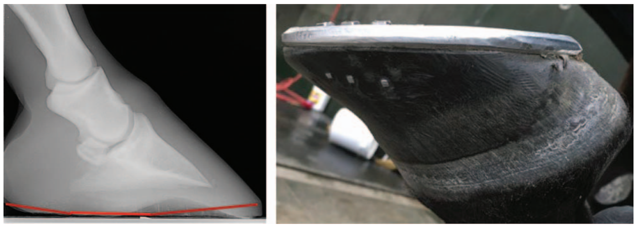

Fig. 15. A foot trimmed in 3 different planes to establish an ideal heel position without compromising the sole depth/protection beneath the wings of the distal phalanx and to increase the palmar angle of the coffin bone.

lated with shoeing to create a similar effect. These features are frog support, rolled heel, rolled toe, broad toe shape. If you look closely at a healthy barefoot, you will notice the foot is not completely flat. The heels and the toe are rolled slightly. The rolled heel helps decrease excessive concussion generated during heel first landing.

The rolled toe helps decrease resistance to breakover and allows the foot to rollover in any direction that is the least stressful for that limb's conformation (Fig. 15).

The rolled heels provide the ability to improve the heel position, by trimming the heels back to the widest part of the frog without invading sole mass beneath the wing of the pedal bone. Horses need as much protection beneath the wing of the bone as possible. This is a common area of soreness in athletes. If the entire foot level and the heels were trimmed back to the widest part of the frog, then the trim would take away too much sole depth. The last component is frog support, which is best done by adding a heart bar, frog cradle, stabilizer plate, thermoplastic form-fitting heel pad, or in some cases, temporary orthotics/sole support (Fig. 16). Many trainers do not like the added weight and decreased traction created with a bar shoe, therefore other mechanical solutions to deal with this problem must be found. One option is to train in the bar shoe and switch to a normal race plate on race day or shortly before. Some cases experience some discomfort with a metal bar or heart-bar. Perhaps the weight of the limb coming down on a metal unyielding bar is too firm for some feet. A thermoplastic heel plate is often tolerated well by even the most sensitive feet. The thermoplastic pad is heated and molded to the heel area. The thermoplastic is firm enough to provide adequate support but yields and flexes slightly.

Temporary orthotics are sole support materials that are placed or wrapped in the soles while the horse is in the stall and then removed when out of the stall. The concept is to provide arch/sole support while the horse is in the stall and allow the horse to train in a normal shoe. This is a 2-part elastomer dental impression putty that is used to make a custom orthotic or arch support for each foot. The removable orthotics are placed into the feet and wrapped in place with Vetwrap. The orthotics can be removed for training and placed back in the foot when the horse is in the stall. The orthotics will provide arch support and help unload the perimeter wall to strengthen the arch and improve the heel structure. Fig. 17 shows a racehorse foot after 5 months of shoeing with a rolled toe/rockered heel shoe and frog support.

The club foot is recognized as having strong heel structures and plenty of heel mass; however, this foot type can also be affected with chronic heel pain. Since the club foot overloads the toe and bone column, arthritis, sidebone, pedal osteitis of the apex of the P-3, navicular bone sclerosis, osteoarthritis, and contracted heels are common pathologies seen. The compressive forces on the navicular bone are increased as the DDFT is pulled taut against the flexor surface of the navicular bone. Club feet often have increased wall growth in the heels and slow wall growth at the toe. This is the foot's attempt to raise the heels and unload or accommodate the contracted DDFT. The foot remodels to accommodate all phases of the stride. Since the DDFT is under the most tension just before heel lift off (break over), it is this phase of the stride, which must be addressed when re-balancing the club foot. Significantly enhancing/easing break over can allow these feet to return to a normal appearance. Figure 18 shows the same club foot after several shoeings to accommodate the contracted DDFT.

Most club feet can achieve equal toe/heel growth and resolve the anterior dish with these simple mechanics. It is important to realize that the contracture is not being "fixed" or resolved, it is merely

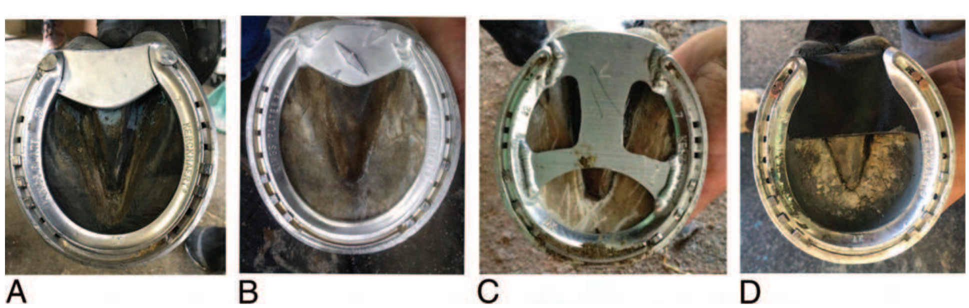

Fig. 16. Frog supports. A, Frog cradle, riveted; B, Frog cradle; C, Stabilizer plate; D: Thermoplastic plate.

Fig. 17. A, Thoroughbred gelding in training, with an under-run heel, prolapsed frog, and flat sole arch. B, Same foot 5 months later after being shod with a roller motion style shoe with frog support. Note the improved hoof angle and heel position.

being accommodated with simple shoeing mechanics and allowing the foot to return to a more normal shape, with even wall growth, no dish, good anterior sole depth, and therefore be a stronger, healthier foot. High-speed video and gait analysis studies are needed to better understand how these club feet respond to this shoeing; however, anecdotal reports and observations reveal these horses seem to lengthen the stride and load the heels more. It is hypothesized that these don't have to take a "short step" to accommodate the tendon in the caudal phase of the stride since the break over is eased they lengthen the caudal phase and thus take longer strides. The other possibility is that they are just more comfortable in this style shoe and change their gait for the better. When presented with a lower-limb lameness that may be secondary to the tendon contracture, it is logical to first address the tendon contracture and secondary club foot/hoof capsule distortion. The club foot is rebalanced by trimming the heels down and moving the breakover point back beneath the anterior coronary band. This makes the foot behave or function more like a normal foot and oftentimes the secondary lameness resolves or greatly improves. As these feet load the heels, the heel contracture tends to improve with time and use; however, in cases with atrophied frogs and robust bars, the heel is encouraged to spread by thinning out the bars, "unhooking" the point of the heels (or opening up the collateral sulci in the region of the heel buttress with the rasp), and loading the frog, sulci, and bars with elastic impression material. These feet often benefit from building the material up slightly above the ground surface of the shoe. Almost creating a "bumper" or artificial frog. This technique helps engage the foot's shock-absorbing structures.

Contracted heels can occur as a result of a chronic heel pain condition in which the heels have not been loaded normally. Heel contracture can also be seen in club feet from mechanical under-loading of the heel region. Contracted heels should be differentiated from collapsed heels; some heel-collapse cases can also look contracted. Collapsed and under-run heels occur from overloading and bending of the horn tubules, whereas heel contracture results from under loading, the horn tubules are usually straight and strong and aren't bent or folding over. Heel contracture can become a secondary source of lameness, worsening the lameness grade, and contributing to the cycle of abnormal landing, foot dysfunction, and lameness. Most heel contractures and collapse improve as the foot is rebalanced and supported.

There are many types of materials and styles of shoes to choose from. The ground surface and the discipline of the horse dictate what type of shoe is most appropriate. For example, too much or too little trac-

Fig. 18. Club foot shod to accommodate the tension of the deep digital flexor tendon, allowing the hoof capsule distortion to improve. Note the even growth rings from heel to toe on the picture on the right, indicating that the hoof is longer, distorting to accommodate the tendon contracture.

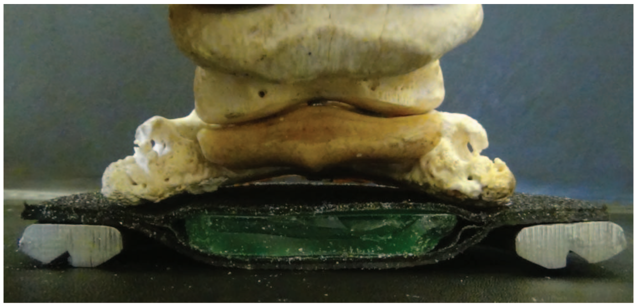

Fig. 19. Shock-absorbing pad with high-impact gel placed over the regular distal interphalangeal joint.

tion can be damaging to the joint and supporting structures. Shoes should be fit appropriately to provide adequate support and protection, without creating unnecessary leverage and torque. The COR of the DIP joint should line up to the center of the weight-bearing surface of the shoe. Depending on the degree of pathology, other shoe modifications are helpful such as ease of break-over, shock absorbing pads (Fig. 19), and arch support. Cases of DIP joint pain typically do not respond well to heel elevation. Studies show that elevating the heels increases pressure in the DIP joint.[14] Roller-motion shoes and a flat pad with soft arch support have the most positive effect on these cases (Fig. 20). Roller motion shoes have a rolled heel and rolled toe. The mechanics of this shoe is believed to decrease the "jarring" at initial ground contact, and decrease resistance to rollover or breakover, thereby decreasing the moment arm about the DIP joint, and decreasing stress on the joint and peri-articular structures.

Fig. 20. Example of a steel keg shoe with a subtle rolled heel and rolled toe to help take stress off the distal interphalangeal joint. The foot is also fit with a leather pad soft sole/arch support to help absorb shock vibrations and support the arch.

Synthetic shoes are available, which allow for more flexibility in the shoe compared to metal shoes. When appropriately applied, these shoes may mimic the barefoot condition more closely while also allowing for protection. If a case needs support for faulty conformation or for a damaged ligament for example, then a metal shoe is probably the best choice as most synthetic shoes are designed to move and flex, and lack the structural rigidity required for support. There are many shoes, sole support materials, and pads available; every case has very specific needs. Evaluating the entire horse, its environment/footing, discipline, pathology, and conformation are necessary to recommend the most appropriate shoeing regime for each case.

Acknowledgments

Declaration of Ethics

The Author has adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Author has no conflicts of interest.

References

1. Clayton H. Biomechanics of the distal interphalangeal joint. *J Equine Vet Sci* 2010;30:401–405.
2. Clayton H. Pastern joint motion in trotting horses, in *Proceedings*. Am Assoc Equine Pract 2000;26:217–219.
3. Abhijit M, Bhosale, J, Richardson B. Articular cartilage: Structure, injuries and review of management, *Brit Med Bulletin* 2008;87:77–95.
4. Kidd JA, Fuller C, Barr ARS. Osteoarthritis in the horse. *Equine Vet Educ* 2001;13:160–168.
5. Easter JE, Watkins JP, Stevens SL, et al. Effect of regional anaesthesia on experimentally induced coffin joint synovitis, in *Proceedings*. Am Assoc Equine Pract 2019;46:214–2.
6. McIlwraith CW. Intra-articular and systemic medications for the treatment of equine joint disease, in *Proceedings*. Am Assoc Equine Pract 1996;42:101–125.
7. Rooney JR. *The lame horse: Causes, symptoms, and treatment*. Chatsworth, CA: Wilshire Book Co; 1974; 117–118.
8. Eliashar E, McGuigan M, Wilson A. Relationship of foot conformation and force applied to the navicular bone of sound horses at the trot. *Equine Vet J* 2004;36:431–435.
9. Kane A, Stover S, Gardner I, et al. Hoof size, shape, and balance as possible risk factors for catastrophic musculoskeletal injury of Thoroughbred racehorses. *Am J Vet Res* 1998;59:1545–1552.
10. Thompson K, Cheung T, Silverman M. The effect of toe angle on tendon, ligament and hoof wall strains in vitro. *J Equine Vet Sci* 1993;13:651–653.
11. Mansmann R, James S, Blikslager A, et al. Long toes in the hind feet and pain in the gluteal region: An observational study of 77 horses. *Equine Vet J* 2010;30:720–726.
12. Van Heel M, Moleman M, Barneveld A, et al. Changes in location of centre of pressure and hoof-unrollment pattern in relation to an 8-week shoeing interval in the horse. *Equine Vet J* 2005;37:536.
13. Hood D. Center of digital load during quasi-static loading, in *Proceedings*. Ann Bluegrass Laminitis Symp 1998;47–62.
14. Viitanen MJ, Wilson AM, McGuigan HP, et al. Effect of hoof balance on the intra-articular pressure in the distal interphalangeal joint in vitro. *Equine Vet J* 2003;35:184–189.

How to Recognize Foot-Related Lameness

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1. Introduction

The horn capsule is an amazing protective feature forming the interface between the horse and the ground, enclosing and protecting multiple vital musculoskeletal structures. On the downside, this inhibits veterinarians from directly visualizing and easily accessing those structures for the assessment of problems.

Foot problems that can be directly visualized include disorders affecting the horn capsule itself, such as wounds, horn cracks, bruising, and keratomas. Laminitis secondary to systematic disease can also be visualized, resulting in the typical laminitic stance in acute disease or indicative horn capsule changes in chronic disease. Certain features (e.g., low underrun/collapsed heels) may predispose horses to certain problems or may be an indicator of an ongoing or historic process (e.g., foot asymmetry with one contracted and one "normal" foot as an indicator of chronic lameness).

Anecdotally, many vets believe that certain movement characteristics are indicative of foot lameness, for example reluctance to turn or a shortened cranial phase of the stride (would specify the gait or gaits) on the straight, resulting in a "pottery" gait in bilaterally foot lame horses. There is currently no scientific evidence for a characteristic foot lameness pattern of movement as far as the author is aware. These beliefs may simply reflect the fact that the likelihood that the lameness comes from the foot is higher than from it coming from other anatomical areas.

Most orthopedic problems in horses are degenerative in nature, constituting the result of "wear and tear" through repetitive minor overloading. The foot is the most common site of front limb lameness in the horse,[1] and the most common structures affected are the deep digital flexor tendon, the navicular bone and its associated ligaments and bursa, and the coffin joint and its collateral ligaments.[2,3] All of these structures are inaccessible to direct visualization or palpation and hence require additional investigative methods.

What Can Be Palpated?

Direct palpation of foot-related soft tissue structures is limited to structures proximal to the horn capsule. Veterinarians can assess the dorsal pouch of the coffin joint for effusion; palpate the origin of the collateral ligament of the coffin joint, the heel, and pastern area for pain; and can get an impression of sinking by palpating the rim of the horn capsule. Hands can be used to assess the temperature of the dorsal hoof wall in suspected laminitis cases, bearing in mind that this cannot be appreciated in all laminitis cases for a variety of reasons and that some people have more sensitive hands than others.

Indirect palpation by using hoof testers is a valuable tool to locate pain points and is arguably the

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most useful in hunting for abscesses. Horses with pain originating from the navicular region show a variable response, making it a less reliable tool. Practitioners often rely on comparing the withdrawal response between left and right legs, and the user ought to be conscious of the fact that the pressure the user applies varies between sides depending on the handedness and experience of the user.[4]

What Can Be "Blocked"?

The author's "go to method" in localizing the site of pain in horses is diagnostic analgesia. Nerve and joint blocks intend to selectively anesthetize anatomical structures or areas. Unfortunately, over the last few years, it has become apparent that these "blocks" are less specific than previously thought. The palmar digital nerve block has traditionally been used to selectively anesthetize the palmar part of the foot. However, studies have shown that this block can numb the whole foot and extend considerably proximally. Other diagnostic analgesia in the foot include the coffin joint block and the navicular bursa block. Both are more specific than the palmar digital nerve block but can also result in anesthesia of surrounding structures.[5,6]

What Can Be Imaged?

Radiography of the foot has been a standard component of assessing suspected foot lameness for decades. Indeed, the first radiograph ever taken in animals was that of a horse's foot.[7,8] Due to the complex anatomy of the foot and the 2D nature of radiographs, multiple projections are standard. These include lateromedial, dorsopalmar, dorsoproximal-palmarodistal, and a palmaroproximal-palmarodistal (skyline, flexor) view. They are amended by additional views as required by the individual case (e.g., oblique projections to assess the wings of the pedal bone if a fracture is suspected on the basis of history, clinical sign, and hoof tester findings). The integrity of synovial structures (namely the coffin joint, navicular bursa, and the digital flexor tendon sheath) can be assessed in the case of wounds or penetrating injuries by injecting positive contrast medium into the structure in question and imaging it afterward.

The limitations of radiography, namely its inherent lack of sensitivity, should be considered. A 30–50% change in bone density is required before it becomes radiographically apparent, which is only achieved in a more chronic state of disease. It should also be considered that once morphological changes become radiographically apparent, they are well established and often remain unchanged for years (a prime example would be osteophytes as a radiographic sign of osteoarthritis). Thus, radiographs serve as a "historic record" of a disease rather than evidence of an acute process; hence, there is often little correlation between radiographic and clinical findings. Exceptions to this rule are fractures and also some lytic processes, such as flexor surface lesion of the navicular bone, which can be considered pathognomonic.

In addition to its lack of sensitivity, and to a certain degree of specificity, radiography's biggest disadvantage is that it does not allow visualization of soft-tissue structures. With most foot-related pain originating from soft tissue,[3] it seriously limits diagnostic ability when it comes to foot lameness.

Magnetic resonance imaging (MRI) is the imaging method of choice for the evaluation of soft-tissue structures, and it is also the only imaging method that allows the visualization of bone edema. The advancement of MRI, in general, and standing MRI, in particular, has simply revolutionized the diagnostic ability in relation to foot lameness. Prior to MRI, practitioners already knew from the clinical picture that a variety of problems existed in horses suffering from heel pain due to the differences in the degree of pain, response to treatment, and prognosis between horses. MRI can now differentiate exactly which structure(s) are involved and how severe the problem is. This is crucial as both lesion type and severity affect prognosis and determine choice of treatment. For example, a lesion in the deep digital flexor tendon requires a completely different approach compared to a lesion in the collateral ligaments of the coffin joint. Having said that, in the author's opinion, diagnostic abilities are far ahead of treatment options and additional work needs to be done to develop more differentiated treatment strategies (podiatric as well as medical) to target specific lesions.

2. Conclusion

In conclusion, the foot remains a diagnostic and certainly a therapeutic challenge despite the huge advancements made with the development and more widespread use of MRI. The diagnosis of foot lameness requires a multimodal and extremely systematic approach combining a thorough clinical exam with careful application and interpretation of diagnostic analgesia with radiographs and MRI.

As most horses presenting to the vet with lameness never go back to the previous level of performance,[3] the author would like to suggest that the ways forward are preventative measures. Biomechanically, the horse is a very "fine-tuned machine" and especially its musculoskeletal system operates within a very narrow safety margin. To minimize the effect of wear and tear and slow down degeneration of tissue, load should be reduced by keeping the horse lean and optimizing load distribution through trimming and shoeing.

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Declaration of Ethics

The Author has adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Author has no conflicts of interest.

References

1. Kaneene JB, Ross WA, Miller R. The Michigan equine monitoring system. II. Frequencies and impact of selected health problems. *Prev Vet Med* 1997;29:277–292.
2. Dyson SJ, Murray R, Schramme MC. Lameness associated with foot pain: Results of magnetic resonance imaging in 199 horses (January 2001–December 2003) and response to treatment. *Equine Vet J* 2005;37:113–121.
3. Gutierrez Nibeyro SD, White NA, Werpy NM. Outcome of medical treatment for horses with foot pain: 56 cases, *Equine Vet J* 2010;42:680–685.
4. Arndt JL, Pfau T, Day P, et al. How reliable is the use of hoof testers? The intra-and inter-operator repeatability of force application to different regions of the foot. *J Equine Vet Sci* 2013;10:884.
5. Schumacher J, Livesey L, DeGraves FJ, et al. Effect of anaesthesia of the palmar digital nerves on proximal interphalangeal joint pain in the horse. *Equine Vet J* 2004;36:409–414.
6. Harper J, Schumacher J, Degraves F, et al. Effects of analgesia of the digital flexor tendon sheath on pain originating in the sole, distal interphalangeal joint or navicular bursa of horses. *Equine Vet J* 2007;39:535–539.
7. Paton and Duncan, March 1896. *Vet J* . Accessed through https://veterinaryrecord.bmj.com/content/172/21/546.full.
8. Frederick Hobday F, Johnson VE. The Röntgen rays in veterinary practice. *Vet J* 1896;69:103–107.

How to Plan the Strategy for Pathological Shoeing

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1. Introduction

Equine podiatry issues are a common occurrence in equine practice and present a challenge to the majority of veterinarians who are understandably inexperienced with general maintenance requirements, trimming, forging, and shoeing. Therefore, they must depend on the experienced hands of a farrier. The farrier trade is a learned art that requires years of hands-on experience with multiple breeds and disciplines to reach a competent level of service. Farriers are expected to have developed an eye for external alterations and the knowledge and skills required to help maintain soundness despite the ill effects of gate issues, developmental deformities, and hoof distortion relative to excessive or lack of growth and pathological related problems. With these credentials farriers can become the eyes and hands that help determine the most appropriate mechanical treatment application. However, working knowledge using radiographs as blueprints for planning treatment strategy is essential for consistent pursuit of success. This is where both highly respected professionals step out of their comfort zone and into the field of podiatry. Podiatry-focused radiographs are the common thread that offer the team members a means to detect mechanical deficits relative to the diagnosis, consider options that would best meet the mechanical requirements, and guide the hands responsible for the strategic details.[1–3] This common thread requires interpretive skills that carry the radiographic clues from the brain to the hands, the hands to the rasp, and final application.

"There is a fine line that runs from the eye to the brain and some things just do not make it across." —Kevin Ashton from the book, "*How To Fly A Horse*"

How true and no one escapes this proverbial learning curve.

The rationale of this how-to session are the problematic issues that face the veterinary/farrier team as they develop and employ the treatment strategy using radiographs as blueprints for pathological foot issues. The objective is to describe a method that offers the operator a means of designing the most appropriate pathological aid using the lateral/medial (LM) and dorsal/palmar or plantar (DP) images as a blueprint and a means of bringing the specific goals to fruition. Converting the specific trim lines of the chosen mechanical plan to the

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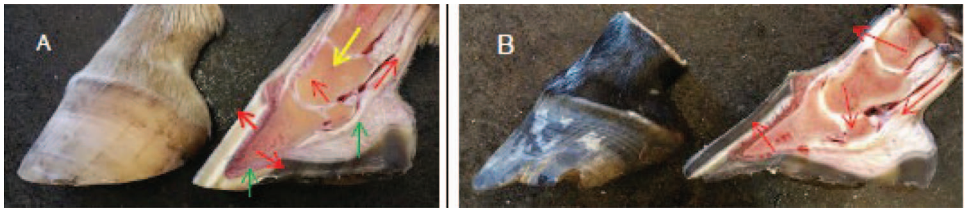

Fig. 1. A, Sagittal cut of a low-grade club foot reveals the evidence of slightly increased DDFT tension producing an increased ground PA, healthy digital cushion but a relatively shallow sole depth. Note the linear arrangement of the pastern and dorsal hoof wall. B, Sagittal cut of a typical low profile contralateral front foot reveals DDFT laxity, which produces a negative ground palmar angle, weak digital cushion but adequate sole depth. Note the pastern sits well behind the dorsal face of the wall but it would be more vertical in the live horse increasing load on the sagging tendon and compressed digital cushion.

hoof capsule is a critical step in the treatment plan.

2. Designing the Step-by-Step Plan

Designing the strategy and the specific shoe requirements requires a sound mechanical plan and this is where the learning curve gets steep. Current low-beam LM and DP images reveal the information that sets the stage for the mechanical thought process. Digital radiography offers immediate information and the ability to make measurements at that moment. This seemingly minute detail enhances the collaborative team efforts between the veterinarian and the farrier, as both professionals are present and involved in the planning process. The team should study the radiograph and correlate as many parameter findings to the external characteristics of the hoof as possible. A notepad and pencil offer a means to learn to feel the forces at play by sketching or tracing the lateral image along with the balance of opposing forces (Fig. 1).

The deep digital flexor tendon (DDFT) and laminae are the two basic suspension components of the coffin bone and digits and in the healthy foot they share equal force on their respective side of the coffin bone.[2] The support components (sole, frog, digital cushion, and associated horn wall and bars) lie distal to and complement the suspension. When load is transferred through the digits, it appears that it must first engage the suspension and then compress the support components maxing out the natural limitations of the remarkably plastic components during peak load. When harmony exists between the suspension and support components, the foot is believed to be "balanced" as it has the ability of full recall following peak load. Hoof capsule distortions appear when this harmony is lost; the foot is "out of balance", and the certain components of the foot no longer have full recall.

Appropriate DDFT tension is important for normal digital structure and function.[4] However, if the hoof capsule is weakened by genetics, overload, injury, disease, environmental factors, or human interferences, the pull of the DDFT is believed to cause or exacerbate distortion of the hoof capsule. The authors share a reliable tendon theory that has evolved from years of exclusive podiatry practice and awareness of tissue response and the medical benefits that are consistently gained by remarkably reducing DDFT tension that opposes compromised components. The application of shifting load away from load-induced vascular compromised tissue to more healthy zones brings meaning to the phrase, "applying more mechanics."

Understanding the forces at play that underlie the mechanical failure allows for a more precise strategic plan to be formulated. Recognizing the subtle or not-so-subtle changes in hoof conformation and understanding what changed internally enables the team to begin to realize how to alter the internal forces in an effort to treat the ill effects of capsule distortion. Designing the strategy and the specific shoe requirements requires a sound mechanical plan and this is where the learning curve gets steep.

Fig. 2. A, Radiopaque paste is used to draw the location of the coffin bone on the lateral hoof wall. B, An LM image showing accurate placement of the radiopaque paste overlying the coffin bone. C, The palmar surface is outlined with radiopaque paste on the solar surface of the foot over the proposed location of the solar rim of the coffin bone. D, A dorsal-60° proximal-palmar-distal image confirming accurate placement of radiopaque paste overlying the solar rim of the coffin bone. This exercise helps train the eye to correlate landmarks with internal anatomy.

Fig. 3. The growth rings are wider at the toe than at the heel. The angle they form is similar to degree of negative palmar angle.

The blueprint can be sketched on a piece of paper or made right on the radiograph using the measuring software available on most units. Alternatively, a picture of the radiograph can be taken on a Smartphone or tablet and manipulated as needed. Either way, reference points should be clearly marked so that everyone on the team understands the mechanical goals of the trim, fabrication, and application of the mechanical aid. The eye, brain to hand exercise programs the information and repetitive reinforcement starts the development of an instinctive eye for mechanics. Understanding the precise location of the bone before putting the rasp to the foot can only be known with radiographic data. Applying radio-opaque paste to the sole and the wall outlining the coffin bone helps train the eye (Fig. 2). The palmar angle (PA), whether positive or negative, will be reflected in the growth ring pattern provided it has been a few weeks post trimming. As a rule, the PA is lowered proportionally to the amount of heel removed. Therefore, the fresh trim and existing pattern may not coincide.

Strategy for Increasing Heel Mass

Wide growth rings at the toe and narrow at the heel will indicate the toe is growing much faster than the heel and most of these feet will have a negative PA (Fig. 3). In the authors' opinion, this is an example of a suspension deficit or lack of DDFT tension. Support for this theory lies in the fact that most low-profile feet have an upright pastern, which subsequently decreased the distance between the origin and insertion of the DDFT. Imagine the effect of physically lifting the PA via the DDFT. If this were possible, the digits would be realigned and effectively reverse the crushing effect due to inadequate suspension, accelerate stronger horn growth, and aid regeneration of the excessively compressed digital cushion. However, a modality has yet to be developed that can increase DDFT suspension capabilities.

Three basic concepts are prevalent relative to treating the crushed heel.

Option 1. Back the obvious long toe up as hard as possible to make the toe angle appear larger and the heels appear stronger. The low-profile foot is often referred to as a long toe underrun heel, but a closer exam reveals a very healthy toe and no heel. Therefore, it is counterproductive to sacrifice the toe in hopes of making the heel appear stronger. Needless to say, this is purely cosmetic and can be frustratingly unproductive.

Option 2. Increase the toe angle and improve the digital alignment with wedged pads and/or wedged shoes. Despite its obvious initial improvement in toe angle relative to the ground, digital alignment, and temporary soundness, this is considered a temporary fix. Wedging reduces tension on an already weak DDFT suspension that results in further heel crushing and frog sag. Farriers worldwide have learned this lesson the hard way.

Option 3. Trim to a zero, or if possible, a positive PA and remove the crushed, folded heel tubules. It is normally not possible to start off with a negative PA and trim to a positive PA from toe to heel. Therefore, the strategy must change. Using the lateral radiograph as the blueprint, the treatment strategy can be planned and followed to meet these prescribed goals. Determining how to raise the PA of front feet by lowering the heels would sound impossible were it not for working knowledge of the influence the DDFT appears to have on the high/low syndrome (Fig. 4).

Trim the crushed, folded heel tubules back to the widest point of the frog, starting well behind the widest point of the foot, taking the horn off at an angle that exposes stronger tubules on end. This

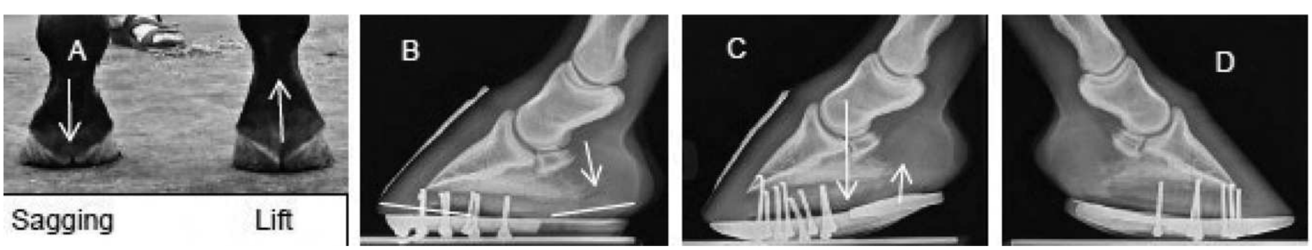

Fig. 4. A, Difference in heel profile in the left vs right forelimb. The left forelimb has inadequate DDFT suspension producing crushed heels and a sagging frog. In comparison, the DDFT is lifting the caudal aspect of the coffin bone (too much suspension) producing strong robust heels and a recessed frog. B, Note the negative PA, ¾ shoe, broken back axis, quarter crack (arrow), and proposed trim lines. C, Second reset with a rockered aluminum shoe with positive pressure frog and buttress bar. D, Right forelimb with a rockered aluminum shoe. Note the nail placement, sole mass, and relatively equal PA in spite of the remarkable difference in the suspension of left vs right.

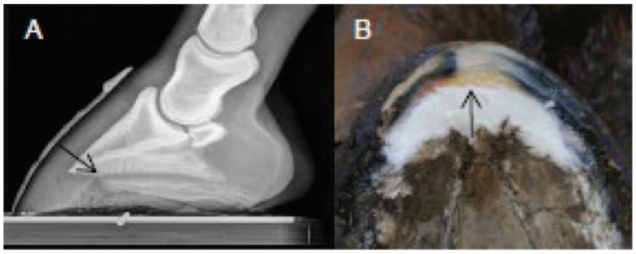

Fig. 5. A, The use of radiographs to determine sole depth and PA to accurately determine the proposed trim lines. Arrow is indicating the apex of the frog. B, Sole is pared away to identify live sole just inside the nonpigmented wall (arrow).

accentuates the frog that was already well below the ground surface of the heels. It is erroneously referred to as a prolapsed frog; however, it is the extreme nature of the folded, crushed heel tubules that gives it the prolapsed appearance. It should be left intact as it offers a means to push the digital cushion dorsally relieving the sagging effect. To trim to a positive PA from behind the widest point of the foot forward in a flat or slightly rockered profile, the farrier should know precisely the sole depth and PA. When radiographs aren't available, the sole can be trimmed as low as possible (Fig. 5).

Using the curved tip of the farrier's knife, the exfoliated sole just off the apex of the frog can be trimmed to live sole just inside the nonpigmented wall or just in front of the apex of the frog. Either technique can be a reliable means of understanding how much sole can be removed to establish a positive PA and flat plane from the tip of the wings forward without fear of getting into the solar papillae. To help replace the frog and digital cushion, weld a bar into the shoe that offers direct, positive frog pressure. The peak of the rocker should be directly distal to the center of articulation and designed to offer adequate positive PA. Sole mass is expected to double when the peak of breakover is directly distal to the center of articulation. When fitted to the foot, the frog bar and only the toe quarters are in contact with the foot, the heels of the shoe should sit 5 to 6 mm away from the heel tubules creating an air gap. Two nails secure the shoe and attention should be given to the response of the horse when the foot is loaded. If there is too much pressure, the horse will usually pick the foot up. If it likes it, it will usually off-load the contralateral foot. Slow motion video can capture the ascending frog and cushion and expansion of the heel bulbs. This helps realign the digits, relieves the excessive load on the heel tubules, and utilizes the tough strong frog to enhance heel mass. Sounds similar to the effect one would obtain if it were possible to physically lift the palmar aspect of the coffin bone by the DDFT, doesn't it? The high/low syndrome is not a problem with the farrier, but a problem for the farrier. It is not curable but certainly manageable.

Strategy for Crushed, Negative Plantar Hindlimbs

The foot that follows behind the steeper foot in front will invariably have a lower heel height and steeper coronary band than its opposite. The mechanical thought process is similar to the crushed, negative palmar forelimb with a few exceptions. The folded heel tubules are rasped back at an angle just behind the wings of the coffin bone; however, the shoe is forged to follow the trim line. Additionally, a shoe is chosen with a narrow stock thickness so that the very prominent frog can make contact with the ground and push the digital cushion back up into the foot (Fig. 6). Full rockers behind are reserved for the extremely thin sole, negative PA rear feet. Thinking through the mechanical and specific requirements of the breed and disciplines and using radiographs to plan the strategy this concept offers the operator a means to eliminate the negative PA, aid heel and digital cushion restoration all the while allowing the horse to remain in training and competition.

Strategy for the High-Profile Foot

A more upright hoof angle and strong, robust heels describes the hoof capsule distortion of the high-

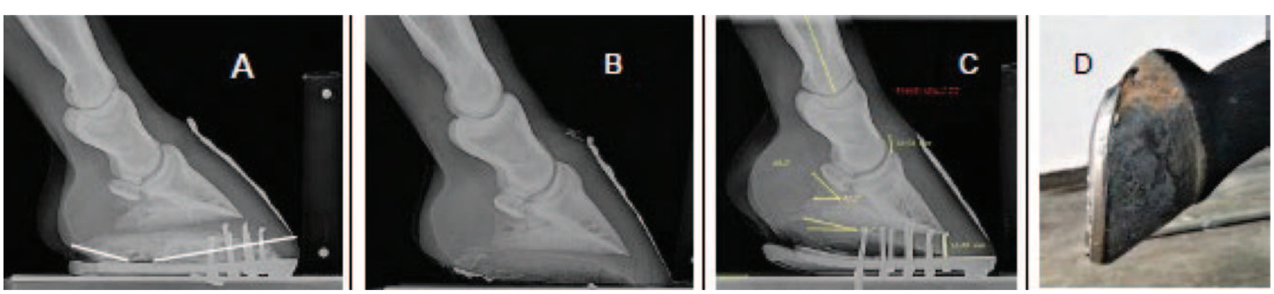

Fig. 6. A, The negative PA hind foot has approximately 20 mm of sole depth. Note the trim lines. B, The foot is trimmed in a flat plane from the wings forward creating a positive PA. Note the radiopaque paste on the trimmed heel, which matches the proposed trim lines in panel A. C, The aluminum race plate is fitted to the trimmed surface. It is typical to find the lateral heel with more damage. The shoe branches do not need to be identical as they only make ground contact as the foot lands. The heel rocker reduces tubule loading on contact as well as through the stance phase. D, Note the slightly rockered heel and flat loading zone.

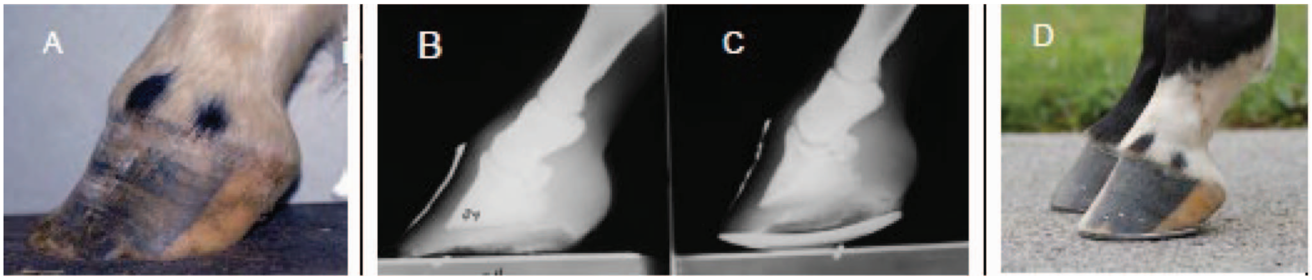

Fig. 7. A, Thoroughbred yearling with grade 3 club. Note the dish in the dorsal hoof wall and diverging heel growth rings. B, LM image at initial presentation. Note the bone angle (54°) and dish in the dorsal hoof wall as seen by the barium paste. C, Eighteen weeks (3 resets) after initial application of rocker motion shoe. Note the approximately zero capsule PA but increased overall ground PA and increased sole depth. The peak of the rocker is slightly forward of the center of articulation. The shoe was set in a thick bead of adhesive[a] for each reset. D, Shod for the sale with owner satisfaction. Dish in the dorsal hoof wall is not noticeable.

profile foot in the high/low syndrome. Based on this clinical feature, the first author came up with a grading system that encompasses the different degrees of hoof capsule distortion seen in the high-profile or club foot.[4]

Grade I: Hoof angle is 3° to 5° higher than the contralateral limb and the pastern is set forward.

Grade II: Hoof angle is 5° to 8° higher than the contralateral limb with growth rings noticeably wider at the heels than the toe. The heels do not touch the ground when trimmed to a normal length.

Grade III: The dorsal hoof wall is dished and the growth rings at the heel are twice as wide as at the toe.

Grade IV: The dorsal hoof wall is heavily dished, and the angle is 80° or more. The coronary band is as high at the heels as it is at the toe. The sole is below the ground surface.

A positive PA with diverging growth rings may vary relative to breed stereotype and pathological conditions. The PA and degree of growth ring divergence will increase relative to the degree of continuous muscle tension of the DDFT and are indicative of too much suspension. Externally, the degree of growth ring divergence corresponds roughly to the PA at the end of a trimming or shoeing cycle. In addition to the increased PA, most of these feet will also have poor sole depth (<10 mm). This indicates that the increased DDFT tension is mechanically restricting toe and sole growth by inhibiting full papillae function that can consistently be demonstrated with venography. When the lack of sole protection presents soundness issues, more beneficial options other than traditional flat shoeing concepts should be considered. Mechanical options are focused on reducing DDFT tension subsequently freeing up the inhibiting ill effects of under perfusion to solar and dorsal tubular growth centers.

Several treatment options are advocated.

Option 1. Regular farrier care focused on removing the excessive heel growth has been advocated by horsemen as well as professionals. Unfortunately, this has more immediate cosmetic appeal than benefits. Removing excess heel without regard for the reason it steadily outgrows the toe can be counterproductive as it increases the very force that contributed to the heel to toe growth imbalance.

Option 2. Inferior check desmotomy can be very effective with the grade II and III club feet, especially when performed prior to load-induced bone damage. Optimum results are obtained when the largest possible surgical gap is obtained at the time of surgery. Reducing the existing 10° to 15° PA to zero using radiographic guidelines assures the largest surgical gap offering optimum results. Pre- and post-shoeing radiographs are paramount for the farrier to determine how to trim to a zero capsule PA with maximum heel mass for the placement of a slightly extended toe shoe. Farriers are accustomed to trimming toe to heel when lowering the heel, but this will not result in a zero PA. Instead, farriers should be familiar with transferring the trim lines from the lateral image to the foot as it is a totally different trim plane. To help visualize this trim line on the foot, place a dot of radio-opaque paste on the skin frog junction and another on the apex of the frog. Connecting these two dots on the lateral image should reveal this plane is parallel to the palmar rim but slightly distal. The rasp should lie in the same identical plane as the heel is removed. This technique can have a steep learning curve but using the image to plan the trim line and shoe placement helps flatten the curve. Checking the trim plane frequently with an LM image can help prevent over trimming and/or an inaccurate trim plane before it's too late. The shoe will only contact the short, flat area of the heel and requires a composite[a] to glue it onto the foot and maintain the zero capsule PA. Caution should be used as many times the toe will be worn very thin and may have horn defects that should be protected with wax to prevent unwarranted abscesses. The authors prefer to apply the pathological shoe prior to surgery to prevent unwarranted trauma to the surgery site when the foot is shod post-surgery. Derotating the PA to zero would greatly increase the tension on the DDFT and compression on the solar corium if al-

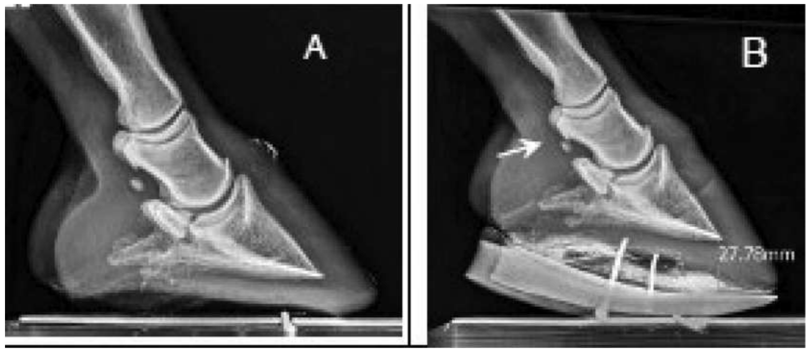

Fig. 8. A, RF LM image. Note the large calcification within the navicular suspensory ligament. B, This very painful lesion (3/5 Obel grade) was treated with a rockered aluminum shoe that raised the ground PA from 3° to 12° and the tendon surface angle from 40° to 50°. Note the location of the lesion and foot mass 6 weeks later.

lowed to bear weight immediately after being shod. To avoid unwarranted trauma, apply a custom fit rubber wedge with one of many cushion support products. The wedge should establish a 20° to 25° ground PA and be secured to the shoe with tape or cast. This offers remarkable DDFT tension release when the surgeon and farrier are unable to simultaneously coordinate the shoeing and surgery. The mechanical benefits of the post-shoeing wedge also facilitates the mid-cannon standing approach when elected and provides an easy PA let down that helps prevent post-surgical pain.

Option 3. Application of a rocker shoe. The rocker concept is an option when the check desmotomy is not an option for clients who are selling prospective high-level sport and racehorses as the surgical blemish and potential risk of associated unsoundness issues can remarkably reduce their value. Therefore, an efficient shoeing option should be elected that can help manage the excessive heel and lack of toe growth. It is obvious that the tension on the DDFT must be remarkably reduced. The goal is to lower the heel length to a zero capsule PA without lowering the ground PA, as that would immediately defeat the purpose of removing heel. The rationale behind these goals is to load the heel tubules at the peak of suspension (the existing PA) in order to increase load on the heel and limit heel papillae production as well as decrease the compressive forces on the solar papillae in order to enhance sole production. The specific trim lines are transferred to the foot based on the specifications made from the LM image with these two goals in mind. A variety of aluminum fabricated shoes can be rockered to fit the zero capsule PA and slightly rockered toe. The shoe should have adequate depth of the branches and the peak of the rocker placed directly underneath the center of articulation to allow the horse to stand comfortably. Post-shoeing radiographs confirm how well the plan was followed and can reveal glaring flaws that require immediate rethinking and alterations (Fig. 7).

When nails are used to attach the rocker shoe to the more mature foot, the pattern varies considerably from the flat shoe nail pattern. The nails should be placed in the center of the shoe instead of forward of the widest point of the foot because the rocker design allows the shoe to move at the same speed as the foot, which limits the stress between the shoe and the hoof. Evidence of this benefit is revealed in the nail holes that do not show wear from reset to reset and in reduced wear on the foot

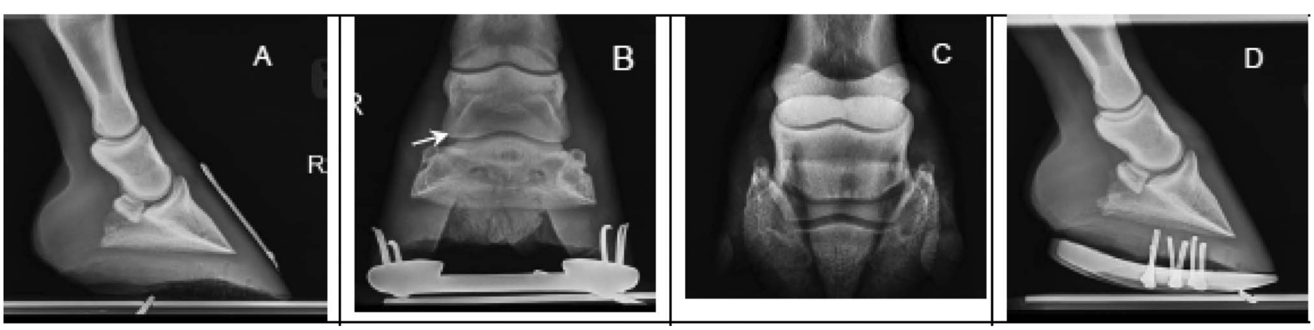

Fig. 9. A, RF LM image shows a zero capsule PA and a 37° tendon surface angle (TSA) before shoeing. Note the distance between the navicular bone and proximal P2. B, RF DP image. C, RF 45° dorsopalmar radiograph. Note the large, cyst-like lesion in the navicular bone in both panels B and C. D, The heels were pushed back to the base of the frog in a similar plane to the palmar rim and the shoe rockered to create an 11° ground PA and 48° TSA.

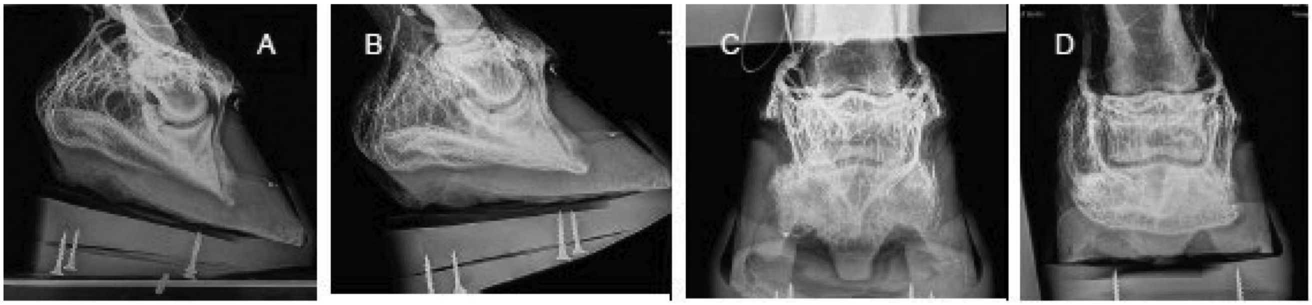

Fig. 10. A, Initial loaded LM image showing the circumflex vessels are void of contrast along the palmar zone. B, Unloaded LM image reveals moderate improved patency to the dorsal sub-lamellar and palmar supply. C, Initial loaded DP image. Note the stark loss of contrast both medial and lateral and along the palmar rim. D, Remarkable improvement in perfusion on the unloaded DP image. This evidence, coupled with the horn response following the tenotomy, strongly supports the tendon theory.

side of the heel branches. Remarkable sole and toe growth and reduced heel growth is to be expected with reasonable predictability. The long-term goal is maintaining an even growth ring pattern and 15 to 20 mm of sole mass.

Case Example 1

Aged trail horse presented with bilateral lameness that was thought to be due to laminitis. Radiographs and clinical exam indicated that the pathology identified within the navicular suspensory apparatus was the most probable cause of lameness (Fig. 8). Trigger showed a favorable response to mechanical-enhanced rockers within days and returned to trail riding soundness.

Case Example 2

An 11-year-old barrel mare presented with an acute onset of a 3/5 right fore (RF) and 2/5 left fore (LF) lameness. Radiographs and clinical exam indicated that the bilateral, remarkable navicular lesions were supportive evidence for the current lameness (Fig. 9). The mare was shod with rockers and showed a steady improvement over 6 weeks and returned to full training and competition following a second reset.

Laminitis

A torrent of clinical evidence supports the tendon theory as a means to complement the treatment of laminitis with mechanical applications designed to reduce the imbalance between the DDFT and its failing antagonist, thereby reducing the ill effects of laminae and solar corium compromise. Vascular compromise may be the cause and/or secondarily the victim of the compartmental syndrome and is yet to be determined. Venographic evidence between the loaded and unloaded images consistently reveals the compromising effect of DDFT tension as it resists the anchoring forces of its direct antagonist in the healthy foot and is even more clearly revealed in feet that have remarkable laminitic damage. The imbalance of the two opposing forces is apparently analogous to a game of tug of war between the DDFT and laminae and the laminae suddenly loses strength. Employing efficient DDFT tension–reducing pathological aids in a timely fashion can diminish the devastating ill effect of the imbalance in forces, ultimately producing remarkable medical benefits. The goal of pathological shoeing in this case is effectively aiding perfusion to mechanically deprived strategic components as soon as possible with the intent to slow or halt the destructive process.

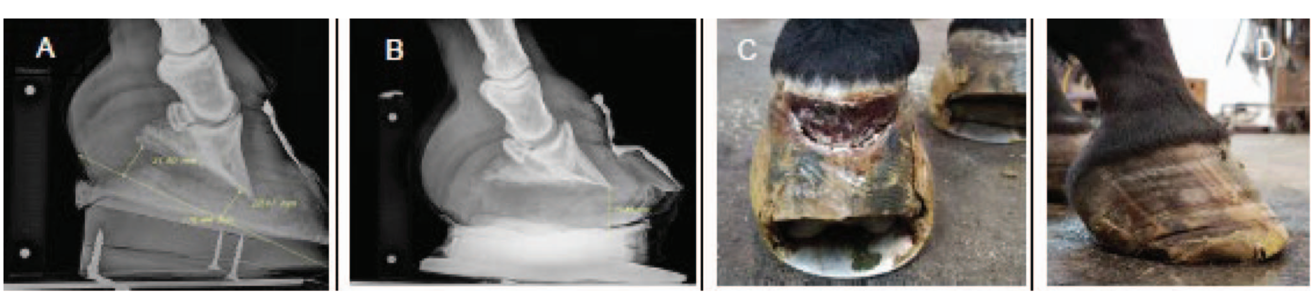

Fig. 11. A, The trim line is drawn 20 mm distal and parallel to the solar rim of the distal phalanx. This assures optimum weight transfer from the apex to adequate heel mass once the tendon is severed. B, Seven weeks postop. Note sole and horn growth. C, Seven weeks postop. Note cornified laminae post-wall ablation and approximately 10 mm new primary horn. D, 9 months postop. Hoof wall defect has completely grown out. Client had begun easy trail riding.

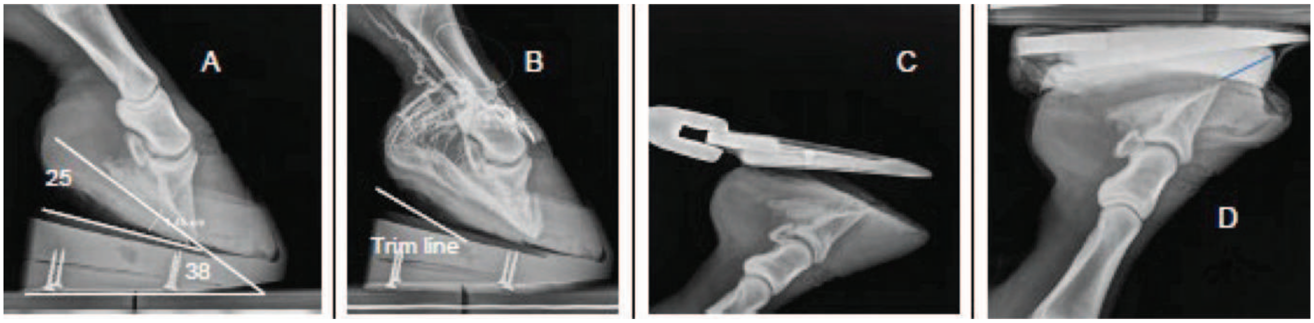

Fig. 12. Right forelimb. A, LM image with the application of a wedged cuff shoe showing a 25° capsule PA and 38° ground PA. B, Loaded LM image revealed stark loss of contrast at the coronary/dorsal hoof. Note the distinct cutoff of contrast at the site of drainage. The white line indicates the trim line. C, The shoe was held on the trimmed heel with farrier tongs to verify the trim plane created a zero capsule PA. D, LM image post-shoe application. The air gap identified between the shoe and foot was filled with cushion support and glued on with Equilox. The sole wall junction was opened for drainage as indicated by the line. Note the parallel arrangement between the palmar rim and the foot side of the shoe. This is an important mechanical requirement. A positive capsule PA at the time of surgery limits reperfusion to the solar plexus.

Minimizing the destructive mechanical forces of the DDFT at the onset of the syndrome, or shortly thereafter, can also minimize and/or prevent displacement of the coffin bone. It is apparent that the cumulative effect of the initial vascular insult and the additional mechanical force that contributes to further compromise sets the stage for the cascading series of events that can steadily destroy the integrity of the strategic components. Unfortunately, the laminitic horse is often presented days to weeks after the most responsive window has long passed.

Even when penetration has occurred, the traditional recommendation for euthanasia demands further considerations as a well-planned strategic protocol can still offer a favorable outcome. However, it does not come easy or inexpensive. Dean Richardson said it best concerning the many obstacles that face catastrophic orthopedic injuries and his thoughts parallel the authors' concerning laminitis: "There is little question that the option, acceptance, and ease of euthanasia combined with the expense and practical difficulty of treating 'laminitis' have thwarted more rapid advances in the field of podiatry."

Case Example 1

Polly, a trail mare, was presented with bilateral chronic laminitis, abscess draining RF and protruding granulation along the dorsal face, presented 8 weeks post-onset grade 4 out of 5 lame. The degree of displacement did not allude to the lesion intensity that was revealed in the venograms (Figs. 10 and 11). The remarkable level of improved perfusion between the loaded and unloaded images was valuable information that helped advise the client concerning the urgent need to perform a DDFT tenotomy combined with derotation shoeing and decompression of the sole/wall sepsis versus the more conservative mechanical option. Information obtained from venogram is being utilized more often as veterinarians learn the technique, indications for performing, and developing interpretive skills. They can be helpful when planning treatment strategies.

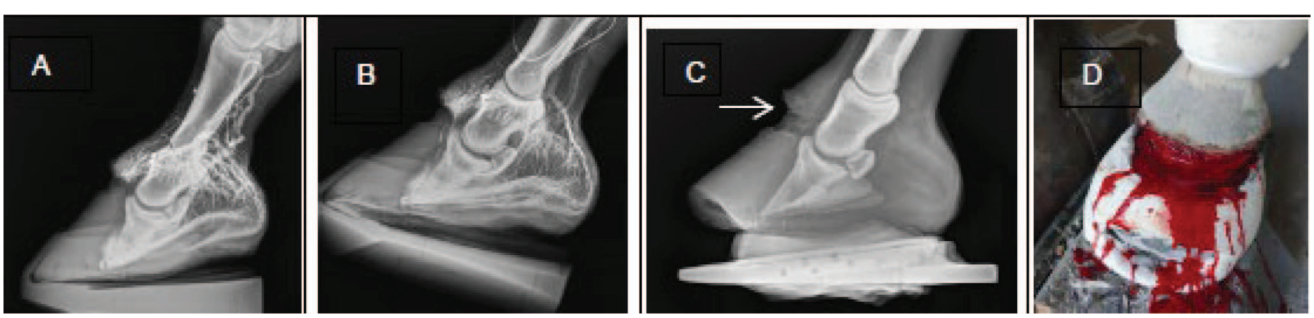

Fig. 13. Left forelimb. A, Initial loaded LM image revealed marked perfusion deficits at the coronary plexus, dorsal sub-lamellar and circumflex vessels. B, The coronary cap, circumflex and solar plexus revealed very little response in the unloaded view. C, Post-shoeing LM image reveals useful data. The extensive blowout (arrow), the sole/wall junction that was opened for septic drainage, zero capsule PA that was maintained with adequate heel mass, the rubber under the apex needs to be trimmed back past the apex of the distal phalanx, as well as the excess on the ground surface. The foot is returned to a 20° device to prevent unwarranted DDFT tension prior to the tenotomy. D, A wall ablation was performed to relieve the impaired circulation. A custom fit piece of half-inch, betadine-impregnated felt was placed in the hoof wall defect and wrapped tightly below the coronary band with 2-inch elasticon and changed daily until the laminae fully cornified.

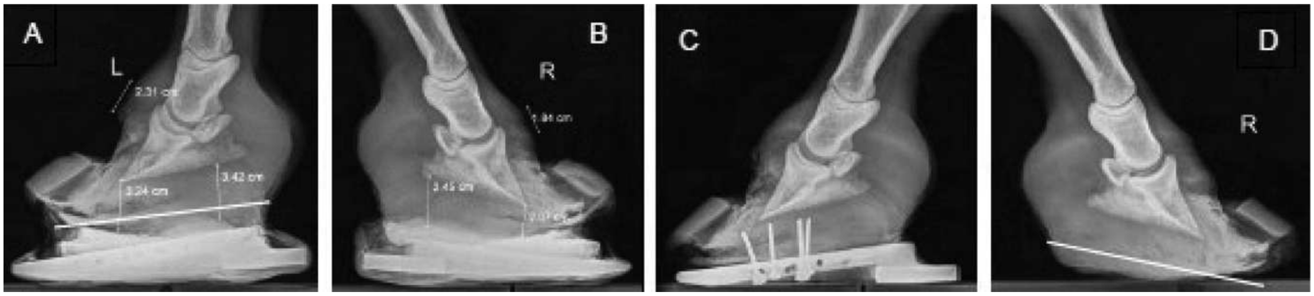

Fig. 14. Three months postop. A, Left pre-trim LM image. Note the uniform growth patterns toe to heel, zero capsule PA, and the proposed trim line. B, Right pre-trim LM Image. Note capsule PA increased and consequently less sole growth. This is a typical response of the steeper (club) foot. C, Left fore post-reset. D, Right fore post-shoe removal with proposed trim line. The trim line should be adjusted to a positive capsule PA if the heel doesn't comfortably make ground contact. The excessive old toe growth is left in place until it has grown down to the level of the apex.

Case Example 2

Broodmare in foal, first trimester with bilateral laminitis approximately 8 weeks post onset. There was drainage at the dorsal coronary bands bilaterally, but the mare was surprisingly quite sound (1 of 5). Both front feet were placed in 15° cuffed wedge shoes for the exam to minimize further damage to the vulnerable apex and traumatized solar corium while radiographs were performed and the planned determined. Baseline radiographs showed marked rotation with minimal bone damage. Venograms were certainly not needed to know that tenotomies were indicated but provided information that offered encouragement for a reasonably good prognosis even though the ultimate prognosis was dependent on the quality and speed of vascular reperfusion to the laminae and solar corium. The degree of lameness is not a reliable damage indicator and even radiographs can offer strikingly different conclusions than venograms. Both feet were derotated using radiographic control with the goal of setting the capsule PA to zero and leaving 20 mm of heel mass. A 5° wedge rail shoe with an extended heel is applied to prevent toe lift and excessive luxation of the coffin joint when the tendon is cut. The mechanical requirements that are necessary to optimize the post-surgery medical benefits are paramount and demand the greatest respect and interest (Figs. 11–16). This ongoing case was showing a favorable response at the time of this report due to the intense collaborative efforts of Harvey Schneiter DVM; his farrier, Craig Wilson; and the first author.

These cases point out the potency of mechanics when used to temporally eliminate the function of the DDFT and the contributing ill effects of it opposing the dysfunctional laminae anchor. The medical benefits that can be obtained are the summation of the tenotomy, wall ablation and ongoing strategic follow up.

4. Conclusion

Planning the strategy for pathological shoeing based on radiographic data and the mechanical requirements necessary to enhance the healing environment was found to be very useful in treating career- and life-threatening foot issues. The learning curve for the mechanical thought process based on the tendon theory is steep for both farriers and veterinarians. It is quite clear that all parties need good experience; must understand the subject matter, their roles, and the gravity of their responsibilities, as well as be able to allocate sufficient time and effort to see the task to fruition. Podiatry issues can often be frustrating when team members are not experienced with the intensity of gathering adequate information required to develop a realistic treatment strategy and utilizing

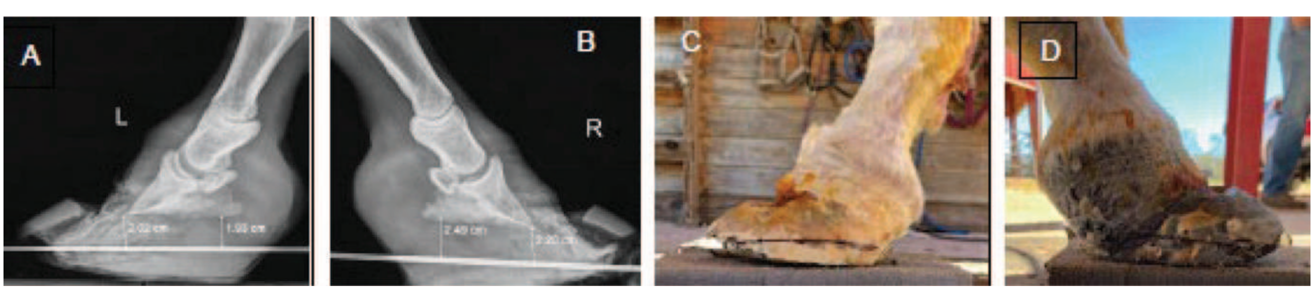

Fig. 15. Four months postop. Left forelimb (A, C), right forelimb (B, D). A and B, Nearly 40 mm of sole on both. A metal rod was used to locate the trim line with the goals to leave a minimum 20-mm sole depth and a zero capsule PA. Note the old horn location. C and D, The hoof was marked using the metal rod and x-ray as a guide.

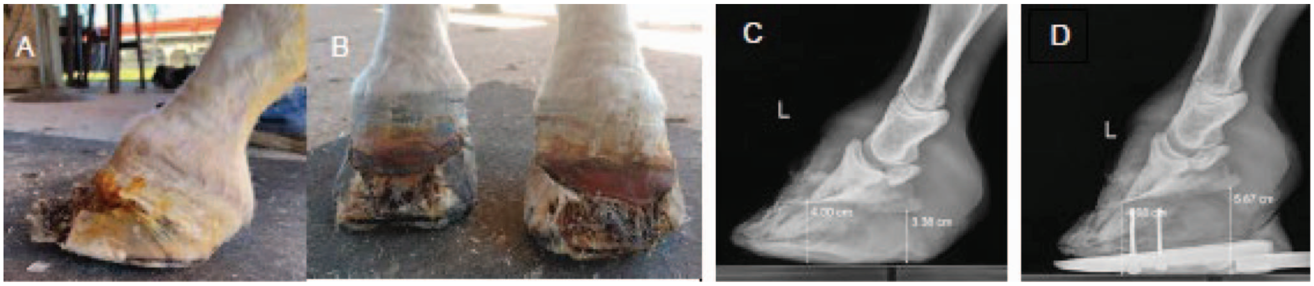

Fig. 16. Four months postop. A, The feet were trimmed to the prescribed line; this resulted in discomfort due to the lower PA. B, Note the uniform growth pattern, quality, and quantity of new horn. C and D, Wedged shoes with heel extension were applied and offered improved comfort.

it to design, fabricate, and apply shoes and or devices as treatment aids. Overall the working knowledge of the basic suspension/support theory has helped the veterinary/farrier team better understand how to develop a well-defined strategy plan for pathological shoeing. Radiographs used as blueprints provide information that is paramount for the planning and follow-up protocols. A disciplined, methodical strategy plan has helped improve the success rate of career- and life-threatening podiatry issues.

Acknowledgments

Declaration of Ethics

The Authors have adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Authors have no conflicts of interest.

References and Footnote

1. Redden RF. Radiographic imaging of the equine foot. *Vet Clin North Am Equine Pract* 2003;19:379–392.
2. Bras RJ, Redden R. Understanding the basic principles of podiatry. *Vet Clin North Am Equine Pract* 2018;34:391–407.
3. Redden RF. Clinical and radiographic examination of the equine foot, in *Proceedings*. Am Assoc Equine Pract 2003:49; 174–185.
4. Redden RF. Hoof capsule distortion: Understanding the mechanisms as a basis for rational management. *Vet Clin North Am Equine Pract* 2003;19:443–462.

[a]Equilox®, Equilox International, Inc., Pine Island, MN 55963.

Hemagglutinin Inhibition Antibody Responses to Commercial Equine Influenza Vaccines in Primed Horses

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Equine influenza is a major respiratory virus with serious economic ramifications. Authors' addresses: William R. Pritchard Veterinary Medical Teaching Hospital (Karam); Department of Medicine and Epidemiology, School of Veterinary Medicine (Wilson, Pusterla), University of California-Davis, Davis, CA 95616; Department of Veterinary Science, Maxwell H. Gluck Equine Research Center, University of Kentucky, Lexington, KY 40546 (Chambers, Reedy); e-mail: bkaram@ucdavis.edu. *Corresponding and presenting author.

1. Introduction

Vaccines from different manufacturers are often used interchangeably despite differences in strains, adjuvants, and antigen masses. There are no studies that show if this practice leads to an adequate antibody response in horses. The objective of this study was to use the hemagglutination inhibition (HI) assay to investigate the humoral immune response to the equine influenza virus (EIV) vaccine from different manufacturers' administered to previously immunized healthy adult horses.

2. Materials and Methods

This was a prospective study using 64 healthy, adult horses historically vaccinated with the same EIV commercial product over the years. Experimental subjects were divided into 3 groups of 20 horses (groups 1, 2, and 3) and vaccinated with 3 different commercially available vaccines. Each group was further subdivided into subjects that received one dose of the respective vaccine and those that received a second dose 30 days later. A fourth group of 4 horses served as environmental sentinels. Serum was collected at different time points from all subjects over 180 days in order to assess antibody responses to contemporary EIV Florida sublineage clade 1 and 2 strains by HI assay. The Kruskal Wallis test was used to determine significant differences in antibody responses among groups. Statistical significance was set at $P < 0.05$.

3. Results

For all three vaccine groups, there was a significant difference between antibody titers measured pre- and postadministration of the first dose of vaccine. In contrast, there was no significant difference between day 30 titers and titers at subsequent timepoints, even in those horses that received a second dose of vaccine on day 30. One limitation is that

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titers based on the HI assay are not reflective of protection.

4. Discussion

In previously immunized horses, administration of a different commercial influenza vaccine containing a different sublineage clade stimulates equivalent HI antibody titers after one booster vaccination.

Acknowledgments

Funding Source

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Declaration of Ethics

The Authors have adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Authors have no conflicts of interest.

Anti-PNAG Titers Correlate with Protection Against Rhodococcal Foal Pneumonia

Susanne K. Kahn, BS†; Colette Cywes-Bentley, MS, PhD; Glenn P. Blodgett, DVM; Patrick J. Sutter, BS; Sarah C. Anthony, BS; Angela I. Bordin, Med Vet, MS, PhD; Daniel R. Vlock, MD, PhD; Gerald B. Pier, PhD; and Noah D. Cohen, VMD, MPH, PhD, DACVIM*

Following transfusion with polysaccharide poly-*N*-acetyl glucosamine (PNAG) hyper-immune plasma (HIP), antibody titers to PNAG and complement deposition onto PNAG correlated with protection against presumed *Rhodococcus equi* pneumonia. Authors' addresses: Equine Infectious Disease Laboratory, Department of Large Animal Clinical Sciences, College of Veterinary Medicine & Biomedical Sciences, Texas A&M University, College Station, TX 77843 (Bordin, Cohen, Kahn); Alopexx Enterprises, LLC, 100 Main Street, Suite 110, Concord, MA 01742 (Vlock); Department of Medicine, Brigham & Women's Hospital, Harvard University, Boston, MA (Cywes-Bentley and Pier); Mg Biologics, Inc., 2366 270th Street, Ames, IA 50014 (Anthony, Sutter); 102 Dash For Cash Road, Guthrie, TX 79236 (Blodgett); e-mail: ncohen@cvm.tamu.edu. *Corresponding author; †presenting author.

1. Introduction

Experimentally, hyper-immune plasma (HIP) to the bacterial polysaccharide poly-*N*-acetyl glucosamine (PNAG) protected foals against presumed *Rhodococcus equi* pneumonia. However, efficacy data of PNAG HIP under field conditions are lacking.

2. Materials and Methods

This study was conducted during the 2019 breeding season at two large breeding farms with a history of *R. equi* pneumonia. Foals were randomly assigned to be transfused within 24 hours of birth with 2 L ($\approx$40 ml/kg) of either anti-PNAG or anti-*R. equi* HIP. Foals at Farm A (n = 120) were monitored twice daily for clinical signs of pneumonia, and foals at Farm B (n = 120) were monitored ultrasonographically for subclinical pneumonia attributed to *R. equi*. Study investigators were masked to the plasma identity until after the analysis was completed. Serum was collected post-transfusion to test for antibodies by ELISA against PNAG, complement (C1q) deposition activity onto PNAG, and *R. equi* VapA protein titers. Antibody titers to PNAG, C1q, and VapA were compared using generalized linear modeling between foals that developed pneumonia (clinical or subclinical) and foals that did not develop pneumonia (Farm A) or subclinical pneumonia (Farm B).

3. Results

Titers to PNAG and C1q titers were significantly ($P < 0.05$) higher among foals protected against either clinical or subclinical pneumonia, but VapA titers were not.

4. Discussion

Titers to PNAG or C1q deposition activity correlated with reduced diagnoses of presumptive *R. equi* pneumonia under field conditions.

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Acknowledgments

Declaration of Ethics

The Authors have adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

Dr. Cywes-Bentley has licensing and potential royalty income for monoclonal antibody to PNAG from Alopexx Pharmaceuticals, LLC. Dr. Gerald Pier has licensing income, equity shares, and potential royalty income from Alopexx Vaccines, LLC for vaccines to PNAG. Sarah Anthony and Patrick Sutter are owner and employee, respectively. Dr. Daniel Vlock is the CEO of Alopexx Enterprises.

Transfusing 2 Liters of Hyperimmune Plasma Is Superior to 1 Liter for Preventing Rhodococcal Pneumonia

Patricia Flores-Ahlschwede, DVM†; Susanne K. Kahn, BS; Scott Ahlschwede, DVM; Angela I. Bordin, Med Vet, MS, PhD; and Noah D. Cohen, VMD, MPH, PhD, DACVIM*

Transfusion with 2 liters of *Rhodococcus equi* hyperimmune plasma is superior to transfusion with 1 liter for protecting foals against pneumonia attributed to *R. equi*. Authors' addresses: Rood & Riddle Equine Hospital in Saratoga, 63 Henning Road, Saratoga Springs, NY 12866 (Flores-Ahlschwede, Ahlschwede); Equine Infectious Disease Laboratory, Department of Large Animal Clinical Sciences, College of Veterinary Medicine & Biomedical Sciences, Texas A&M University, College Station, TX 77843-4475 (Kahn, Bordin, Cohen); e-mail: ncohen@cvm.tamu.edu. *Corresponding author; †presenting author.

1. Introduction

Rhodococcus equi is an important cause of foal pneumonia for which transfusion of plasma hyperimmune against *R. equi* (REHIP) has efficacy in reducing disease incidence. However, limited data are available regarding the optimal plasma volume to transfuse.

2. Materials and Methods

Records were reviewed from 158 foals born in 2019 at 2 farms in New York to determine whether foals transfused with 2 L of REHIP were less likely to develop *R. equi* pneumonia than foals transfused with 1 L. Foals with pulmonary abscesses of diameter >1 cm that developed at least 3 of the following clinical signs were defined as presumed rhodococcal pneumonia: coughing, tachypnea, increased respiratory effort, fever, or lethargy.

3. Results

Foals transfused with 2 L of REHIP were significantly ($P < 0.05$) less likely to develop pneumonia (30%, 19/64) than foals transfused with 1 L or less (62%, 58/94). Foals born during April or May (59%, 44/74) were significantly ($P = 0.01769$) more likely to develop pneumonia than foals born before April (39%, 33/84). The odds of pneumonia remained significantly ($P = 0.0457$) lower among foals transfused with 2 L after adjusting for effects of birth-month using multivariable logistic regression.

4. Discussion

Transfusion of 2 L of REHIP is superior to transfusion of 1 L for decreasing the cumulative incidence of subclinical *R. equi* pneumonia.

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Acknowledgments

Funding Source

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Declaration of Ethics

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Conflict of Interest

The Authors have no conflicts of interest.

Comparative *in vitro* Susceptibility of Bacterial Isolates from Horses to Trimethoprim/Sulfadiazine and Trimethoprim/Sulfamethoxazole

W. David Wilson, BVMS, MS, HonDACVIM*; and Judy E. Edman, BS

In vitro susceptibility testing of 479 bacterial isolates from horses, including *Streptococcus equi* subsp. *zooepidemicus* (n = 282), *S. equi* subsp. *equi* (n = 55), *Corynebacterium pseudotuberculosis* (n = 96), and *Actinobacillus equuli* (n = 46) revealed that 478 (99.7%) were highly susceptible to both trimethoprim/sulfadiazine (TMP-SDZ) and trimethoprim/sulfamethoxazole (TMP-SMZ). Minimum inhibitory concentration (MIC) values for all susceptible isolates were between ≤0.12/2.4 μg/mL and 1/19 μg/mL for both drug combinations and most isolates were susceptible to the lowest concentration tested (≤0.12/2.4 μg/mL). Whereas 52.5% of *S. zooepidemicus* isolates and 60% of *S. equi* isolates had an MIC value for TMP-SDZ that was one concentration higher than for TMP-SMZ, this result is unlikely to be of clinical significance and does not justify the extra-label use of TMP-SMZ in preference to available FDA approved oral TMP-SDZ formulations. Authors' address: Department of Medicine and Epidemiology, School of Veterinary Medicine, University of California–Davis, Davis, CA 95616; e-mail: wdwilson@ucdavis.edu. *Corresponding and presenting author.

1. Introduction

Bacterial infections are common in adult horses and foals and are associated with substantial morbidity and mortality. *Streptococcus equi* subsp. *zooepidemicus* (*S. zooepidemicus*), *S. equi* subsp. *equi* (*S. equi*), *Actinobacillus equuli* (*A. equuli*) and, in some geographic areas, *Corynebacterium pseudotuberculosis* (*C. pseudotuberculosis*), are among the most prevalent and important bacterial pathogens, causing disease in the respiratory tract and other body systems.[1] Potentiated sulfonamides (trimethoprim/sulfonamide combinations) are frequently included in treatment protocols for infections with these and other bacteria because a broad spectrum of pathogens are susceptible to these drugs.[2] Additionally, potentiated sulfonamides are well absorbed following oral administration to both adult horses and foals.[3–7] Of the potentiated sulfonamides, only trimethoprim/sulfadiazine (TMP-SDZ) formulations are currently FDA approved for use in horses; the label indication being treatment of lower respiratory tract infections caused by *S. zooepidemicus*. For many years, TMP-SDZ formulations for oral use were not available in the United States; therefore, practitioners instead used the human-label trimethoprim/sulfamethoxazole (TMP-SMZ) formulations in an extra-label manner, in compliance with the provisions of the Animal Medicinal Drug Use Clarification Act (AMDUCA).[8] Now that several FDA-approved TMP-SDZ products are available, there is minimal justification for use of the human-label TMP-SMZ formulation because such use is rarely justified under the provisions of AMDUCA.

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These include the provision that there is no approved new animal drug that is labeled for such use and that contains the same active ingredient, which is in the required dosage form and concentration, except where a veterinarian finds, within the context of a valid veterinarian-client-patient relationship, that the approved new animal drug is clinically ineffective for its intended use.[8] Two important determinants of clinical efficacy of antibiotics are pharmacokinetics, including bioavailability following administration by routes other than intravenous, and susceptibility of commonly encountered bacteria to the antimicrobial drug or combination in question.[1,9] Several studies have shown that TMP-SDZ is well absorbed after oral administration to horses and has a pharmacokinetic profile that is consistent with efficacy following oral dosing at 12-hour intervals.[4–7,10] To date, there is a paucity of data regarding the comparative *in vitro* susceptibility of *S. zooepidemicus* and other equine-origin bacterial pathogens to TMP-SDZ and TMP-SMZ. The objective of this study was therefore to generate such data for *S. zooepidemicus* and other common equine pathogens.

2. Methods

Antimicrobial susceptibility testing was performed on equine-origin isolates of *S. zooepidemicus* (n = 282), *S. equi* (n = 55), *C. pseudotuberculosis* (n = 96), and *A. equuli* (n = 46). The *Actinobacillus* spp. tested included *A. equuli* subsp. *equuli* (n = 14), *A. equuli* subsp. *hemolyticus* (n = 14), *A. equuli* subsp. *hemolyticus* biovar 1 (n = 14), and *A. equuli* subsp. *hemolyticus* biovar 2 (n = 5). These bacteria had been collected between 1986 and 2016 from adult horses and foals with clinical disease, and had been stored as frozen stabilates at −80°C in skim milk or on glass beads.[a] The identity of each bacterial isolate was confirmed based on colony morphology, Gram-staining characteristics, biochemical characteristics, and results of genetic testing using the matrix-assisted laser desorption ionization–time of flight mass spectrometry system. Susceptibility testing was performed using the broth microdilution procedure[b], following Clinical Laboratory Standards Institute protocols.[11] Briefly, one bacterial colony was inoculated into brain heart infusion broth and incubated for 4 hours at 35°C. A small amount of this inoculated broth was then added to 0.85% NaCl solution to achieve a 0.5 McFarland Standard concentration, as measured using a nephelometer. Ten microliters of this suspension were added to Mueller Hinton broth, and plates[b] were inoculated with 100 μL of the Mueller Hinton broth in each well. The following bacterial strains were run weekly as controls in accordance with the standard quality control procedures in place at the Veterinary Medical Teaching Hospital Microbiology Laboratory (MDL): *Staphylococcus aureus* America Type Culture Collection (*ATCC*) *29213*, *Enterococcus faecalis ATCC 29212*, *E. coli ATCC 25922*, *E. coli ATCC 35218*, and *Pseudomonas aeruginosa ATCC 27853*.

Sensititre™ plates[b] were custom made for the MDL by the manufacturer. The range of TMP-SDZ or TMP-SMZ concentrations tested was 0.12/2.4 μg/mL to 8/152 μg/mL for each antimicrobial combination. The minimum inhibitory concentration (MIC) was recorded as the lowest concentration of antimicrobial drug combination (TMP-SDZ or TMP-SMZ) that inhibited visible growth of bacteria. An isolate was considered to be susceptible to TMP-SDZ or TMP-SMZ if its MIC value was $\leq$ 2/38 μg/mL, as recommended by the Clinical Laboratory Standards Institute.[11] The respective concentrations at which 50% (MIC50) and 90% (MIC90) of isolates of a particular bacterial species were susceptible to TMP-SDZ and TMP-SMZ, were also determined. In order to create numerical data that could be analyzed, only the concentration of TMP in the fixed ratio combination was used. Concentrations that were at or below the lower limit of quantitation of the MIC test (i.e., $\leq$ 0.12 μg/mL) were ascribed a value of 0.12 μg/mL to facilitate statistical analysis using the Wilcoxon signed-rank test for paired data. A P-value of $\leq$ .05 was used to ascribe statistical significance to differences between groups (TMP-SDZ vs TMP-SMZ).

3. Results

Overall Findings

The MIC values for both TMP-SDZ and TMP-SMZ against isolates of *S. zooepidemicus*, *S. equi*, *C. pseudotuberculosis*, and *A. equuli* are shown in Table 1. Of the 479 isolates tested, only 1 (0.21%), a *S. zooepidemicus* isolate, was resistant to TMP-SDZ. The same isolate was also resistant to TMP-SMZ.

S. equi subsp. *zooepidemicus*

Of the 282 *S. zooepidemicus* isolates tested, 281 (99.6%) were susceptible to both TMP-SDZ and TMP-SMZ (MIC $\leq$ 2.0/38 μg/mL), whereas 1 (0.4%) isolate was resistant to both drug combinations (MIC = 8/152 μg/mL). With the exception of the resistant isolate, all *S. zooepidemicus* isolates were highly susceptible, with MIC values ranging between $\leq$0.12/2.4 μg/mL and 1/19 μg/mL for both TMP-SDZ and TMP-SMZ (Table 1). One hundred thirty-four of the 282 *S. zooepidemicus* isolates (47.5%) had an MIC value that was the same for both TMP-SDZ and TMP-SMZ, whereas 148 isolates (52.5%) had an MIC value for TMP-SDZ that was one concentration higher than for TMP-SMZ. In other words, 52.5% of isolates were one dilution less susceptible to TMP-SDZ than to TMP-SMZ. Statistical analysis showed this difference to be highly significant ($P < .0001$). The MIC_{50} values for TMP-SDZ and TMP-SMZ were 0.25/4.75 μg/mL and 0.12/2.4 μg/mL, respectively. The MIC_{90} value for both drug combinations was 0.25/4.75 μg/mL.

S. equi subsp. *equi*

Of the 55 *S. equi* isolates, all (100%) were highly susceptible to both drug combinations (MIC range of

Table 1. MIC Values for TMP-SDZ and TMP-SMZ Against Isolates of *Streptococcus. equi* subsp. *zooepidemicus*, *S. equi* subsp. *equi*, *Corynebacterial pseudotuberculosis* and *Actinobacillus equuli*

		No. of Isolates Susceptible at Each Antimicrobial Dilution (μg/mL)*						
Organism (No. of Isolates)	Antimicrobial*	≤0.12/2.4	0.25/4.75	0.5/9.5	1.0/19	2.0/38	4.0/76	8.0/152
S. zooepidemicus (282)	TMP-SDZ[a]	101	175	4	1			1
	TMP-SMZ[a]	243	37		1			1
S. equi (55)	TMP-SDZ[b]	21	33	1				
	TMP-SMZ[b]	50	5					
C. pseudotuberculosis (96)	TMP-SDZ	95	1					
	TMP-SMZ	95	1					
A. equuli (46)	TMP-SDZ	43	2	1				
	TMP-SMZ	43	2	1				

*Mean MIC values for antimicrobials (TMP-SDZ and TMP-SMZ) identified with the same superscript letter are significantly different from each other ($P < .001$) for the bacterial species included in each row.

≤0.12/2.4 μg/mL to 1/19 μg/mL). For TMP-SDZ, 21 isolates had an MIC of ≤0.12/2.4 μg/mL, 33 had an MIC of 0.25/4.75 μg/mL, and 1 had an MIC of 0.5/9.5 μg/mL (Table 1). For TMP-SMZ, 50 isolates had an MIC of ≤0.12/2.4 μg/mL and 5 had an MIC of 0.25/4.75 μg/mL. Twenty-three (42%) of the 55 *S. equi* isolates had the same MIC for both TMP-SDZ and TMP-SMZ, 33 (60%) had an MIC for TMP-SDZ that was one concentration higher than for TMP-SMZ and 1 (1.8%) had an MIC value for TMP-SMZ that was 1 concentration lower than for TMP-SMZ. Statistical analysis showed MIC values for TMP-SMZ to be significantly lower than those for TMP-SDZ ($P < .0001$). The MIC_{50} and MIC_{90} for TMP-SDZ were both 0.25/4.75 μg/mL, whereas the MIC_{50} and MIC_{90} for TMP-SMZ were both ≤0.12/2.4 μg/mL.

A. equuli

All *A. equuli* isolates were highly susceptible to both TMP-SDZ and TMP-SMZ; MIC values ranged from ≤0.12/2.4 μg/mL to 0.5/9.5 μg/mL for both drug combinations (Table 1). MIC values for TMP-SDZ were identical to those of TMP-SMZ. Forty-four of the 47 isolates (93.6%) had MIC values of ≤0.12/2.4 μg/mL for both drug combinations, 2 isolates (4.3%) had MIC values of 0.25/4.75 μg/mL and 1 isolate (2.1%) had an MIC value. of 0.5/9.5 μg/mL. No significant differences were observed in MIC values between TMP-SDZ and TMP-SMZ.

C. pseudotuberculosis

All isolates of *C. pseudotuberculosis* were highly susceptible to both TMP-SDZ and TMP-SMZ and the two drug combinations showed equal antimicrobial activity (Table 1). The MIC value for 95 of 96 isolates was ≤0.12/2.4 μg/mL for both TMP-SDZ and TMP-SMZ. The remaining isolate had an MIC value of 0.25/4.75 μg/mL for both drug combinations. The MIC_{50} and MIC_{90} values were ≤0.12/2.4 μg/mL for both TMP-SDZ and TMP-SMZ and no significant differences were observed between them.

4. Discussion

The almost universal susceptibility of the commonly encountered equine bacterial pathogens tested in this study to the potentiated sulfonamide antimicrobials attests to their potential utility for treating a range of Gram-positive and Gram-negative bacterial infections in horses. Of the potentiated sulfonamide antimicrobials, only the TMP-SDZ combination is licensed for use in horses; the label indication being treatment of respiratory infection caused by *S. zooepidemicus*. In addition to the favorable pharmacokinetic profile of TMP-SDZ after oral administration to both adult horses and foals, the label indication is supported by the findings of this antimicrobial susceptibility study. Two hundred eighty-one of 282 (99.6%) *S. zooepidemicus* isolates were found to be susceptible to TMP-SDZ (MIC ≤2/38 μg/mL). Of these, 276 (97.2%) were susceptible at concentrations ≤ 0.25/4.75 μg/mL. Although statistical analysis using the Wilcoxon signed-rank test showed that MICs for TMP-SMZ were significantly lower than those for TMP-SDZ against *S. zooepidemicus* and *S. equi*, this difference was typically one dilution and is unlikely to be of clinical significance because the MIC was approximately 10-fold lower than the cut-off for susceptibility (2/38 μg/mL). Additionally, those isolates that had MIC values greater than 0.25/4.75 μg/mL for TMP-SDZ also had higher MIC values for TMP-SMZ. Furthermore, Diagnostic Laboratories rarely include concentrations lower than 0.5/9 μg/mL in quantitative (MIC) susceptibility tests on clinical isolates or use the non-quantitative Kirby-Bauer test. Under these circumstances, reported susceptibility profiles for TMP-SDZ and TMP-SMZ would typically be identical.

The above results do not support the extra-label use of TMP-SMZ in preference to approved formulations of TMP-SDZ; in fact, such use of TMP-SMZ could be interpreted as violating the provisions of the AMDUCA and should be discouraged.

Acknowledgments

Declaration of Ethics

The Authors have adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

This study was funded by Aurora Pharmaceutical, Inc., 1196 Highway 3 South, Northfield, MN 55057. Although the funding source poses a potential conflict of interest, the Authors have no financial interest in Aurora Pharmaceutical, Inc.

References and Footnotes

1. Wilson WD. Rational selection of antimicrobials for use in horses, in *Proceedings*. Am Assoc Equine Pract 2001;47:75–93.
2. Adamson PJ, Wilson WD, Hirsh DC, et al. Susceptibility of equine bacterial isolates to antimicrobial agents. *Am J Vet Res* 1985;46:447–450.
3. O'Fallon ES, McCue PM, Gustafson D. Pharmacokinetics of sulfadiazine and trimethoprim suspension in neonatal foals, in *Proceedings*. Am Assoc Equine Pract 2019;65:518.
4. Gustafsson A, Baverud V, Franklin A, et al. Repeated administration of trimethoprim/sulfadiazine in the horse—Pharmacokinetics, plasma protein binding and influence on the intestinal microflora. *J Vet Pharmacol Ther* 1999;22:20–26.
5. Brown MP, Gronwall R, Castro L. Pharmacokinetics and body fluid and endometrial concentrations of trimethoprim-sulfamethoxazole in mares. *Am J Vet Res* 1988;49:918–922.
6. Sigel CW, Byars TD, Divers TJ, et al. Serum concentrations of trimethoprim and sulfadiazine following oral paste administration to the horse. *Am J Vet Res* 1981;42:2002–2005.
7. Duijkeren EV, Vulto AG, Sloet van Oldruitenborghoosterbaan MM, et al. A comparative study of the pharmacokinetics of intravenous and oral trimethoprim/sulfadiazine formulations in the horse. *J Vet Pharmacol Ther* 1994;17:440–446.
8. FDA. Animal Medicinal Drug Use Clarification Act of 1994 (AMDUCA). *Title 21, Code of Federal Regulations, Part 530 (21 CFR* 530). 1994. Available from: https://www.fda.gov/animal-veterinary/acts-rules-regulations/animal-medicinal-drug-use-clarification-act-1994-amduca.
9. Haggett EF, Wilson WD. Overview of the use of antimicrobials for the treatment of bacterial infections in horses. *Equine Vet Educ* 2008;20:433–448.
10. McClure SR, Koenig R, Hawkins PA. A randomized controlled field trial of a novel trimethoprim-sulfadiazine oral suspension for treatment of *Streptococcus equi* subsp *zooepidemicus* infection of the lower respiratory tract in horses. *J Am Vet Med Assoc* 2015;246:1345–1353.
11. Clinical Laboratory Standards Institute. *Performance standards for antimicrobial disk and dilution susceptibility tests for bacteria isolated from animals VET01S.* 3rd ed. Wayne, PA: Clinical and Laboratory Standards Institute; 2015.

[a]Microbank™, Pro Lab Diagnostics, Inc., Richmond Hill, ON L4B 1K3, Canada.
[b]Sensititre™, Thermo Fisher Scientific, Waltham, MA 02451.

Validation of a Point-of-Care Polymerase Chain Reaction Assay for the Detection of *Streptococcus equi* subspecies *equi* in Nasal Secretions from Horses with Suspected Strangles

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The point-of-care (POC) polymerase chain reaction (PCR) assay obtained acceptable results in terms of sensitivity, specificity, and overall agreement when compared to a quantitative polymerase chain reaction (qPCR) platform for the detection of *Streptococcus equi* ss. *equi* in respiratory secretions from equids. Authors' addresses: Brazos Valley Equine Hospital, 20069 N US 281, Stephenville, TX 76401 (Willis), Department of Medicine and Epidemiology, School of Veterinary Medicine, University of California–Davis, 1 Garrod Drive, Davis, CA 95616 (Barnum, Pusterla); e-mail: atwillisdvmdacvim@gmail.com. *Corresponding author; †presenting author.

1. Introduction

Current diagnostic testing for strangles requires confirmation of *S. equi* detection via conventional bacterial culture and/or polymerase chain reaction (PCR). The latter analytical platform is considered to be the gold standard for detection of the streptococcal organisms. The study aimed at validating a point-of-care (POC) PCR assay for the detection of *Streptococcus equi* subspecies *equi* (*S. equi*) in rostral nasal swabs from horses with suspected acute strangles and to compare the results against the molecular gold standard of quantitative polymerase chain reaction (qPCR).

2. Materials and Methods

Two hundred thirty-two individual swabs collected from the rostral nasal passages were characterized via qPCR as *S. equi* positive, *S. equi* subspecies *zooepidemicus* (*S. zooepidemicus*) positive, and *S. equi* and *S. zooepidemicus* negative by qPCR. The samples were analyzed using the POC PCR according to the manufacturer's recommendations. Further, limit of detection was determined using 10-fold dilutions of a plasmid containing the *S. equi* target sequence (*eqbE* gene).

3. Results and Discussion

The overall agreement between the two PCR platforms was 85.8%. The specificity and sensitivity of the POC PCR assay was 89% and 84%, respectively. The limit of detection of the qPCR assay and the POC PCR analyzer was 3 and 277 *eqbE* target genes of *S. equi*, respectively. Overall agreement and short turnaround time make the POC PCR assay a

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potential molecular diagnostic platform allowing detection of *S. equi*.

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The Authors would like to thank Fluxergy for providing access to PCR readers and providing the test cards to run the POC PCR. None of the authors on this paper have a financial or personal relationship with other people or organizations that could inappropriately influence or bias the content of the paper. The authors would like to thank all equine veterinarians who submitted samples to the laboratory.

Declaration of Ethics

The Authors have adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Authors have no conflicts of interest.

Alterations in the Fecal Microbiome of Horses with Antimicrobial-Associated Diarrhea Compared with Antibiotic-Treated and Non-Treated Healthy Case Controls

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Horses with antimicrobial-associated diarrhea (AAD) have severe alterations of their fecal microbiome compared with control horses and minor changes compared with horses on antibiotics that maintained normal feces. Other factors may contribute to the development of diarrhea. Authors' address: Texas A&M University, College of Veterinary Medicine, College Station, TX 77843; e-mail: carnold@cvm.tamu.edu. *Corresponding and presenting author.

1. Introduction

Horses receiving antimicrobials may develop diarrhea due to changes in the gastrointestinal microbiome. This matched case-controlled study compared the fecal microbiome in hospitalized horses on antibiotics that developed diarrhea (AAD), hospitalized horses on antibiotics that did not develop diarrhea (ABX), and a healthy, non-hospitalized control population (CON).

2. Materials and Methods

Naturally voided fecal samples were collected from AAD horses (n = 17) the day that diarrhea developed and matched to ABX (n = 15) and CON (n = 31) horses for diet, antimicrobial agent, and duration of antimicrobial therapy ($\leq$ 5 days or $>$ 5 days). Illumina sequencing of 16S rRNA genes on fecal DNA was performed. Alpha and beta diversity metrics were generated using QIIME 2.0. A Kruskal-Wallis with Dunn's post-test and analysis of similarities (ANOSIM) testing was used for statistical analysis.

3. Results

Microbiome composition in AAD was significantly different from CON (ANOSIM, R = 0.568, P = .001) and ABX (ANOSIM, R = 0.121, P = .0012). The microbiome of AAD and ABX horses had significantly decreased richness and evenness than CON horses ($P < .05$). Actinobacteria (q = 0.0192) and Bacteroidetes (q = 0.0005) were different between AAD and CON. Verrucomicrobia was markedly decreased in AAD compared to ABX and CON (q = 0.0005).

4. Discussion

Horses with AAD have a dysbiosis compared to CON horses, and show minor differences in bacterial community composition to ABX horses.

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Video Endoscopy at Public Auctions in the United States

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1. Introduction

Endoscopy of the upper airway is an integral part of the examination of racing and prospective racing horses. Since the development of flexible endoscopes, the procedure has become more and more commonplace. Although video endoscopy has been available for decades, portability to make video endoscopy a simple stall-side procedure has only been developed in recent years. This portability makes production of a large number of video-endoscopy studies in a short time frame a much more feasible procedure.

2. Why

During public auction, often, large numbers of buyers are interested in individual horses for purchase. Many of these buyers will have enough interest in an individual horse that they will engage their veterinarian to examine the animal via upper airway endoscopy. It is not uncommon for popular horses to have multiple exams of more than 10 veterinarians performing endoscopic examinations in a single day. As a matter of fact, at some very popular sales, it becomes commonplace.

There are concerns that multiple upper airway examinations on a particular horse could lead to injury or inflammation that may either harm the horse or lead to changes in its airway appearance over a short time frame. Other concerns are based on the thought that many endoscopic procedures under restraint on individual horses represent some level of unnecessary discomfort to the animal.

More than 20 years ago, it was recognized that multiple examinations of horses with radiography during the presale period was cumbersome and difficult to complete for both the veterinarian and the sales consignor. To address this issue, sales repositories were created to house presale radiographs taken by the consignor's veterinarian during the days leading up to the sale.

Although endoscopy of horses is less of a time commitment to the veterinarian, having video-endoscopy studies also placed in the sales repository has advantages. It may reduce the number of exams performed on an individual horse, thus decreasing the amount of stress and discomfort placed on the animal. It will also allow the veterinarian that is employed by a potential buyer to be more time efficient in their workload when they must negotiate multiple exams during a short time period.

3. Current Examples

As of the 2019 US auction season, availability of video-endoscopy studies that have been produced by

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the sales consignor's veterinarians has become more and more commonplace. Many of these have been placed in the sales repository for viewing yet, at the time of this writing, there are very few protocols established as far as requirements or minimum standards for these videos. Also, the major US auction companies have not currently altered their conditions of sale warranties on airways to reflect any relationship to the video-endoscopy exam provided.

Other Thoroughbred sales throughout the world, such as those held in England, Ireland, France[a], Australia, and New Zealand[b] have seen varying acceptance of the use of repository video-endoscopy exams. None of the auction companies in these countries have mandated that video-endoscopy studies be provided for buyers to view.

4. American Association of Equine Practitioners Guidelines

In 2016 a working group of the American Association of Equine Practitioners (AAEP) was established to develop standards and protocols for video endoscopy at sales due to continued interest and discussion by the industry stakeholders. This working group produced the following:

Protocol for Pre-Sale Video-endoscopic Examination of the Upper Airway at Public Auction (2016)[c]

- Equipment must be capable of producing a digital video image of excellent quality.
- Horse must be identified appropriately, and that identification must be in digital format with character generation on the screen, and/or video of the catalog page, followed by unbroken video of the face prior to introduction of the scope into the nares (right or left) and up to the larynx. This is a single-stream video with no editing. The veterinarian performing the video, or the consignor will submit each upper-airway video on an individual flash drive or CD. Upper airway videos should be stored in a file separate from the radiographs in the repository in case of client request for one or the other.
- Standard technique must include maximum abduction of the arytenoids induced by swallowing (multiple times) and nasal occlusion. The duration of the video must be sufficient to identify all laryngeal and pharyngeal structures as well as observing their maximal function within the context of a resting exam.
- The interval between the pre-sale video-endoscopic exam and the selling session will not exceed 10 days.

5. Equipment

As mentioned before, recent developments in video-endoscopy equipment has allowed more portability and thus ease of use to make production of quality endoscopy studies more common. It is no longer required to transport large-tower video-endoscopy units to the horse or to transport the horse to a facility with such equipment to create a good study. There are currently several portable units on the market. These units vary from video camera–equipped fiberoptic endoscopes to digital scopes with video viewing attached or with Wi-Fi or Bluetooth wireless connectivity. Several of these units have simple character generation capability and some even have the capability to read the subject horse's identifying microchip and add that information to the video produced.

6. Procedure

Producing the video requires one to approach the procedure in a standardized fashion so that each video created is similar in basic format. Although it may be required from time to time, tranquilization should not be a standard procedure as it may affect function of the airway to some degree. Most horses tolerate the procedure well under traditional methods of restraint and will not need tranquilization.

As discussed in the AAEP-approved protocol above, the exam requires either character generation that identifies the horse embedded in the video produced and/or the visualization of the horse's catalog page and the horse's face in one continuous video stream as one introduces the scope into the nares. The author suggests doing both so that there is little question as to the identity of the horse being examined.

It is important that when doing the exam, that one is conscious to not only visualize all important pharyngeal and laryngeal structures but to also be aware that frequent movement of the scope within the upper airway can make the video hard to watch.

Nearly all exams will be done visualizing only one nasal passage as it is somewhat rare in horses at a sale to be concerned about issues with the structures within that part of the airway. Once in the pharynx, it is important to view the guttural pouch openings and the pharyngeal recess as well as directing downward to visualize the larynx and soft palate. Fields of view among video endoscopes vary and although many scopes will have a large enough field of view to see the entire pharynx/larynx without moving, others will have to be repositioned to see all structures.

The examination of upper airways at sales is mostly concerned with laryngeal structure and function, epiglottis structure and soft palate dynamics. These structures and functions must be viewed on the video in sufficient fashion as to give the viewer an adequate idea that they would feel as comfortable viewing the video as they would if they performed the examination themselves. This requires the veterinarian creating the video to take appropriate time to adequately view all structures, make the horse swallow multiple times and also to occlude the horse's nares to make the horse take several deep breaths to exhibit its maximal arytenoid movement.

It is understood by most that even an excellent video may not be satisfactory to all that would view them due to multiple issues. Some veterinarians may not be satisfied with the length of the exam or timeliness of the procedure related to the actual time of the sale. There also may be concerns by some examining veterinarians that sales conditions do not adequately protect the buyer from a changing airway due to conditions of inflammation from the time of the initial exam to the time of the actual sale of the horse. But a well-produced video that is representative of the horse at the time the exam is performed will likely reduce the number of examinations needing to be performed on the individual sale horse.

7. Sales Conditions

At the time of this writing, none of the major sales companies in the US have addressed any conditions of sale that would be affected by the placement of video-endoscopy studies that are placed in the repository.

Acknowledgments

Declaration of Ethics

The Author has adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Author has no conflicts of interest.

Footnotes

[a]Berk JT. Lexington, KY (personal communication) 2020.
[b]Hance S. Oklahoma City, OK (personal communication) 2020.
[c]AAEP Position Statements (2016).

Endoscopic Evaluation of Nasal Discharge

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1. Introduction

Nasal discharge can represent something benign, life threatening, or anything in between. For these reasons, the examiner should have an idea of what could be causing the discharge based on the history and clinical signs so they are sure to look thoroughly in the correct area during an endoscopic examination. Most cases of nasal discharge will be unilateral and the examiner can focus on one side. However, it is always important to evaluate both sides, preferably the "normal side" first to see what normal is for this particular horse and to see if there are any abnormalities that are not yet clinically evident.

The source of any nasal discharge can usually be determined by a comprehensive upper airway endoscopy. Split the examination into the main compartments: guttural pouch, pharynx, sinus cavities, and nasal passage. Discharge emanating from the caudal aspect of the middle meatus is almost always the result of fluid exiting the sinus cavity through the nasomaxillary opening and is indicative of either a primary or secondary sinusitis. Infrequently, the disease process drains into the nasal cavity further rostrally, and the origin of the discharge can only be seen if the endoscope is passed down the entire middle meatus. For this reason, the endoscope should be passed through the ventral meatus and not just look at the caudal aspect of the nasal passage. Unlike the nasomaxillary opening, any discharge at the opening of the guttural pouch can be draining from the pouch or can be the result of discharge within the pharynx being pushed into the opening during swallowing and may not represent a guttural pouch problem. Therefore, evidence of discharge at the guttural pouch opening is not always because of the material coming from the guttural pouch.

Nasal discharge is typically not an emergency, but any horse with nasal hemorrhage more than a trickle should be evaluated immediately. Although bilateral epistaxis is most commonly from exercise-induced pulmonary hemorrhage, is not a large volume, and is not life threatening, a moderate to severe bleed not associated with extreme exercise can be secondary to guttural pouch mycosis, could be from one or both nares, and could be life threatening. If a large clot or volume of blood is evident on endoscopic examination at the guttural pouch opening, no further evidence is needed prior to referral for surgery. Trying to endoscopically evaluate the inside of the guttural pouch close to the time of a severe bleed is usually futile because the amount of blood within the pouch will obscure visualization and attempting this may only make matters worse.

Other causes of epistaxis to consider are trauma, neoplasia, fungal infections, retropharyngeal ab-

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scess rupture into the guttural pouch, or ethmoid hematomas.[1] All of these conditions typically cause a much lower blood volume relative to guttural pouch mycosis. Blood emanating from the nasomaxillary opening can also be the result of traumatic bleeding into the sinus without external evidence of trauma. Neoplasia or fungal infection that cause epistaxis is usually seen easily on endoscopic examination, and blood is often mixed with purulent discharge. These conditions may only show evidence of discharge at the nasomaxillary opening, from the region of the ethmoid recess, or other locations along the nasal cavity. Fungal infections are most commonly found along the dorsal and rostral margins of the septum.

Purulent discharge usually represents a response to bacterial infection of the guttural pouch or sinus cavities.[1] Complete examination of the ventral and middle meatus is recommended because a separate opening into the nasal cavity may be infrequently present or the material becomes so inspissated that it becomes contained entirely within the middle meatus. Primary bacterial infections of the sinus without an underlying cause are common. Culture from the nasal passage with a swab is not usually rewarding, but a promising technique has been described to culture directly from the nasomaxillary opening and can provide some support for primary vs. secondary sinusitis.[2]

Uncommonly, sinusitis can also become severe enough to cause nasal obstruction and/or facial deformity, but more commonly these distortions are associated with a neoplastic or cystic mass. Ethmoid hematomas can also cause some nasal obstruction but rarely cause facial deformity and will produce small-volume epistaxis, not purulent discharge. Cysts usually cause facial or nasal deformity and typically do not cause any nasal discharge unless a secondary sinusitis occurs. Differentiating the cause of the symptoms is important prior to any decisions about treatment because most neoplastic diseases have a poor prognosis. Signalment, history, and diagnostic imaging should provide enough information for the clinician to differentiate the etiology of the disease.

2. Endoscopic Evaluation of the Sinus

When there is a clear indication of sinus disease via nasal endoscopic evaluation, further imaging (computed tomography or radiographs) can provide more information about the possible etiology. Yet, there is still limited information from those diagnostic techniques, and endoscopic examination of the sinus can provide more information and a possible method of treatment.[3] There are several descriptions of sinoscopic approaches. A frontal 22-mm trephination is preferred. Familiarity with normal anatomy is essential. This approach will allow access to the major sinus cavities and allow the treatment of many abnormalities with minimal surgical trauma to normal structures. Although the approach provides direct access to the frontal, dorsal conchal, and caudal maxillary, breaking down the ventral conchal bulla will allow access to the ventral conchal sinus and rostral maxillary sinus.[3]

Acknowledgments

Declaration of Ethics

The Author has adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Author has no conflicts of interest.

References

1. Dixon PM, Parkin TD, Collins N, et al. Historical and clinical features of 200 cases of equine sinus disease. *Vet Rec* 2011; 169:439.
2. Gergeleit H, Verspohl J, Rohde J, et al. A prospective study on the microbiological examination of secretions from the paranasal sinuses in horses in health and disease. *Acta Vet Scand* 2018;60:43.
3. Perkins JD, Windley Z, Dixon PM, et al. Sinoscopic treatment of rostral maxillary and ventral conchal sinusitis in 60 horses. *Vet Surg* 2009;38:613–619.

New Concepts in the Management of Epiglottic Entrapment

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1. Introduction

Epiglottic entrapment is often associated with younger racehorses and can be associated with exercise intolerance, respiratory noise, and coughing, but can also be observed in non-racehorses and may be intermittent initially.[1–4] Acute or simple entrapments consist of a thin portion of the subepiglottic membrane engulfing the epiglottic cartilage and in itself is unlikely to cause respiratory obstruction,[5] but may precipitate dorsal displacement of the soft palate.[6] Other commonly recognized features of an epiglottic entrapment may include thickening and/or ulceration of the entrapping membranes, as well as deformation of the epiglottic cartilage particularly in chronic entrapments. The "outline" of the epiglottis underneath the entrapping membrane can provide some indication the degree of pathology and the prognosis.[7]

Many approaches have been described for surgical correction of epiglottic entrapment.[7–15] Axial division of the entrapping fold is a commonly utilized technique and several methods to perform axial division have been described. Axial division is usually completed under endoscopic guidance and may be performed completely via the endoscope using a laser through the endoscopic biopsy channel, or may be performed using a bistoury knife passed alongside the endoscope (Fig. 1). Common approaches include transnasally or transorally and division may be accomplished either with the horse standing using sedation and local anesthetic or with the patient under general anesthesia. The presence of a thickened or ulcerated entrapping membrane may necessitate alternative methods such as the resection of tissue through similar surgical approaches or through a laryngotomy (Fig. 2). In general, it appears that horses that undergo resection to resolve the entrapment will not have as good a prognosis.[7,11] For this reason efforts should be made to resect tissue only when necessary.

To perform a standing transendoscopic axial division, horses should be moderately sedated and the throat blocked topically. If the horse is heavily sedated, they will not swallow at all during the procedure. Having them infrequently swallow is advantageous because it creates the normal tension on the membranes. With a laser setting of 18W, a bare laser fiber is dragged in contact fashion from the central caudal edge of the entrapping membrane toward the rostral tip of the epiglottis to cut the entrapping membrane. If the membrane over the dorsal surface of the epiglottis is not under sufficient tension such that each cut leads to a greater separation of tissues, the laser fiber is used to perform

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Fig. 1. A simple epiglottic entrapment that should be amenable to axial division.

similar cuts to the membrane on the ventral surface of the epiglottis. This often results in a resumption of greater tension on the membranes over the dorsal surface and the further cuts are dictated by areas of greatest tension until complete division of the membranes allowed visualization of the dorsal surface of the epiglottis and reduction of the membranes to a position ventral to the epiglottis. Swallowing is stimulated to ensure the membranes will not reentrap over the epiglottis. Resection of any membrane is performed when tissue is judged to be excessively thick or fibrous, such that the tissue will not reduce into a position ventral to the epiglottic edge after initial axial division. If resection of the tissue is performed, a transesophageal grasping forceps[a] is passed up the contralateral nostril and as small a margin of the membrane as possible is grasped and resected until complete exposure of the dorsal and lateral margins of the epiglottis.

Fig. 2. An epiglottic entrapment with severe ulceration that will likely require some degree of membrane resection to resolve the entrapment.

Alternatively, a hook can be used to keep the membrane dorsal to the epiglottis off the epiglottis and under tension. The tissue just over the hook is transected. Postoperative recommendations are for 3 weeks of stall rest and hand walking, prior to re-evaluation and likely return to training with simple entrapments. Several more weeks of rest are recommended for most horses that required resection of any membrane. Follow-up endoscopic examinations to particularly evaluate the ventral surface of the epiglottis are recommended for any horses that require resection of any membrane to better determine time to resume training.

Acknowledgments

Declaration of Ethics

The Author has adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Author has no conflicts of interest.

References and Footnote

1. Lumsden JM, Stick JA, Caron JP, et al. Surgical treatment for epiglottic entrapment in horses: 51 cases (1981–1992). *J Am Vet Med Assoc* 1994;205(5):729–35, Sep 1.
2. Aitken MR, Parente EJ. Epiglottic abnormalities in mature nonracehorses: 23 cases (1990–2009). *J Am Vet Med Assoc* 2011;238:1634–1638.
3. Tan RH, Dowling BA, Dart AJ. High-speed treadmill videoendoscopic examination of the upper respiratory tract in the horse: The results of 291 clinical cases. *Vet J* 2005;170:243–248.
4. Brown JA, Hinchcliff KW, Jackson MA, et al. Prevalence of pharyngeal and laryngeal abnormalities in Thoroughbreds racing in Australia, and their association with performance. *Equine Vet J* 2005;37:397–401.
5. Williams JW, Meagher DM, Pascoe JR, et al. Upper airway function during maximal exercise in horses with obstructive upper airway lesions. Effect of surgical treatment. *Vet Surg* 1990;19:142–147.
6. Parente EJ, Martin BB, Tulleners EP, et al. Dorsal displacement of the soft palate in 92 horses during high-speed treadmill examination (199–1998). *Vet Surg* 2002;31:507–512.
7. Kieffer PJ, Aceto H, Stefanovski D, et al. Using quarterly earnings to assess racing performance in 66 Thoroughbreds after transendoscopic laser surgery for treatment of epiglottic entrapment. *Vet Surg* 2018;47:605–613.
8. Greet TR. Experiences in treatment of epiglottal entrapment using a hook knife per nasum. *Equine Vet J* 1995;27:122–126.
9. Ross MW, Gentile DG, Evans LE. Transoral axial division, under endoscopic guidance, for correction of epiglottic entrapment in horses. *J Am Vet Med Assoc* 1993;203:416–420.
10. Tulleners EP. Transendoscopic contact neodymium:yttrium aluminum garnet laser correction of epiglottic entrapment in standing horses. *Vet Surg* 1990;19:181–190.
11. Beste KJ, Ortved KF, Rossignol F. Transendoscopic correction of epiglottic entrapment with a silicone-covered laser guide and diode laser in 29 horses. *Vet Surg* 2020;49:131–137.
12. Honnas CM, Wheat JD. Epiglottic entrapment. A transnasal surgical approach to divide the aryepiglottic fold axially in the standing horse. *Vet Surg* 1988;17:246–251.

13. Perkins JD, Hughes TK, Brain B. Endoscope-guided, transoral axial division of an entrapping epiglottic fold in fifteen standing horses. *Vet Surg* 2007;36:800–803.
14. Lacourt M, Marcoux M. Treatment of epiglottic entrapment by transnasal axial division in standing sedated horses using a shielded hook bistoury. *Vet Surg* 2011;40:299–304.
15. Coleridge MO, DiGiovanni DL, Rodgerson DH, et al. Endoscopic, transoral, reduction of epiglottic entrapment via wire snare technique. *Vet Surg* 2015;44:348–351.

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Clinical Indications for a Tie-Back Surgery

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1. Introduction

In general, a tie-back surgery is indicated when the arytenoid cartilage collapses into the airway during exercise causing airflow obstruction, which usually produces upper airway (UA) noise and usually adversely affects performance. However, the need to perform a tie-back procedure depends on the use or intended use of the horse. It is well known that recurrent laryngeal neuropathy (RLN) clinically affects the left arytenoid cartilage. The exact etiology of the distal axonopathy of the recurrent laryngeal nerve is not known, but this causes atrophy of the cricoarytenoideus dorsalis muscle, adversely affecting abduction of the arytenoid cartilage. Incomplete abduction of the right arytenoid cartilage is generally due to laryngeal dysplasia, arytenoid chondritis, or right recurrent laryngeal nerve trauma. These conditions can also affect the left arytenoid cartilage, but are infrequent causes of inadequate abduction compared to RLN.

Horses that cannot fully abduct the arytenoid cartilage during a resting exam do not all need a tie-back procedure. There are several factors that need to be considered when determining what recommendations to make, with cost of the procedure being a consistent factor. Most of the other factors are as follows:

What is the history and/or presenting complaint? Is UA noise the primary problem? If so, this can often be significantly improved with a bilateral ventriculocordectomy (VCE). It is important to recognize this procedure is not always effective. Is performance the primary problem? In the racehorse, evaluation of the race record is helpful. If so, a tie-back procedure and usually a left VCE are indicated. Is this an incidental problem found on a pre-sale exam? If so, recommendations should be made based on the intended use of the horse.

What is the intended use of the horse? Is this a Thoroughbred (TB) racehorse, an eventer, jumper, dressage horse, show horse, draft horse, Western performance horse, pleasure horse, etc.? The tie-back procedure is needed more for horses that perform using strenuous physical exertion for extended periods. For example, an accomplished event horse is more likely to benefit from a tie-back than a show hunter. However, if exercise intolerance from RLN is a problem for a horse regardless of discipline, a tie-back would likely be beneficial. It should be noted that, although not commonly used, a nerve transplant surgery may be of benefit in a sport horse with an anticipated long career.[1]

What is the age of the horse? Generally, in the author's opinion and that of others, tie-back procedures should not be performed prior to about 24 months of age, as the cartilage does not hold the suture as well in an immature horse. Also, in the author's opinion, left arytenoid paresis in the immature TB (long yearling) may best be approached with a nerve transplant surgery.[1] It often takes >6 months to see the results of the nerve transplant surgery and during this period it is usually too early to perform a tie-back procedure.

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2. What Do the Diagnostic Tests Show?

Physical Exam

During the physical exam, are there abnormalities other than arytenoid paralysis that could adversely affect performance of the horse, e.g., sinusitis, Horners syndrome, laryngeal dysplasia, etc.? Does the larynx palpate like arytenoid paralysis or laryngeal dysplasia? With laryngeal dysplasia, a gap can usually be palpated between the cricoid and thyroid cartilages on the affected side.

UA Endoscopic Exam at Rest

During the endoscopic exam, are any abnormalities noted other than abnormal arytenoid cartilage movement? What is the arytenoid movement grade at rest (nasal occlusion being part of this exam)? In competition horses, grade IV and most grade III arytenoids will collapse during exercise and need a tie-back procedure.[2] Does the arytenoid cartilage appear slightly thickened (chondritis) or slightly malformed (laryngeal dysplasia)? These conditions can look similar to left arytenoid paresis.

Laryngeal Ultrasound Exam

The laryngeal ultrasound exam is a very helpful tool for examining the UA.[3] Are the left cricoarytenoid lateralis and vocalis muscles hyperechoic when compared to the right? This is a very reliable ultrasonographic finding in support of RLN. Is the left cricoarytenoid dorsalis muscle smaller than the right? This is also proving to be a useful ultrasonographic finding supporting RLN.[4] Is the arytenoid cartilage of abnormal size and shape? With chondritis the arytenoid is usually thickened. Is there evidence of laryngeal dysplasia? The hallmarks of this abnormality are lack of the cricothyroid joint and a thyroid cartilage that extends further dorsal than the muscular process of the arytenoid cartilage. The ultrasound exam findings regarding changes to the laryngeal musculature are not consistent in long yearlings and very early in the development of RLN.

UA Endoscopic Exam During Exercise

This exam is now usually done with remote overground endoscopy rather than on the treadmill and remains the gold standard for evaluation of arytenoid cartilage function. Does the arytenoid cartilage collapse during strenuous exercise? Do any other tissues collapse into the airway? Do both arytenoid cartilages collapse when the head is flexed (dynamic laryngeal collapse)? The latter condition is more commonly seen in Norwegian Cold-Blooded Trotters, Saddlebreds, and Hackney ponies.

3. Does the Client Understand the Possible Complications Following a Tie-Back Procedure?

Inadequate Abduction (Failed Tie-Back)

A failed tie-back is not uncommon. This is generally the result of the sutures cutting into the cartilage. This may require another tie-back procedure, which is generally more effective than approaching this with an arytenoidectomy.

Aspiration and Coughing

Aspiration and coughing is not common. This is generally a result of an adverse affect on swallowing mechanics, with ingesta gaining access to the airway. This can be, but is not always associated with excessive abduction.

Surgical Site Infection

Surgical site infection is not common. This is usually associated initially with a postop seroma. Generally easy to resolve if promptly addressed.

Suture Penetrating into the Airway Lumen

A suture penetrating into the airway lumen is very uncommon. This should be noticed during surgical placement of the sutures using intraop endoscopy.

Chondritis

Chrondritis is very uncommon.

4. Conclusions

In summary, assuming the diagnosis of RLN is accurate, in horses where the problem is performance limiting or will be performance limiting (e.g., 2-year-old TB racehorse), a tie-back procedure should be considered. In horses where UA noise is the primary problem, a bilateral VCE may be adequate to resolve the noise.

Acknowledgments

Declaration of Ethics

The Author has adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Author has no conflicts of interest.

References

1. Rossignol F, Brandenberger O, Perkins JD, et al. Modified first or second cervical nerve transplantation technique for the treatment of recurrent laryngeal neuropathy in horses. *Equine Vet J* 2018;50:457–464.
2. Rakestraw PC, Hackett RP, Ducharme NG, et al. A comparison of arytenoid cartilage movement in resting and exercising horses. *Vet Surg* 1991;20:122–127.
3. Garrett KS, Woodie JB, Embertson RM. Association of treadmill upper airway endoscopic evaluation with results of ultrasonography and resting upper airway endoscopic evaluation. *Equine Vet J* 2011;53:365–371.
4. Satoh M, Higuchi T, Inoue S, et al. External transcutaneous ultrasound technique in the equine cricoarytenoideus dorsalis muscle: Assessment of muscle size and echogenicity with resting endoscopy. *Equine Vet J* 2019, https://doi.org/10.1111/evj.13209.

Varied Presentations of Arytenoid Chondropathy

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1. Introduction

For the purposes of this presentation, arytenoid chondropathy refers to any disease affecting the structure of the cartilage or the mucosal covering. The varied presentations in general include ulcers, granulomas, chondromas, and chondritis (active and inactive). Ulcers are areas of mucosal loss over the cartilage. Granulomas refer to granulation type tissue protruding into the lumen of the larynx from the cartilage surface. Chondromas refer to cartilage masses protruding into the lumen of the larynx from the cartilage surface that are covered by mucosa. Chondritis refers to thickened cartilage, which can be active and inflamed, or inactive and quiet.

The disease is usually unilateral, affecting the left or right side, but can be bilateral. The cause of these abnormalities is likely the result of inflammation. The cause of the inflammation is likely related to infection. More than likely the mucosal integrity has been compromised, allowing bacteria to gain access to the submucosal tissue and cartilage.

2. Clinical Signs

The most common clinical sign seen with arytenoid chondritis, granulomas, or chondromas is upper airway (UA) noise. Mucosal ulcers or small granulomas may be found in yearlings on a presale exam that make no noticeable UA noise.[1] Arytenoid chondritis is noticed in athletes early in the course of the disease as small changes in the larynx create airflow turbulence and UA noise. Chondritis in broodmares and pleasure horses is generally not noticed until the arytenoid is large enough to create UA noise at a walk or trot. Broodmares that are affected are often in respiratory distress when first noticed.

3. Diagnostics

Arytenoid cartilage structural abnormalities are generally easily diagnosed during an endoscopic exam of the UA. However, some abnormalities can be subtle, e.g., slight thickening of an arytenoid cartilage may mimic an arytenoid with grade III movement. An ultrasound exam can be very useful diagnostically.[2] The size and thickness of the arytenoid can be evaluated. Abnormal echogenicity of the cartilage and/or tissues around it can be noted, including the status of the laryngeal musculature.

4. Mucosal Ulcers

Mucosal ulcers are infrequently found, usually just dorsal to the area of the vocal process of the arytenoid. These presumably form from excessive contact between the left and right arytenoids, possibly also related to concurrent UA inflammation. They are more commonly found in athletes, but have been

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found in Thoroughbred sales yearlings. The ulcers generally respond to decreased exercise, anti-inflammatory medication, and antibiotics.

5. Granulomas

Granulomas of varying size can protrude into the laryngeal lumen. The base of the granuloma usually starts at the cartilage surface and many actually form around an entrance to a tract that continues into the arytenoid cartilage. These usually can be resected endoscopically with a diode laser or laryngeal scissors, or can be approached through a laryngotomy. It is difficult to predict which granulomas will reform, which is not unusual.

6. Chondromas

Chondromas are generally mucosal covered inactive cartilage masses that protrude into the lumen of the larynx. The adjacent body of the arytenoid cartilage is often mildly thickened. If the arytenoid can abduct reasonably well, these masses are best left alone.

7. Chondritis

The arytenoid can vary greatly in thickness. As mentioned above, a slightly thickened arytenoid may look like a grade III arytenoid. An ultrasound exam helps make an accurate diagnosis in these cases. An endoscopic exam during exercise in questionable cases may also be helpful to determine the appropriate treatment. Most arytenoid chondritis cases are obvious during an endoscopic exam. Acute cases show active inflammation with reddening and swelling of the laryngeal tissues. The inflammation also affects the surrounding tissues. Initially these horses should be treated aggressively medically to reduce the size of the inflamed tissues. Treatment should include systemic antibiotics, non-steroidal anti-inflammatory drugs, and steroids. Nebulizing the UA ± a throat spray is helpful. Once the arytenoid cartilage becomes thickened, it is very difficult to significantly reduce the size of the cartilage. As the cartilage itself becomes thickened, the cartilaginous tissue separates and the center fills with fibrous tissue. The fibrous tissue core does not reduce in size. Thus, the cartilage remains enlarged.

The recommended treatment for horses with a clinically significant enlarged arytenoid cartilage is arytenoidectomy. Many athletes can still perform following this procedure.[3,4] However, very few can reach the level of performance that they had previously achieved. For bilaterally affected horses, e.g., broodmares, removal of the largest arytenoid cartilage or a permanent tracheotomy is beneficial.

Acknowledgments

Declaration of Ethics

The Author has adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Author has no conflicts of interest.

References

1. Kelly G, Lumsden JM, Dunkerly G, et al. Idiopathic mucosal lesions of the arytenoid cartilages of 21 Thoroughbred yearlings: 1997–2001. *Equine Vet J* 2003;35:276–281.
2. Garrett KG, Embertson RM, Woodie JB, et al. Ultrasound features of arytenoid chondritis in Thoroughbred horses. *Equine Vet J* 2013;45:598–603.
3. Barnes AJ, Slone DE, Lynch TM. Performance after partial arytenoidectomy without mucosal closure in 27 Thoroughbred racehorses. *Vet Surg* 2004;33:398–403.
4. Parente EJ, Tulleners EP, Southwood LL. Long-term study of partial arytenoidectomy with primary mucosal closure in 76 Thoroughbred racehorses (1992–2006). *Equine Vet J* 2008;40:214–218.

Right-Sided Abnormalities in Laryngeal Function

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1. Introduction

Abnormalities in right-sided laryngeal function in horses are seen infrequently. There are 3 causes of loss of right-sided function: 1) right-sided laryngeal hemiplegia, 2) arytenoid chondropathy, and 3) fourth branchial arch defects (4-BAD).

2. Right-Sided Laryngeal Hemiplegia

Damage to the right recurrent laryngeal nerve and subsequent partial or complete loss of right-sided arytenoid function is rare and nearly always associated with some sort of trauma to the nerve. Right-sided idiopathic laryngeal hemiplegia (ILH), similar to far more common left-sided ILH, probably does not occur. The most common recognized causes of right-sided laryngeal hemiplegia (LH) are perivascular injections, leaking or malpositioned IV catheters, direct blunt or penetrating trauma to the neck, or infectious processes resulting in abscessation in the laryngeal or perilaryngeal regions (e.g., strangles, cellulitis in the neck). In many cases it is possible to elucidate a history of previous right jugular venipuncture or catheterization or there may be an obvious thrombophlebitis present on physical examination. Occasionally there will also be damage to the adjacent vagosympathetic trunk resulting in signs of Horner's Syndrome.

The endoscopic findings will be identical to the typical findings seen with left-sided ILH and they are graded in the same manner. There should also be obvious (by either laryngeal palpation or laryngeal ultrasound) atrophy of the cricoarytenoideus dorsalis (CAD) and cricoarytenoideus lateralis (CAL) muscles (Fig. 1). The treatment options are conservative (anti-inflammatory therapy including NSAIDs and steroids) in acute cases and surgical (right-sided laryngoplasty) in chronic cases. The prognosis for return to athletic function should be similar to the prognosis for left-sided ILH as long as adequate and long-lasting abduction of the right arytenoid is achieved.

3. Arytenoid Chondropathy

Loss of right-sided function in cases of arytenoid chondropathy is due to a mechanical inability of the affected arytenoid to abduct because the enlarged arytenoid impinges on the adjacent thyroid cartilage. The degree of loss of function is directly related to the amount and direction of arytenoid body enlargement and can vary from no loss of function to complete inability to abduct the arytenoid and potentially even further loss of the laryngeal lumen by luminal enlargement of the arytenoid.

The endoscopic findings are well recognized and are characterized by one or more of the following: 1) misshapen, "S" shaped, or enlarged corniculate process, 2) axial projections of granulation tissue or thickened epithelialized arytenoid cartilage into the

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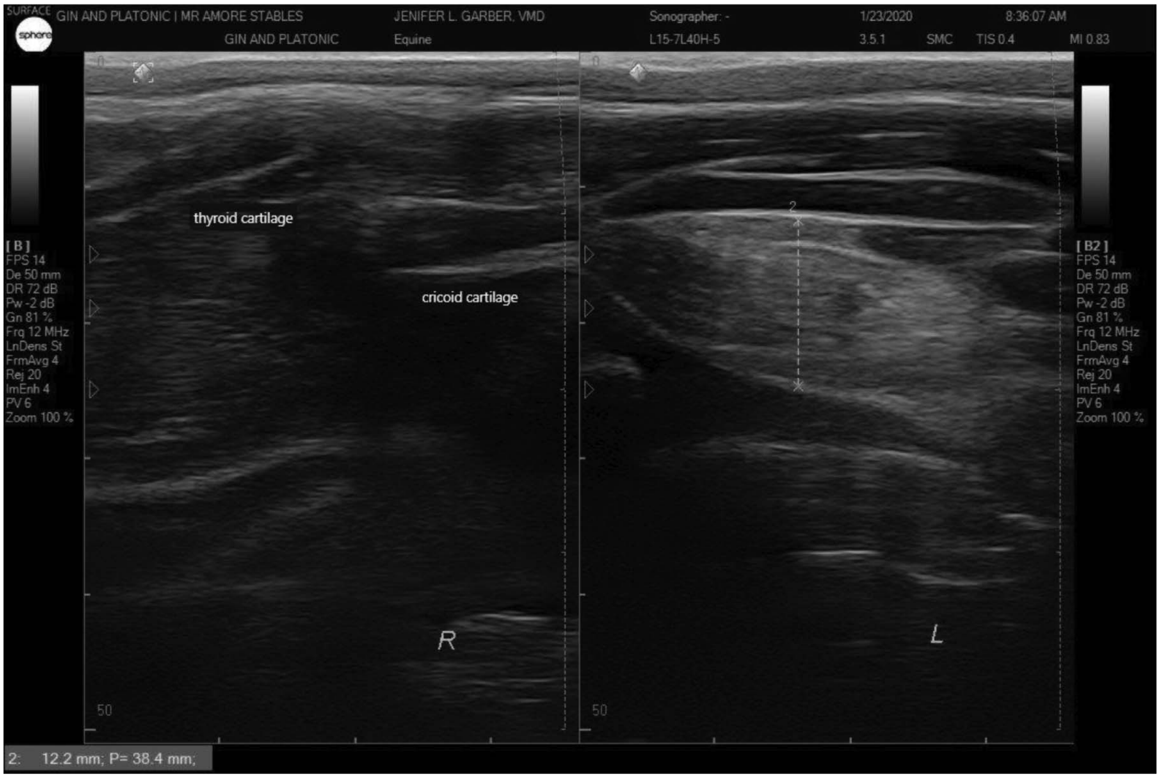

Fig. 1. The right cricoid and thyroid cartilages do not articulate in this ultrasound image. Image courtesy of Dr. Jenifer Garber.

laryngeal lumen, or 3) unilateral rostral displacement of the palatopharyngeal arch. It is important to recognize that there should be no CAD muscle atrophy detected on laryngeal palpation (or CAL atrophy on ultrasound exam), emphasizing the usefulness of learning one or both techniques in evaluating any laryngeal function abnormality (Fig. 2).

The treatment options depend to some degree on the chronicity of the problem and the degree of loss of function. Acute chondropathies with associated laryngeal edema should always be treated medically (antibiotics, topical and systemic steroids, and NSAIDs), regardless of the degree of function loss. In some cases, complete function may return once the edema has resolved. In more chronic cases with only slight loss of function, medical therapy or medical therapy in association with laser removal of axial luminal granulation tissue and cauterization of draining tracts is indicated. Once chronic arytenoid enlargement has caused a significant loss in function, the only option is a partial arytenoidectomy. It is important to recognize that a tie-back procedure will not work in these cases because the laryngoplasty sutures will not be able to abduct the arytenoid any further than the normal CAD muscle is able to abduct it due to the mechanical impingement of the enlarged arytenoid on the lamina of the thyroid cartilage.

4. Fourth Branchial Arch Defects

Fourth branchial arch defects (4-BADs) are seen frequently enough as a cause of upper airway problems that they must be in the differential diagnosis for any loss of arytenoid function with normal endoscopic anatomy (e.g., no arytenoid enlargement). In fact, a 4-BAD should be the primary differential in right-sided function abnormalities until proven otherwise. The distribution of 4-BADs is 65% right sided, 10% left sided, and 25% bilateral.[1]

The embryonic fourth branchial arches are responsible for the formation of the wings of the thyroid cartilages, the cricothyroid articulations, the cricothyroid muscles, and the cricopharyngeus and thyropharyngeus muscles (upper esophageal sphincter). The primary clinical signs are variable degrees of exercise intolerance and upper airway noise. The degree of exercise intolerance with the condition is extremely variable with some horses unable to perform even low-level athletic activity whereas others are able to race successfully. Less common clinical signs are chronic colic and dysphagia related to the abnormal upper esophageal sphincter. In cases of 4-BAD the CAD muscle is normal but the arytenoid does not abduct due to either a mechanical impingement of the arytenoid on a thyroid lamina that extends dorsal to the muscular process or, perhaps more likely, an abnormal course of the CAD muscle due to rotation of the cricoid cartilage and loss of the caudal cornu of the thyroid cartilage on the affected side resulting in the larynx forming an incomplete "box" with one side of the box unable to support the contraction of the CAD muscle.

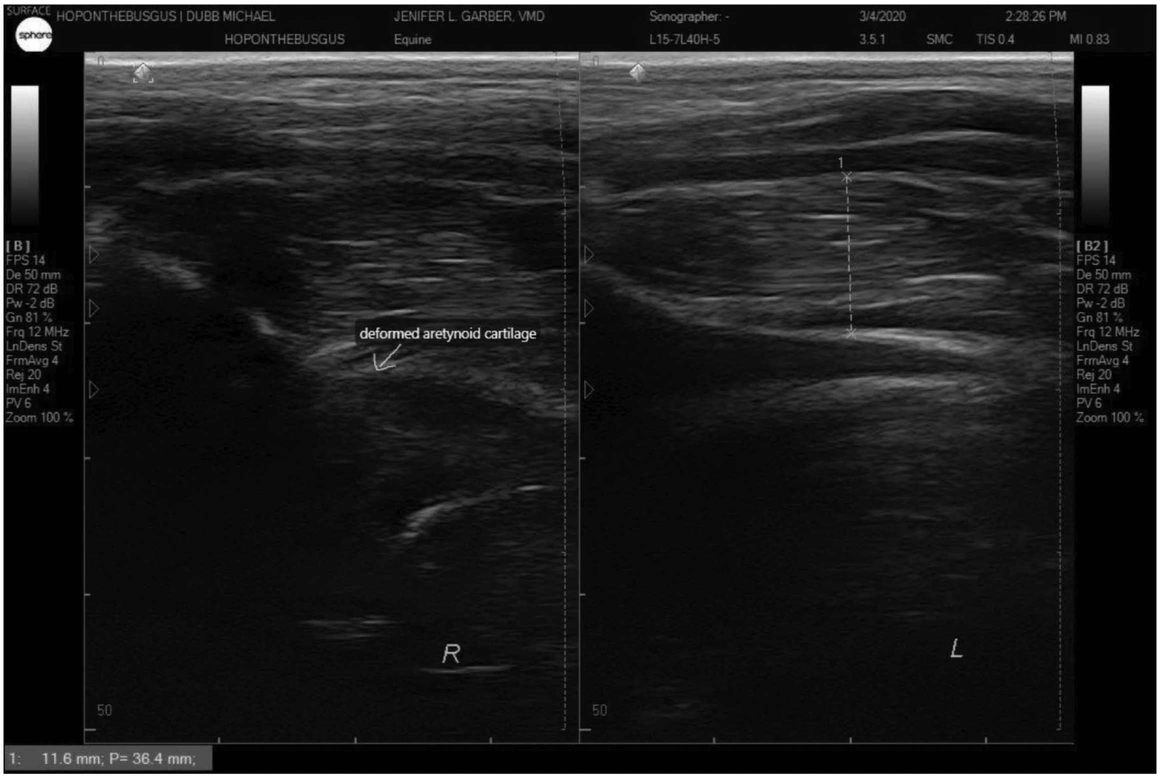

Fig. 2. This ultrasound image shows enlargement of the right arytenoid cartilage. Image courtesy of Dr. Jenifer Garber.

The endoscopic findings in unilateral cases of 4-BAD can look exactly like cases of laryngeal hemiplegia. There is usually some loss of function on the affected side with otherwise-normal endoscopic anatomy. In bilateral 4-BAD cases there is often rostral displacement of the palatopharyngeal arch (so-called Pope's cap). Laryngeal palpation is again extremely helpful in distinguishing right-sided laryngeal hemiplegia from a 4-BAD. In the case of a 4-BAD, the muscular process will be difficult to identify due to dorsal extension of the thyroid cartilage lamina. In addition, there will be a palpable space between the caudal cornu of the thyroid cartilage and the cricoid cartilage due to the absence of a cricothyroid articulation. An ultrasound exam of the larynx is diagnostic and unless there is a clear and incontrovertible history of the horse having previously normal laryngeal function, horses with right-sided loss of laryngeal function should have an ultrasound exam of the larynx performed to rule out 4-BAD before considering tie-back surgery. The ultrasound findings in 4-BAD cases are 1) no detectable cricothyroid articulation, 2) the thyroid cartilage extends dorsal to the muscular process, and 3) the CAL muscle is in an abnormal location (the space between the thyroid and cricoid cartilages). There is currently no surgical treatment for the condition, although in some horses that are able to perform at near normal levels of their intended use, management of secondary dynamic airway problems disclosed by over the ground endoscopy can improve performance and reduce or eliminate upper airway noise.

While resting endoscopy is extremely useful and essential in evaluating abnormalities in laryngeal function, some laryngeal problems can have similar resting endoscopic findings (laryngeal hemiplegia and 4-BAD or LH and chondropathy). Added information provided by laryngeal palpation and/or laryngeal ultrasound is nearly always needed in these cases to make an accurate diagnosis. This is particularly true when evaluating right-sided abnormalities and when considering surgery.

Acknowledgments

Declaration of Ethics

The Author has adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Author has no conflicts of interest.

Reference

1. Lane JG. Fourth branchial arch defects in Thoroughbred horses: A review of 60 cases, in *Proceedings*. Second World Equine Airways Symp 2001;1–15.

Examining the Effects of an Extract of *Biota orientalis* in the Osteochondral Fragment-Exercise Model of Osteoarthritis

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Significant symptom-modifying and disease-modifying effects were seen following oral treatment with *Biota orientalis*[a] in an equine *in vivo* model of osteoarthritis. Authors' address: C. Wayne McIlwraith Translational Medicine Institute, Equine Orthopaedic Research Center, Colorado State University, Fort Collins, CO 80523; e-mail: kaseabaugh@yahoo.com. *Corresponding and presenting author.

1. Introduction

Osteoarthritis (OA) is the most common and economically significant cause of lameness in horses. Oral joint supplements are frequently used to reduce the development and progression of OA. The oil extract from the seed of *Biota orientalis*[a] (BO) has been researched *in vitro* as a standalone active ingredient and *in vivo* in combination with other biocompounds. The current study evaluated the efficacy of BO for symptom- and disease-modifying activity in a model of OA.

2. Materials and Methods

OA was induced in one middle carpal joint in each of 16 horses on Day 0. Treatment with BO or placebo was also initiated on Day 0. All horses were exercised 5 days a week starting on Day 14 through the termination of the study on Day 70. The horses were monitored for lameness, radiographic changes, and synovial fluid changes. On Day 70, tissue from the middle carpal joint was assessed macroscopically and histologically.

3. Results

Compared with placebo, a significant decrease was found in synovial fluid prostaglandin E_2 of horses treated with BO. Further, a significant decrease in radiographic evidence of OA was also found in the BO-treated horses.

4. Discussion

This study demonstrates a disease modification associated with prophylactic treatment using BO in induced equine OA and confirms positive results of previous studies.

Acknowledgments

Funding Source

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Research Abstract—for more information, contact the corresponding author

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Declaration of Ethics

The Authors have adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Authors have no conflicts of interest.

Footnote

[a]*Epiitalis*® contained in product 4CYTE™, Interpath Global, Ballarat, Australia.

Surgical Management of Subchondral Cystic Lesions of the Medial Femoral Condyle with an Absorbable Implant

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A transcortical extra-articular approach to facilitate curettage, irrigation, and placement of an absorbable implant to treat subchondral cystic lesions of the medial femoral bone condyle may be a useful surgical treatment option to improve lameness as well as the radiographic appearance of subchondral cystic lesions. Authors' addresses: Equitecnica Equine Hospital, Parma, Italy (Ravanetti); Clinique Veterinaire Equine Méheudin, Ecouché, France (Lechartier, Hamon); Universitá Stadi Milano, Department of Health, Animal Science, and Food Safety, Lodi, Italy (Zucca); Hagyard Equine Medical Institute, 4250 Iron Works Pike, Lexington, KY 40511 (Sandow, Spirito, Baker); e-mail: csandow@hagyard.com. *Corresponding and presenting author.

1. Introduction

Subchondral cystic lesions of the medial femoral condyle may be a source of lameness, resulting in poor performance, and can negatively influence buyers' decisions on horses sold at public auction.

2. Materials and Methods

Horses with subchondral cystic lesions of the medial femoral condyle were identified on survey radiographs prior to public auction or during lameness examination. Fifty-seven horses met inclusion criteria and were 10–26 months of age. The surgical procedure involved curettage of and placement of an absorbable implant in the cyst under radiographic guidance. Follow-up lameness and radiographic examinations were performed at 1, 2, 3, and 4 months postoperatively.

3. Results

There was an 80% radiographic reduction in the size of the cyst in 53/57 horses (92%). For the cases with lameness follow up, 47/48 horses (97.9%) were sound up to 4 months after surgery. Two cases required repeat operation due to implant migration.

4. Discussion

The surgical technique described here may be a useful option for the management of subchondral cystic lesions of the medial femoral condyle in juvenile horses. The multicenter nature and some subjective assessments have inherent limitations.

Research Abstract—for more information, contact the corresponding author

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Conflict of Interest

The Authors have no conflicts of interest.

Evaluation of Long-Acting Ceftiofur Crystalline Free Acid as a Pre-Operative Antibiotic in Field Castrations

Thomas Bergstrom, DVM*; Meredith Frey, DVM; Saangeeta Rao, BVSc, MVSc, PhD; and Luke Bass, DVM, MS, DABVP-Equine

The use of ceftiofur crystalline free acid (CCFA) in a long-acting formulation as a pre-operative antibiotic in equine field castrations does not offer any reductions in post-operative inflammatory markers when compared to procaine penicillin G. Authors' addresses: Department of Clinical Sciences, University of California–Davis, Davis, CA 95616 (Bergstrom); Department of Clinical Sciences, Colorado State University, Fort Collins, CO 80523 (Frey, Rao, Bass); e-mail: bergstrom.tb@gmail.com. *Corresponding and presenting author.

1. Introduction

This study aims to determine whether a single dose of long-acting ceftiofur crystalline free acid (CCFA) used as a pre-operative antimicrobial in equine field castrations offers any reduction in post-operative inflammatory markers when compared to procaine penicillin G (PPG).

2. Materials and Methods

Sixty-five horses aged 8 months to 2 years were randomly assigned to the CCFA (N = 33) or PPG (N = 32) treatment groups. Horses were castrated using general anesthesia and closed castration technique with scrotal ablation. Measurements of quantitative (serum amyloid A values, total nucleated cell count, fibrinogen, total protein) and qualitative (scrotal edema and preputial edema) inflammatory markers were performed in all horses preoperatively and postoperatively on days 3, 8, and 14. Complications in the post-operative period were recorded.

3. Results

No clinically significant difference in any post-operative inflammatory markers between the CCFA and PPG group was detected. In the CCFA group 48% of horses experienced post-operative complications compared to 31% in the PPG group. Castration induced significant elevation in serum amyloid A ($P < .0001$), preputial edema ($P < .0001$), and scrotal edema ($P < .0001$) at day 3. These values returned to baseline levels by day 8. Horses with grade 3 or above preputial edema were also found to have elevated serum amyloid A values ($P < .001$).

4. Discussion

The data from this study indicates CCFA used as a pre-operative antibiotic for routine castration offers no advantages over PPG. The difference in complication rate between groups is likely of minimal clinical importance as all complications were mild and self limiting.

Research Abstract—for more information, contact the corresponding author

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Acknowledgments

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Funding for this study was provided by Zoetis; however, they did not have input on study design or the results of this study.

Declaration of Ethics

The Authors have adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Authors have no conflicts of interest.

Investigation into Lumbosacral Vertebral Anatomy and Growth Plate Closure in Quarter Horses

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Lumbosacral physes were inactive by 24 months of age, and lumbosacral pathology may be more common than is currently recognized. Authors' addresses: University of Tennessee, College of Veterinary Medicine, 2407 River Drive, Knoxville, TN 37996 (Collar); Oregon State University, Carlson College of Veterinary, Medicine, 700 SW 30th Street, Corvallis, OR 97331 (Russell, Huber, Duesterdieck-Zellmer); University of California–Davis, School of Veterinary Medicine, 2309 Vet Med 3A, Davis, CA 95616 (Stover); e-mail: ecollar@utk.edu. *Corresponding and presenting author.

1. Introduction

Prior research has identified lumbosacral anatomical variations and physeal closure abnormalities in Quarter Horses (QHs) investigated for lumbar vertebral fracture. Therefore, the study objectives were to characterize anatomy and growth plate closure of the lumbosacral vertebrae in QHs.

2. Materials and Methods

Lumbosacral specimens were collected from 16 QHs humanely euthanized for reasons other than lumbosacral disease (aged 0 to 22 years old). Specimens were assessed using computed tomographic, gross, and histological (H&E) examination.

3. Results

Six lumbar vertebrae were found in 15/16 (94%) cases, with dorsal spinous process divergence at L5 to L6 in 3/16 (19%) cases. Physeal inactivity was present in cases as young as 4 months of age, with L4 to S1 physes inactive in all cases 2 years of age or older. Residual physeal cartilage was present in cases 5 to 8 years of age. Chondrocyte disorganization (7/12; 58%) and retention (11/12; 92%) with adjacent increased bone compaction was frequently observed in cases with unfused physes. Lumbosacral articular facet pathology was present in 11/16 (69%) cases. Articular subchondral linear lucency with associated sclerosis was present in 9/16 (56%) cases (aged 4 months to 22 years).

4. Discussion

Physeal disorganization with bone compaction occurred frequently, potentially as a mechanism for physeal senescence or indicating stress and pathology in these regions. This study provides further insight into the equine lumbosacral spine.

Acknowledgments

Support was provided by an American Quarter Horse Foundation Young Investigators Grant.

Declaration of Ethics

The Authors have adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Authors have no conflicts of interest.

Research Abstract—for more information, contact the corresponding author

NOTES

Characteristics of Complete Tibial Fractures in Racehorses

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Tibial fractures in racehorses are associated with a pre-existing stress fracture. Racehorses are at highest risk of sustaining tibial fracture early in their career or after return from layup. Authors' addresses: California Animal Health and Food Safety Laboratory System, San Bernardino Branch, University of California-Davis, Davis, CA 92408 (Samol, Uzal); California Animal Health and Food Safety Laboratory System, Davis Branch, Davis, CA 95616 (Hill); School of Veterinary Medicine (Arthur); Department of Surgical and Radiological Sciences (Stover), University of California-Davis, Davis, CA 95616; e-mail: masamol@ucdavis.edu. *Corresponding and presenting author.

1. Introduction

Tibial stress fractures are a common cause of acute hindlimb lameness in racehorses. Complete tibial fractures cause ~3% of deaths in racehorses. It is unknown if pre-existing stress fractures are associated with tibial fractures.

2. Materials and Methods

Necropsy reports of 115 racehorses that had a complete tibial fracture (1990–2018) were retrospectively reviewed. Signalment and exercise histories of affected horses were compared to those of racehorses that died because of non-tibial musculoskeletal injury or non-musculoskeletal cause and of control live racehorses (chi-square, Fisher's exact test, matched logistic regression [$P \leq 0.05$)]).

3. Results

Most fractures occurred during training (68%) and in 2- to 3-year-old horses (73%). Most horses (97%) had unilateral fractures without side predisposition. Most fractures were diaphyseal 44 and oblique (40%). Of 61 fractures examined for callus, 64% had periosteal callus associated with the fracture. Callus was most prevalent in the proximolateral cortex (72%) and caudal cortex of the distal diaphysis (28%). Of 28 racehorses with exercise history, 57% never raced, and 36% had recorded layup period, and those horses were ≤3 years of age. Affected horses had fewer high-speed events, cumulative distances, and active career days than control horses.

4. Discussion

Tibial fractures were associated with pre-existing stress fracture early in a horse's career. Most catastrophic fractures were associated with proximolateral stress fractures, which may be challenging to detect clinically.

Research Abstract—for more information, contact the corresponding author

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Declaration of Ethics

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Conflict of Interest

The Authors have no conflicts of interest.

Detection and Residence Time of Bisphosphonates in Bone of Horses

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Bisphosphonates reside in the bone for extended periods of time, leading to potential long-term pharmacologic effects and increasing the potential for unfavorable outcomes in young and/or athletic horses. Authors' addresses: K.L. Maddy Equine Analytical Pharmacology Laboratory (Knych, McKemie); California Animal Health and Food Safety Laboratory (Samol, Uzal); School of Veterinary Medicine (Arthur), University of California-Davis, Davis, CA 95616; University of Kentucky Veterinary Diagnostic Laboratory, 1490 Bull Lea Road, Lexington, KY 40511 (Janes, Kennedy); Kentucky Horse Racing Commission, Building B, 4063 Iron Works Pkwy, Lexington, KY 40511 (Scollay); e-mail: hkknych@ucdavis.edu. *Corresponding and presenting author.

1. Introduction

Bisphosphonates are potent antiresorptive agents that have been used for several years in human medicine. There are currently no reports describing the residence time in horse bone; however, in humans, bisphosphonates can remain in bone for years, equating to an extended pharmacologic effect. Knowledge of the residence time of bisphosphonates in bone could allow for a better understanding of the long-term effects of these compounds and ultimately more judicious use. To that end, the objective of this study was to begin to characterize the disposition of bisphosphonates in the bone of horses.

2. Materials and Methods

Two horses received clodronate[a] (1.8 mg/kg [intramuscular]) and two tiludronate disodium[b] (1 mg/kg [intravenous]). Bone and teeth were collected at 4 days from 1 horse in each drug group and at 30 days from the second horse in each group. Additionally, postmortem blood, synovial fluid, aqueous humor, and bone samples from racehorses with various histories of bisphosphonate administration were collected and concentrations determined.

3. Results and Discussion

Clodronate and tiludronate concentrations exceeded the highest calibrator (0.338 μg/gram) in all bones and teeth tested at 4 and 30 days postadministration. In a post-mortem sample, clodronate was detected at concentrations exceeding 0.338 μg/gram in bone from a horse with a reported administration of 18 months. This drug was not detected in other sample types collected from this horse.

Research Abstract—for more information, contact the corresponding author

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Conflict of Interest

The Authors have no conflicts of interest.

How to Safely Restrain a Laterally Recumbent Horse

Rebecca Husted, PhD*; Michelle Egli, DVM; and Ashley Davenport, DVM

Recumbent horses are notoriously difficult to safely restrain. It is important for equine practitioners, technicians/nurses, and their staff to know how to safely, efficiently, and effectively restrain animals without injury either to the horse or to personnel. Every equine practitioner and technician/nurse is expected to perform this task on demand, but is taught on the job. The purpose of this paper is to provide guidelines and information for improving safety and effectiveness of animal handler(s) when attempting to restrain a laterally recumbent equine for field, clinical, or technical rescue procedures and introducing the foot-in-neck method of physical restraint. Authors' addresses: Technical Large Animal Emergency Rescue, Inc., 1787 GA HWY 18 E, Macon, GA 31217 (Husted); Delmarva Equine Clinic, 1008 South Governors Avenue, Dover, DE 19904 (Egli); Horner and Nash, DVM, PC, 255 McGarity Road, Canton, GA 30115 (Davenport); e-mail: delphiacres@hotmail.com. *Corresponding and presenting author.

1. Introduction

Horses that are "down" in recumbency experience fear, they may cause self injury, or they may injure a person while struggling to rise. The musculoskeletal region of the neck is a powerful lever and is used by the horse to rise from recumbency. Thus, restraint by a handler (Fig. 1) is useful to minimize struggling while the practitioner is deciding on a protocol for treatment, chemical restraint, or euthanasia.

Rotating the head back, aligned with the neck, and tipping the nose up delays the horse's attempts to roll into a sternal position, then stand.[1,2] Even if a horse is physically incapable of standing, such as while waking up from general anesthesia, it can make uncoordinated efforts to stand and flail (Fig. 2) due to powerful flight instincts if sympathetically stimulated.[3]

Legacy Knee-on-Neck Method

The Legacy "knee-in-the-neck, tip-the-nose-up" method has been used for generations, especially since effective chemical sedation and anesthesia weren't available to equine practitioners until the 20th century (Fig. 3). This Legacy method of attempting to hold down a laterally recumbent horse during clinical veterinary procedures places the handler's knee onto the neck of the horse, using the full weight and pressure of a kneeling person to physically restrain the horse, then the handler uses upper body strength to rotate the head and tip the nose skyward by pulling on the halter. Legacy methods have caused injuries to personnel via kick, strike, and ergonomic injuries. Practitioners, technicians/nurses, and professional animal handlers in the industry share personal narratives of being thrust backward, kicked or struck by a hoof, or suffering rope injury while

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Fig. 1. Laterally recumbent horse waking up from general anesthesia is restrained with the animal handler standing dorsal to the animal's neck (instead of sitting or kneeling), with their foot placed approximately behind the atlanto-occipital joint, the nose is tipped upward, and with protection for the downside eye. Photo courtesy of Dr. Michelle Egli.

Fig. 3. Horse in lateral recumbency. Any stimulation can cause the horse to struggle violently. The handler shows the Legacy position and is holding the halter to tip the nose up. Note the use of a helmet by the handler to prevent head injury. Blindfold and head protector have not yet been applied. Photo courtesy of Dr. Tomas Gimenez.

attempting to hold down a 1,000-lb (453-kg) or larger recumbent horse.[a,b]

Clearly, a larger, heavier, and stronger person increases the odds of success at restraining an animal that is far quicker, stronger, and heavier than one person, or even several persons. As the equine industry (and technician/nurse population) has become predominantly female, with generally smaller body weight, frame size, and strength compared

Fig. 2. Veterinarians are expected by clients to address debilitated or downed horses. Here, personnel are forced to take dangerous positions between the front legs and the animal's head when they do not have assistance from an animal handler. A limitation for practitioners is the number of personnel available to conduct "free" versus "attended" recoveries in the field. Photo courtesy of Raymond Phillips; Photo courtesy of Caren Chellgren.

Fig. 4. Firefighters work to stabilize a down horse, manipulating it with webbing out of a swale, and then to a sternal position to encourage it to stand. One handler is on the neck in Legacy position, while the other is placing a human personal flotation device (PFD) around the head for protection. Over the years, handlers rejected the "knee-on-neck" as a more dangerous position. Photo courtesy of Katherine Davis/Battalion Chief Darrell Mitchell.

with males—the old methods that worked marginally for a 200-pound (91-kg) man, don't work well for a 130-pound (59-kg) woman.[c]

One constraint of legacy methods is the handler's dubious location for safety (on their knees with their head looking down)—limiting their ability to get out of the way if the horse lunges, attempts to roll or to stand (handler would have to be able to stand up faster than the horse can struggle up). Legacy methods have resulted in injuries to personnel including ergonomic injuries (back, hip, knees) by people attempting to rise; horses striking with the hind foot to the person on the head; horse rolling to sternal then standing reflexively faster than the human's ability to get out of the way when the horse stands up; and pulling the handler headlong into the space between the neck and front legs while struggling, etc.[d]

Fire/rescue organizations work hard to reduce exposure and injuries to fire/rescue personnel responding to incident scenes, depending on "lessons learned" and they make continual improvements to methods and techniques to increase safety.[4] Hard questions about obvious risks of using the Legacy method (Fig. 4) have been asked by first responders. Over the years, fire/rescue organizations adopted mandatory improvements to equine restraint methodologies taught to their personnel for large-animal rescue—including rejection of the Legacy and adoption of the "foot-on-neck" method. These restraint improvements are shared here with veterinary professionals to improve safety for anyone involved in response to recumbent equine situations.

Modern best practices as taught to fire/rescue personnel now include an improved "foot-on-neck" method that provides greater leverage for the handler while increasing the handler's ability to move out of the way of a lunging animal (Fig. 5). It improves personal safety for animal handlers while allowing improved jugular and facial area access for the equine practitioner (IV access, catheterization and maintenance, facial artery pulse, ocular reflexes, and oral mucous membrane evaluation.)

2. Materials and Methods

Recommended Personal Protective Equipment

Practitioners and staff should carry some basic equipment to facilitate personnel safety when handling recumbent equines.

- Gloves (high dexterity) to prevent rope burns.
- Boots (with or without steel/composite toe).
- Protective helmet with chinstrap.
- Knife and/or multi-tool to cut rope in an emergency.

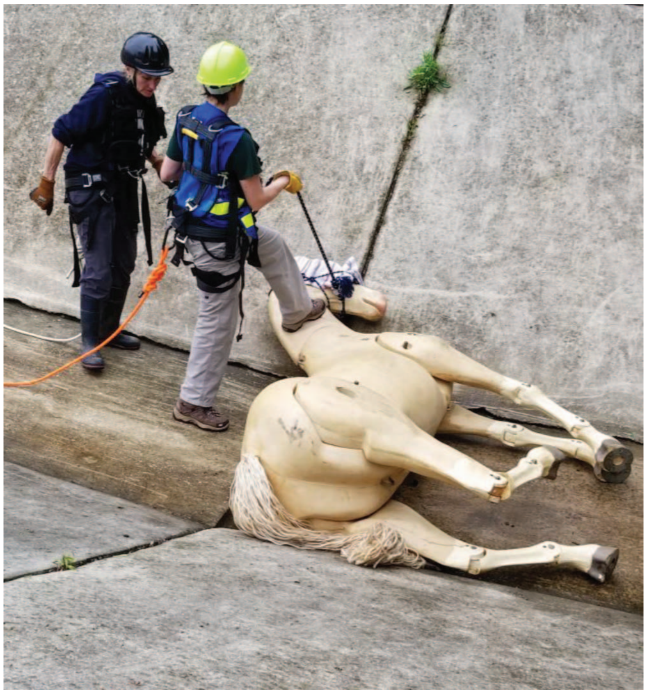

Fig. 5. A full-size, jointed horse mannequin[a] is utilized for training of emergency personnel in proper positioning for safe handling and manipulation of recumbent horses. Here, students and veterinarians can practice use of the foot-on-neck method to learn to properly restrain a down horse. Photo courtesy of Dr. Ruth Franczek.

- Professional shirt/jacket or scrubs with logo to identify yourself.

Note: Helmets are proven protective equipment and are mandatory for professional emergency responders due to Occupational Safety and Health Administration (OSHA) rules about situations where there is any possible impact.[5] They are highly recommended for anyone dealing with horses in recumbent or recovery situations for the same reasons.[6]

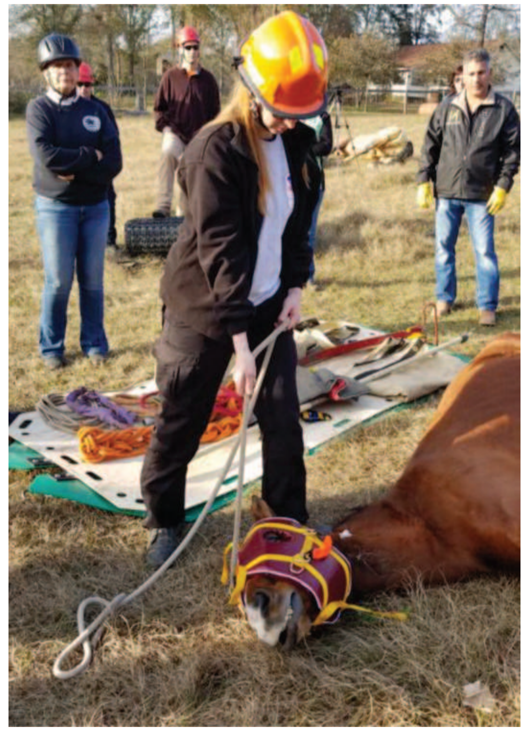

Fig. 7. An anesthetized horse in recovery is restrained effectively in lateral recumbency by a female student that weighs less than 140 pounds using the foot-on-neck method. The head and eyes are protected by a Häst Head Protector.[h] Photo courtesy of Dr. Rebecca Husted.

Recommended Recumbent Animal Restraint Equipment

- Halter/8-to-12-foot lead rope.
- Head protection and/or blindfold.

Fig. 6. Control of the head by having an animal handler distribute their weight while standing, with the foot located directly behind the atlanto-occipital joint. In this photo, the horse has on a halter and lead, with a Becker head protector and blindfold in place for general anesthesia (castration).

Fig. 8. A horse down in a ditch in a pasture with fire/rescue, law enforcement, and veterinarian on scene. The horse handler and other personnel are in dangerous positions attempting to hold the head or standing between the legs. Photo courtesy of Oxford Fire Department, Michigan.

Description of Foot-on-Neck Method

"Best practices" for handling as taught to fire/rescue personnel (who are commonly not familiar with horses) include restraint methods for lateral recumbence to provide greater control to the handler at the head, while increasing their leverage and weight advantage. This increases the handler's ability to move out of the way if the horse struggles to get up, keeps personnel out of the way of flailing hooves, and prevents potential ergonomic injuries by allowing the handler's weight to be balanced on their legs instead of kneeling.

The "foot-on-neck" method is more ergonomic. It allows the animal handler to use the lead-rope for leverage to tip the nose skyward, while placing the bottom of their foot on the neck of the horse (directly behind the atlanto-occipital joint; Fig. 6) and using their body weight to discourage the horse from rising. Tipping the nose up slightly is desirable as it makes it more difficult for the horse to rise,[7] and keeps the animal handler out of the way of the neck. This also provides the veterinarian with better access to the jugular vein (catheter insertion and maintenance, administration of drugs) and the facial area (assessment of capillary refill times, facial artery pulse, orbital, and oral mucous membranes). It is still possible for a trained animal handler to assess respiratory rate (watching chest rise or nostril movements), assess ear and eye reactions, and cover the eye with a blindfold while holding in this manner (Fig. 7).

3. Results

Horses do not instinctively comprehend how to let humans help them, nor do they have the capacity to understand that the responders' intent is to help. When dealing with a fearful recumbent horse, personnel must adopt defensive strategies to stay safe.[e] One person (the handler) must maintain control of the head until the animal is evaluated, treated, recovered completely, euthanized, or packaging is complete (if using a rescue glide for transport). Dangerous places for humans to be positioned include directly in front of the legs or head, between the legs, or standing over/above a recumbent horse (Fig. 8). All personnel must stay clear of the horse's legs (recumbent horses can flail or struggle with no warning).

Fig. 9. A debilitated yearling is found down and hypothermic, unable to stand. The handler, in full personal protective equipment and under direction of a veterinarian, has assessed minimal concern for struggling; thus, she is supporting the head on her knees in preparation for adding head protection. However, this is a difficult position to arise from quickly if the animal should struggle. Photo courtesy of Washington State Animal Response Team.

The Role of the Animal Handler

Proper positioning of personnel can prevent injuries—use of the standing with one foot-on-neck method increases safety of both the handler and the veterinarian treating the horse. Complacency, lack of exposure, or inappropriate training may cause handlers to underestimate the extreme weight, strength, and speed of a recumbent horse. Control of the head is crucial to equine restraint. The handler should place a halter and lead-rope or emergency rope halter on the recumbent horse before doing anything else. Next, place some type of head protection (towel, shirt, cheap human personal floatation device, Häst Head Protector,[f] or similar full head protection device) on and under the horse's head. Special attention should be paid to prevention of nerve paralysis and myopathy, and efficient recoveries prevent medical issues seen with slow response.[g] A blindfold should be used to protect the eyes and limit visual stimulation. From their standing position, the handler can watch the horse for movement reflexes, observe breathing rate by watching the chest rise, and report changes in muscle flaccidity or reflexes, while the veterinarian can access the head and neck more freely.

4. Discussion

In both clinical and field—owners, veterinarians, staff, and first responders have been injured by recumbent horses while attempting to assist or treat them.[h] Proper restraint by a trained animal handler, with or without sedation/anesthesia, prevents needless injuries to both humans and horses. Unless completely exhausted, debilitated, or hypother-

Fig. 10. Horses go down in trailers and other confined spaces where handlers have no ability to easily escape if the horse struggles. These situations require the handler to offer restraint from a safe position until sedated—here—from outside the trailer, using a riding pad for head protection and as a blindfold. Photo courtesy of Basin Fire Brigade.

mic to the point of not struggling, animals should be profoundly sedated or anesthetized for procedures to reduce the chance of injury to personnel.

The Horse's Perspective

Recumbency, from the perspective of the animal, is very different from human perception. Horses that may appear to be lying calmly are extremely stressed and fearful (Fig. 9). Recumbent horses often lie quietly for a few minutes due to exhaustion, but their instinct drives them to struggle unpredictably and violently. The primary problem of recumbency quickly becomes overshadowed by the secondary problems (decrease in gut motility, down lung congestion, nerve and muscle impingement and damage), thus a plan must be made efficiently to get the horse to the recovery position (sternal), then on its feet.[8]

For many technical rescue manipulations, the animal handler must be able to lift, support, and move the head in coordination with the team rolling, sliding, moving, and/or packaging the recumbent horse patient.[9] Standardization of animal handler training for technical animal rescues by the fire service is ongoing.[10,11]

Factors To Consider

- What is the weight and size of the horse?
- Is there an injury to the horse's neck or head that prevents use of this method?
- What is the disposition/breed/reactivity of the horse?
- Is the horse in pain? Has analgesia been administered?
- Training: Does the animal handler have experience and training with use of physical restraint of mannequins[i] and real recumbent horses? Are they in a safe position?
- Equipment: Does the handler have a good quality halter and lead-rope to maintain control of the head, with head protection or at a minimum a towel to use as a blindfold?
- Is there egress room for handler or are there obstacles? What is footing quality?
- Are there going to be questions from observers about why you are using this method that looks different from past methods (i.e., standing versus knee in neck)?

Obstacles Add Danger

Recumbent animals in certain scenarios (confined space: entrapped in an overturned trailer, with a leg through the bars of a stall) are subject to abnormal orientation and make for extremely dangerous positions for the animal handler. Always consider administration of sedation (IM, oral) before putting any handler into such a dangerous position (Fig. 10).

5. Conclusion

Use of these updated methods and simple equipment with personal protective equipment will contribute to effective equine restraint and improved ergonomic and kinetic safety for veterinary handler personnel while allowing successful and efficient outcomes of lateral recumbency in clinical, field, and technical rescue incidents.

Acknowledgments

Declaration of Ethics

The Authors have adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Authors have no conflicts of interest.

References and Footnotes

1. Fowler M. *Restraint and handling of wild and domestic animals*. 3rd ed. New York, NY: John Wiley & Sons; 2008, 113–119.
2. Muir WW, Hubbell JAE. *Equine anesthesia—Monitoring and emergency therapy*. 2nd ed. London, UK: Elsevier; 2010.
3. Kastner SBR. How to manage recovery from anaesthesia in the horse—to assist or not to assist? *Pferdeheilkunde* 2010: 26;604–608.
4. Gimenez T, Gimenez R, May K, eds. *Technical large animal emergency rescue*. New York, NY: John Wiley & Sons; 2008.
5. Impact Safety Rule—Occupational Safety and Health Administration (OSHA). Available from: https://www.osha.gov/laws-regs/regulations/standardnumber/1926/1926.100. Accessed March 5, 2020.
6. Butterworth, J. Think ahead: Safety first for equine vets. *Vet Rec* 2016:178;295–296.
7. Dreissen B. Assisted recovery. In: Doherty T, Valverde A, eds. *Manual of equine anesthesia and analgesia.* Ames, IA: Blackwell Publishing Ltd; 2006, 343–344.
8. Gimenez RM, Smith S. How to manipulate a recumbent horse (entrapment, clinical, or technical emergency rescue situations, in *Proceedings.* Am Assoc Equine Pract 2017;63: 403–412.
9. Gimenez T. The golden hours of equine emergency rescue. *Equine Vet* 2012;2:26–29.
10. NFPA 1670 Standard. Available from: https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=1670. Accessed March 10, 2020.
11. NFPA 1006 Article. https://www.nfpa.org/News-and-Research/Publications/NFPA-Journal/2014/July-August-2014/Features/Rescue-Me. Accessed March 10, 2020.

[a]Hanson S, Newnan GA (personal communication) 2015.
[b]Bottger J, Anderson SC (personal communication) 2017.
[c]Mitchell D, Canton GA (personal communication) 2018.
[d]Franczek R, Dover DE (personal communication) 2019.
[e]Lack A, Starkeville MS (personal communication) 2020.
[f]Häst Head Protector, Häst, PSC, Floyd, VA. http://rescue.hastpsc.com/. (804) 286–0832.
[g]Miller RM (personal communication) 2014.
[h]Langston MD (personal communication) 2019.
[i]RESQUIP Horse Mannequin, Spring Lake, NC. https://4hoovessmart.com/online-store?olsPage=products&page=3. (910) 494–8210.

How to Treat Coronary Band Dystrophy

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1. Introduction

Coronary band dystrophy (CBD) appears to be increasingly recognized and diagnosed in equine veterinary practice as a distinct dermatological disease that affects the equine coronet. However, the information on this disease in the equine veterinary literature is sparse.[1–4] The disease is frustrating to treat, labor intensive on the part of the caregiver, and is often non-responsive to treatment. CBD is described as an idiopathic defect in cornification of the coronary band that predominately affects the heavy breeds of horses,[a,b] but in the study described in this paper, the cases were either Warmblood or Warmblood-cross horses. There appears to be no apparent age or gender predisposition, all four hooves are generally affected to a variable extent, and long-term treatment may often be palliative rather than curative.[1] An immune-mediated pathway appears to be the logical explanation as the disease is responsive to systemic corticosteroids and recently, a report describing methotrexate being used to treat CBD appears to be promising.[c] The response to these two drugs may indicate that the term, CBD, is not actually correct and that chronic immune-mediated coronitis may be more appropriate. A form of pemphigus foliaceus termed pemphigus coronitis has been incriminated but has not been completely proven. This report describes the successful (although it must be emphasized, not curative) treatment of greater than 20 horses that were diagnosed with CBD. Interestingly, 7 horses subsequently developed chronic proliferative pododermatitis (canker) secondary to CBD.

2. Materials and Methods

The records of 18 horses treated for CBD from 2015 until the end of 2019 were reviewed. Horses were selected from referral cases that had severe clinical signs of hyperkeratosis of the coronary bands involving all 4 feet and where other causes for these lesions could be excluded. The form of hyperkeratosis noted consisted of the formation of thick crusts on the coronet, showed hemorrhage and ulceration when removed, interfered with normal hoof wall growth, and did not respond to routine veterinary care. Furthermore, the lesions were not limited to the coronet but also appeared on the bulbs of the heels and the base of the frog. The breed distinction was either Warmblood or Warmblood crossed with Thoroughbred. Interestingly, quite a few of these horses (6) were imported to the United States at least a year prior to showing clinical signs. Sex was divided into 10 geldings, 7 mares, and 1 stallion and were aged between 7 and 18 years. The bulk of the cases were either treated by or personally overseen by the author while the remainder of the horses were treated through the author's consulting practice and although there were good follow-up reports

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Fig. 1. Hair above coronet sticking straight out, thin bead of abnormal horn and tightly backed growth rings below coronet.

from the caregivers, the results could not be personally verified.

Clinical Signs

When the horse is presented with CBD, the horse may or may not show lameness depending on the extent of the disease. In general, the coronary bands are proliferative with crusting, scaling, variable erythema, and often ulceration. In some instances, the ergots and chestnuts are also affected with the same lesions.[1–4] Hooves may be thickened with poor consistency of the hoof wall, irregular ridges, scaling and closely packed growth rings.

While the severity of the disease may vary, the initial changes at the coronary band may be subtle but can rapidly progress until the clinical signs are apparent. Generally, the hair that lays flat against the proximal coronet will begin to rise off the coronet and the proximal extent of the coronet will begin to thicken. As the disease progresses, a thin bead of dark brown, eroded, soft horn will be noted just below the hair and the hair will begin to stick straight out. At this point, hoof wall growth distal to the coronet will decrease as noted by the tightly packed growth rings (Fig. 1). Over time, the coronet at the hairline will swell, the bead of soft horn will enlarge, and the hoof wall below the abnormal horn will show crusts and scaling. The abnormal horn will start to widen toward the heels and then extend over the bulbs of the heels down to the frog (Fig. 2, A and B). In the palmar or plantar section of the foot, the abnormal growth at the coronet at the heels will grow down into the hoof capsule and the crusted horn will grow distally and cover the bulb extending to the frog. The hair overlying the bulbs will now be standing erect. The crusted horn will often crack, ulcerate, and a clear serous exudate may be present. At this point, the abnormal horn may extend onto the surface of the frog if the frog is located below the ground surface of the hoof wall at the heels or ultimately may develop canker if the frog is recessed between the walls of the hoof capsule. In some cases, the thick crusted horn that covers the bulbs of the heels and the base of the frog will turn into a light brown, soft epithelium that is covering a caseous white exudate that resembles cottage cheese. This type of tissue is indicative of proliferative pododermatitis or canker.[5] Horses may be lame if the CBD is so severe that there is ulceration at the coronet, a deep fissure present at

Fig. 2. A, Advanced case, hair sticking upward. B, Abnormal growth at coronet continuing wide bead of abnormal horn with cracks into the heel bulbs. Horn covering the bulbs is soft and crusts/scaling below the bead, friable with fissures. Note fissure in central sulci of the frog extending into the bulbs.

Fig. 3. Thickened coronet descending into the bulbs and frog where tissue has developed into canker confirmed by biopsy. Note prolapsed frog.

the base of the diseased frog or the horse has developed canker (Fig. 3). A complete blood count and serum chemistry was performed on each horse and found to be within normal limits.

Diagnosis

A tentative diagnosis is made on the clinical appearance and progression of the lesions localized to the coronet and heel bulbs. A definitive diagnosis is attained by ruling out other skin lesions such as pemphigus foliaceus, eosinophilic exfoliative dermatitis, dermatophilosis, zinc deficiency, selenium toxicity and infestation with *Chorioptes equi*.[1,3] The diagnosis can be confirmed with a biopsy. It should be noted that confirmation of pemphigus requires immunofluorescence staining which is not commonly done nor commonly available.[d] An incisional biopsy was obtained under local anesthesia from the coronet at the junction of the heel quarter and the heel bulb. The biopsy reports in this study showed the epidermis to be hyperplastic with marked acanthosis and the formation of long papillary fronds in the dermis. A moderate layer of orthokeratosis hyperkeratosis covered the surface of the epithelium over the coronary band dermis (Fig. 4A). Increased numbers of lymphocytes and plasma cells can be seen in the dermal papilla (Fig. 4B). The presence of lymphoid cells in the dermis is potentially compatible with an immune-mediated condition.[c] A recently published pathology paper has an excellent photomicrograph of a section of the coronet illustrating the histology of CBD (Fig. 4C). As the biopsies were similar in the first few cases in this report, biopsies were discontinued because the wounds were difficult to heal.

Treatment

Medication

Treatment is labor-intensive and an owner/client commitment is necessary for success. The horse is placed on a descending dose of oral prednisolone[e] administered at 1 mg/kg q24h for 10 days, 0.5 mg/kg, q24h for 10 days, and 0.25 mg/kg, q24h for 10 days.[6] After 30 days, the dose is continually decreased, and the days of administration are spaced further apart until the lowest possible dose to prevent reoccurrence is administered once or twice weekly. Also, at the onset of treatment, minocycline[f] is given orally at 4 mg/kg, q12h in an attempt to treat any possible low-grade infection present in the coronary band.[7] Firocoxib[g] is given orally at 171 mg, q24h for 3 days as a loading dose,[8] and the 57 mg, q24h for a total of 14 days. This anti-inflam-

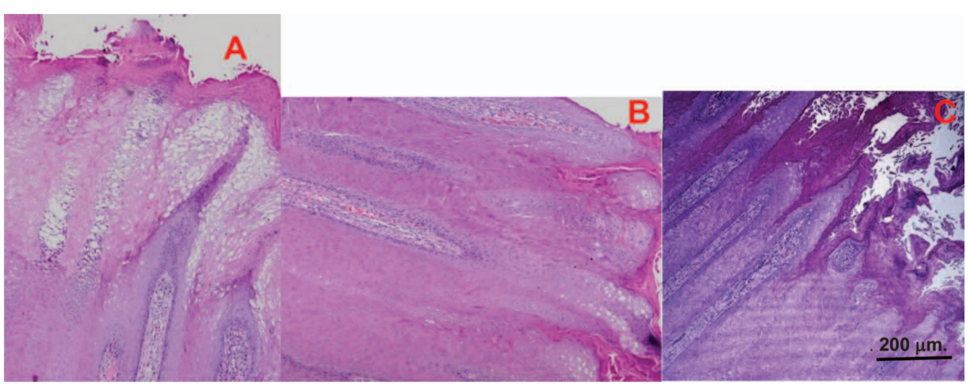

Fig. 4. A, CBD biopsy slide: The epidermis is hyperplastic with marked acanthosis and formation of papillary fronds. B, Mild-to-moderate increase of lymphocytes in the dermal papilla (image courtesy of Derek Knottenbelt). C, Section of coronet illustrating histology of CBD. Reprinted with permission: "Pathology Practice," Twitchell. *J Am Vet Med Assoc*, 2014;245:385.

Fig. 5. Dorsal surface of the coronet and solar surface of the same foot illustrated in Fig. 2, 3 weeks after initial treatment.

matory medication is used to counteract inflammation and discomfort associated with the initial debridement and subsequent daily debridements.

Topical Treatment of the Coronet

If the clinician does not perform this type of work, the initial foot care should be performed with an interested and skilled farrier. Most of these cases show either poor hoof conformation or a hoof capsule distortion with prolapsed frogs or recessed frogs, long toe–low heel, or clubfoot conformation. Improving the foot conformation will redistribute the forces on the solar surface of the foot which in turn will decrease the stresses on the coronet. To accomplish the appropriate farriery, the author has found the best method is to remove the shoes initially and begin treatment in the barefoot state. If the frog is prolapsed below the hoof wall and there is a fissure in the central sulci of the frog, leaving the horse barefoot will reposition the frog to the same plane as the heels of the hoof capsule, the fissure will heal and the frog will no longer be traumatized. Otherwise, the heels of the hoof capsule are trimmed to where the frog and the hoof capsule are on the same plane and the rest of the hoof capsule is shaped as described in a recent paper on barefoot methodology.[9]

The horse is mildly sedated with the clinician's medication of choice allowing the horse to remain coordinated. The hair around the entire coronary band is clipped using a number 40 surgical clipper blade. All loose exfoliating horn is removed from the frog with a sharp hoof knife. The affected hoof is placed on a farrier foot stand and the bulk of the abnormal hoof wall, crusts, and scales are removed with the smooth side of a farrier rasp. The same procedure is performed over the bulbs of the heels to the base of the frog. A medium-grit sanding block is then used to continue sanding the coronet and bulbs until there is a clear demarcation between the skin and the coronet. Following debridement, there may be some serous exudate or mild hemorrhage in which case a dry bandage can be placed for 24 hours. The horse is bedded with wood shavings or sawdust for the drying effect and turned out in a small dry paddock for a few hours per day if dry. The wear on the frog should not exceed new horn growth being produced, so it is important that the footing is not too hard, or shoes can be replaced if necessary. The coronary bands are cleaned every few days with a medium grit sanding block, then wiped with a moist gauze pad with saline and a thin layer of either a hydrocortisone 2.5% ointment[h] or a betamethasone 0.5%/allantoin 1.5% ointment[i] is applied. The frogs are cleaned daily with a wire brush and then painted with solution of benzoyl peroxide in 10% acetone[j]. This treatment is continued by the horse's caretaker until the new growth has normalized and then as needed if symptoms begin to return (Fig. 5).

Canker

Seven of the horses developed canker in various feet subsequent to showing signs of CBD. This may show a correlation between the two disease entities and CBD may predispose the foot to canker. The gross appearance of canker is generally diagnostic, but a biopsy is always an option for confirmation in these cases. The biopsy is generally read out as chronic proliferative pododermatitis.[10] The coronary bands and the bulbs showing CBD were treated as described earlier in the text. Briefly, the treatment of canker consists of placing a tourniquet above the fetlock to provide a bloodless field which will enhance careful and thorough debridement of all disease tissue to where there is a clear demarcation between normal and abnormal tissue. The demarcation can be observed by a change in the appearance and consistency of the frog along with small pin-point hemorrhages noted in the tissue. Debridement is then followed by cryotherapy. Benzoyl peroxide in 10% acetone combined with metronidazole powder is applied to the debrided area and the foot is bandaged. The bandages are changed every second day, the debrided tissue is cleaned with a suitable mild antiseptic solution, rinsed with sa-

Fig. 6. Heel bulbs and frog of the same foot with canker illustrated in Fig. 3, 6 weeks post-treatment.

line, and then the medication and bandages are reapplied.[10] The use of shoes and treatment plates are discouraged as a dry environment on the solar surface of the foot is preferred. Once the frogs have healed and cornified, the treatment continues as outlined for CBD (Fig. 6). The treatment may seem involved but can be performed very efficiently by the horse's caretaker on a daily or every-second-day basis in a short period of time.

3. Results

All horses in this study responded to the described treatment protocol and returned to full work. Success was described as marked improvement in coronary band and hoof appearance within 3 to 6 weeks after treatment was initiated. In addition, horses returned to full work when shoes were replaced, horses had an acceptable macroscopic appearance of the coronary band and hoof wall, required minimal daily foot care, and were able to be reduced to at least every-other-day steroid administration and remain disease free (Fig. 7, A–C). Again, it must be emphasized, that due to the suspected genetic and auto-immune implications of this disease, permanent remission is generally not achieved.

4. Discussion

To the author's knowledge, there are only two reports in the literature on CBD and one is a pathology report.[3,4] These reports described the clinical signs and diagnosis but provided minimal information on treatment. This report details both systemic treatment as well as in-depth foot care as the combination appears to be necessary for improvement. As long-term corticosteroids are necessary for treatment, it strongly suggests CBD to be an immune-mediated disease. These horses appear to have a specific antigen associated with the keratinized hoof wall that is involved. Pemphigus remains a possible cause as it has several subtypes that could affect an antigen located in a single type of tissue. A descending dose of prednisolone was chosen due to its good bioavailability, excellent anti-inflammatory effects and appears to be a minimal risk factor for developing laminitis.[11] Minocycline, an oral antibiotic with good bioavailability and good tissue penetration, was used at the initiation of treatment for the possibility of a low-grade infection in the coronet.

Foot care combined with the initial systemic therapy appears to be essential for a successful outcome. Taking the horse out of work during the initial treatment phase allows the feet to rest and prevents trauma to the healing tissue. Removing the shoes allows the feet to be trimmed properly, effectively improves any hoof capsule distortions or abnormal hoof conformation, and leaves all the affected tissue readily accessible for daily treatment. It appears important to remove all abnormal horn and crusts from the coronet and bulbs to allow penetration of the topical medication at the skin coronet junction. The topical corticosteroid ointment or the combination of betamethasone for its anti-inflammatory effect and allantoin for its astringent properties appear to be effective in decreasing abnormal growth. The affected tissue at the bulbs (and frogs) will generally be soft, void of adequate horn thickness, and contain multiple fissures. The use of benzoyl peroxide in 10% acetone as an astringent seems to improve the horn and promote cornification. If canker is present, the frog is treated as a separate

Fig. 7. Lateral and palmar view (A & B) of foot in Fig. 3, 6 weeks later just before replacing shoes and resuming work. A straight bar shoe (C) is used to stabilize the hoof capsule and allow the fissure to continue healing.

entity as described above in combination with treatment for CBD.

The final, essential, and extremely important aspect of this treatment is the commitment of the owner/caretaker to persevere through with the treatment plan. Although the treatment is not difficult; it is time consuming and the treatment not only has to be performed daily or on a frequent basis but must be thorough, consistent, and with attention to detail.

Acknowledgments

Disclaimer

Compounded products can vary significantly in their respective potency.

Declaration of Ethics

The Author has adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Author has no conflicts of interest.

References and Footnotes

1. Stannard AA. Disorders of cornification. *Vet Dermatol* 2000;11:187–189.
2. Scott DW, Miller WH Jr. Miscellaneous skin diseases. In: Scott DW, Miller WH Jr., eds. *Equine dermatology*. 2nd ed. Maryland Heights, MD: Elsevier Saunders; 2011, 462–463.
3. Menzies-Gow NJ, Bond R, Patterson-Kane JC, et al. Coronary band dystrophy in two horses. *Vet Rec* 2002;150:665–668.
4. Twitchell EL, Hartman RA. Pathology in practice. *J Am Vet Med Assoc* 2014;245:385–387.
5. O'Grady SE, Madison JB. How to treat equine Canker, in *Proceedings*. Am Assoc Equine Pract 2004;50:202–205.
6. Oosterlinck M, Deneut K, Dumoulin M, et al. Retrospective study on 30 horses with chronic proliferative pododermatitis (canker). *Equine Vet Educ* 2011;23:466–471.
7. Schnzavel LV, Papich MG, Divers TJ, et al. Pharmacokinetics and distribution of minocycline in mature horses after oral administration of multiple doses and comparison with minimum inhibitory concentrations. *Equine Vet J* 2011;44:453–458.
8. Cox S, Villarino N, Sommardahl, C et al. Disposition of firocoxib in equine plasma after an oral loading dose and a multiple dose regimen. *Vet J* 2013;198:382–385.
9. O'Grady SE. Various aspects of barefoot methodology relevant to equine veterinary practice. *Equine Vet Educ* 2015;28:321–326.
10. Redding WR, O'Grady SE. Nonseptic diseases associated with the hoof complex. *Vet Clin North Am Equine Pract* 2012;28:416–420.
11. Jordon VJ, Ireland JL, Rendle DI. Does oral prednisolone treatment increase the incidence of acute laminitis? *Equine Vet J* 2017;49:19–25.

[a]Adair HF, Knoxville, TN (personal communication) 2020.
[b]Werner HW, North Granby, CT (personal communication) 2020.
[c]Knottenbelt DC, Killearn, Scotland (personal communication) 2020.
[d]Bain FT, Placitas, NM (personal communication) 2020.
[e]Prednistab®, Henry Schien Animal Health, Dublin, OH 43017.
[f]Minocycline Hydrochloride Capsules, USP 100 mg, Torrent Pharma Inc., Basking Ridge, NJ 07920.
[g]Equioxx, MWI Veterinary Supply Elizabethtown, PA 17022.
[h]Hydrocortisone Ointment USP 2.5%, MWI Veterinary Supply Elizabethtown, PA 17022.
[i]Betamethasone/allantoin ointment, 4-oz jar, Doc Lane's Veterinary Pharmacy, Lexington, KY 40505.
[j]Benzoyl peroxide in 10% acetone, 480 mL, Doc Lane's Veterinary Pharmacy, Lexington, KY 40505.

How to Perform Standing Needle Arthroscopy Beyond the Stifle

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1. Introduction

Joint pathology is the leading cause requiring veterinary referral in horses and a prompt diagnosis is crucial to maximize athletic performance and minimize the progression of osteoarthritis.[1,2] Current advancements in traditional and advanced imaging have improved the diagnostic capabilities of equine veterinarians.[3–5] Nonetheless, arthroscopy remains the gold standard for the diagnosis and/or treatment of most articular pathologies, especially for cartilage evaluation and intra-articular soft-tissue lessions.[3,5–8] Arthroscopy has been traditionally performed under general anesthesia (GA) but nowadays, there are standing arthroscopic techniques reported for diagnostic and treatment purposes to avoid the risks and cost associated with GA.[9–12]

A needle arthroscope[a] has been recently introduced in veterinary medicine and has the potential to change the diagnostic approach of veterinarians as it has been done in the human field for some instances.[13] This technology is portable, affordable, allows direct joint evaluation through a minimally invasive approach, and can be performed in the standing patient. Thus, needle arthroscopy can allow practitioners to bypass the diagnostic limitations found in certain areas difficult to image with traditional and advanced imaging (i.e., stifle and shoulder), to improve the diagnostic capabilities before recommending surgery or advanced diagnostics under GA for cases with unrewarding results after traditional imaging (i.e., carpus, tarsus, and carpal sheath) or to perform standing arthroscopic removal of simple osteochondral fragments in standing patients (i.e., dorso-proximal first phalanx fragments).

The objective of this paper is to describe how to perform standing needle arthroscopy in several synovial structures where its use could be beneficial for diagnostic or therapeutic purposes. In addition, the benefits and limitations of the technique for every region will be highlighted.

2. Materials and Methods

The procedures were carried out with a 1.2-mm diameter and 65-mm long or 100-mm long (only for the shoulder joint) needle arthroscope[a]. This arthroscope has a 10° forward-viewing angle and is reusable (5 to 8 times in general) after performing gas or cold sterilization.

A custom-made splint adjustable in length and foot angle and a splint base adjustable in height and angle were designed in collaboration with an orthotics research center to ensure stable limb flexion during arthroscopic examination of the car-

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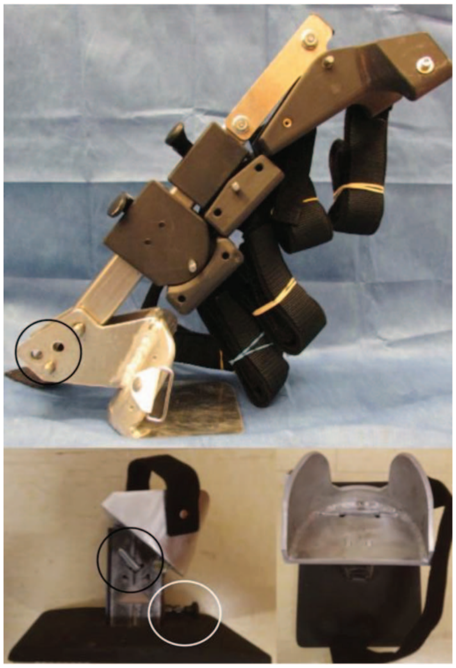

Fig. 1. The top image depicts the custom-made splint. The splint has an adjustable length and foot angle (black circle). The bottom image depicts the splint base, which is adjustable in length (white circle) and angle (black circle).

Fig. 2. A sedated horse positioned inside standing stocks. The white arrow depicts the bag placed below the prepuce to collect urine. A soft mat is to the right of the horse to facilitate the comfort of the technicians and the surgeon.

pus, tarsus, and carpal sheath (Fig. 1). Several segments of the splint were adjustable (vertical length, hoof piece and base angle, height and thickness of padding blocks) to accommodate limbs of different sizes and to warrant sterility during the procedure. Minimal pre-operative splint training was performed with the horses to avoid an acclimation effect.

The technique and feasibility of the needle arthroscope to arthroscopically explore the metacarpo/tarsophalangeal (MCP/MTP), middle carpal (MC), radiocarpal (RC), scapulohumeral (SH), and tarsocrural (TC) joints and the carpal sheath was first assessed in cadaveric specimens. Then, 6 horses without history of musculoskeletal disease were enrolled to validate the use of the needle arthroscope in the aforementioned synovial structures except the MCP/MTP joint (clinical cases only). The studies were approved by the local Institutional Animal Use and Ethics Committee. For the MCP/MTP joint, horses admitted for standing arthroscopic removal of simple osteochondral fragments located in the dorsal recess of the joint were enrolled.

For the synovial structures experimentally evaluated, an intra-articular visualization score was attributed to every articular structure, with 3 for complete visualization, 2 for sub-complete (approximately 51% to 99% of the structure visualized), 1 for partial (approximately 1% to 50% of the structure visualized) and 0 for no visualization.

The pre-operative protocol, arthroscopic technique and post-operative care followed after horses were introduced in standing stocks and sedated with detomidine and butorphanol will be described next for every synovial structure. During the procedure, a light plane of sedation was maintained with a constant rate infusion (CRI) of 0.1% detomidine ± butorphanol titrated as needed. Horses were administered phenylbutazone before and 8 to 12 hours after the procedure. To prevent urine contamination of the surgical field from males, a bag attached to a metallic ring and held in place with a roll of gauze around the abdomen of the horse (Fig. 2) was placed below the prepuce for forelimb surgeries except the SH joint and they were catheterized in a standard fashion for hindlimb surgeries. For mares, a plastic sheet was attached to the back of the stocks and placed right behind the thigh area to prevent urine spillage into the surgical field for hindlimb surgeries. The region of interest was clipped immediately before the procedure.

Metacarpo/Tarsophalangeal Joint (Dorsal Recess)

- Horse position was adjusted within the stocks with a transverse bar placed either cranially (forelimb surgery) or caudally (hindlimb surgery) to increase the distance of the operated limb/s from the stocks' frame. If available, a modified stocks door as used to perform standing tie-back surgery may facilitate distancing the affected limb from the stock frame. The

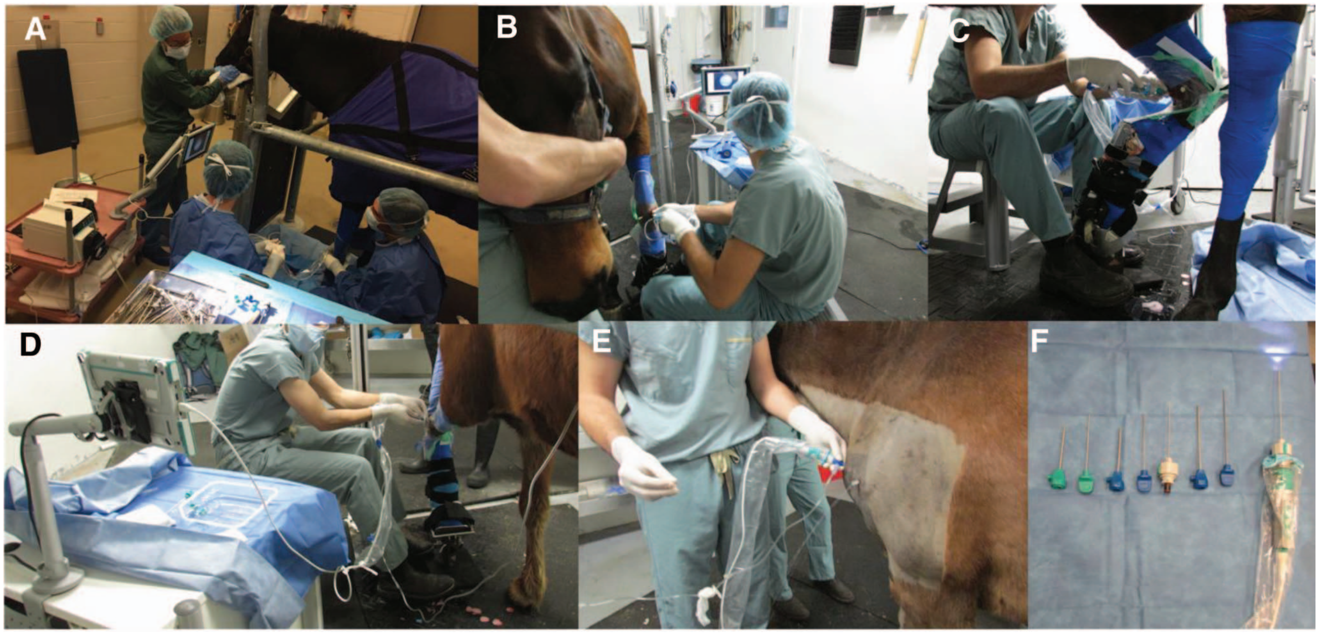

Fig. 3. Set-up to perform standing-needle arthroscopy in the metacarpophalangeal (A), radiocarpal (B), tarsocrural (C), carpal sheath (D), and scapulohumeral (E) joints. 65-mm and 100-mm needle arthroscopes, cannulas (2.4-mm diameter in blue and 2.2-mm in green), and obturators are depicted in the image (F).

horse is covered by a blanket to prevent hair from falling into the surgical field.

- If unilateral hindlimb surgery was performed, a Kimzey splint[b] was placed in the contralateral limb to prevent the horse from resting the affected hindlimb during the procedure. Additionally, butorphanol was not used for hindlimb surgeries to further prevent limb resting.
- Local analgesia, limb preparation, and draping was similar to previously described.[8] Briefly, after aseptic preparation of the fetlock region, a line block just above the dorsal joint recess and intra-articular anesthesia (30 mL) were performed with 2% mepivacaine hydrochloride. In addition, a sterile self-adhesive elastic bandage was placed from proximal cannon bone to mid-radius/tibia to prevent hair from falling into the surgical field. Next, a sterile adhesive drape was placed around the fetlock and then the foot and kneeling mat were covered with a surgical drape first and then, by an adhesive "U" drape.
- The surgeon should kneel just laterally to the affected limb on a soft mat or wear knee pads unless the stocks can be lifted. Additionally, the arthroscopic screen can always be placed cranially (author's preference) or alternated between cranial or caudal according to fragment location, limb affected and/or dominant hand (Fig. 3A).
- A 65-mm-long needle arthroscope and a 2.4-mm outer diameter cannula (regular cannula is 2.2-mm diameter) is recommended to be able to provide enough fluid delivery after an instrument portal is placed (Fig. 3F). Either a pressure infusion bag or a peristaltic pump[c] (author's preference) is used to ensure joint distention during the procedure. Special attention to fluid delivery settings during each phase of surgery is critical to prevent fluid extravasation or joint capsule rupture if a peristaltic pump is used.
- A standard approach to the MCP/MTP joint was carried out after a 3-mm skin incision with an 11# blade was performed.[14] A sharp obturator was used to penetrate the joint capsule perpendicularly to the incision. At this level, cartilage is covered by the synovial plica and cannot be damaged. After joint penetration, the sharp obturator was replaced by a blunt obturator and the cannula and obturator were advanced into the joint in a horizontal direction. Lastly, the blunt obturator was replaced by the arthroscope and joint exploration started.
- At the end of the procedure, 250 to 500 mg of gentamicin or amikacin were injected into the joint. The 3-mm arthroscopic portal was left unsutured to improve cosmetic appearance and prevent suture removal complications for that portal. Routine bandaging was performed for 2 weeks. At 2 weeks, sutures were removed from the instrument portal and hand walking was started.

Middle Carpal and Radiocarpal Joints (Dorsal Recesses)

- The animals were placed slightly outside of the stocks to prevent interference with the stocks' frame. A lower limb bandage was placed and then the splint was attached to the limb to be operated on (Fig. 3B).
- After a first scrub of the carpal region, a line block with lidocaine hydrochloride 2% just proximal to the dorsal aspect of the RC joint and intra-articular anesthesia of both joints with 20 mL of mepivacaine hydrochloride 2% were performed. The carpus was then sterilely prepped and draped as follows: a sterile elastic bandage was placed proximally and distally to the carpus and a sterile adhesive drape was placed around the carpal region.
- After draping, the splinted limb was attached to the splint base to achieve a carpal angle of 110° flexion, which achieved satisfactory evaluation of both joints in cadaveric specimens. This step was purposely done right before arthroscopic exploration to minimize the time horses were held with their carpi flexed.
- The surgeon sat cranio-laterally to the limb during the procedure and used one hand to direct the scope while the other hand was used to held/stabilized the limb. Thus, the 360° sterile draping is recommended.
- Routine dorsal arthroscopic approaches to the carpus were performed after a 3-mm skin incision was done.[14]
- During the procedure, an assistant was available to hold the splinted limb as needed to reduce limb movement. Additionally, the splint base was designed with a wide base to prevent limb rocking and also to allow the surgeon to step on it to further prevent limb movement (Fig. 3B). The described features to minimize limb movement were also used during TC arthroscopy and carpal sheath tenoscopy.
- A 65-mm-long needle arthroscope and a 2.2-mm outer-diameter cannula (regular cannula) was used. A pressure infusion bag was used to ensure joint distention during the procedure.
- Joints were injected with 250 mg of gentamicin at the end of the procedure, incisions were left unsutured, and limbs were routinely bandaged for 4 to 5 days. After this period, horses returned to paddock turnout.

Tarsocrural Joint (Dorsal Recesses and Plantarolateral Recess)

- Horses were placed inside the stock as far as possible from the back to prevent interference with the stocks' frame. A lower limb stable bandage was placed and the splint applied.
- As for the carpus, a regional line block with lidocaine hydrochloride 2% just proximal to the dorsomedial, dorsolateral, and plantarolateral joints recesses was administered following a surgical scrub. Then, intra-articular anesthesia with 20 mL of mepivacaine hydrochloride 2% diluted in 30 to 40 mL of an isotonic solution was administered. The tarsal region and the contralateral limb were next draped as described for the carpal region. Lastly, the splinted limb was attached to the splint base with the tarsus flexed at 90°.
- The surgeon sat cranio-laterally to the limb during the procedure and used one hand to direct the scope while the other hand held/stabilized the limb. Thus, the 360° sterile draping is recommended.
- A 65-mm long-needle arthroscope and a 2.2-mm outer-diameter cannula (regular cannula) was used. A pressure infusion bag was used to ensure joint distention during the procedure.
- As for the previous joints, it is recommended to use the sharp trocar first to pierce the joint capsule and then replace it by the blunt trocar before further advancing the cannula within the joint. This approach ensures a tight seal around the arthroscopic cannula and minimizes fluid extravasation. The dorsolateral approach was made slightly axial to the center of the dorsolateral outpouching and the cannula/obturator were introduced toward the lateral malleolus of the tibia. The dorsomedial approach was made between the extensor tendon bundle and the saphenous vein to maximize joint visualization and the cannula/obturator were introduced toward the medial malleolus of the tibia. The plantarolateral approach was made in the caudocentral to caudoproximal aspect of the outpouching to prevent interference with the lateral trochlea of the talus (Fig. 3C).
- Joints were injected with 250 mg of gentamicin at the end of the procedure, incisions were left unsutured, and limbs were routinely bandaged for 4 to 5 days. After this period, horses returned to paddock turnout.

Carpal Sheath (Proximolateral Recess)

- Horses were either placed slightly outside of the stocks or completely caudally to prevent interference with the stocks' frame. A lower-limb bandage was placed and the splint was attached to the limb to be operated on (Fig. 3D).
- After a first scrub of the lateral carpal region, a line block with lidocaine hydrochloride 2% just proximal to the proximolateral recess of the carpal sheath and intrathecal anesthesia of the sheath with 20 mL of mepivacaine hy-

drochloride 2% diluted in 40 mL of an isotonic solution were performed. A sterile elastic bandage was placed proximally and distally to the carpus and an adhesive drape was circumferentially placed around the carpal region.
- After draping, the splinted limb was attached to the splint base to achieve a carpal angle of 30° from the vertical plane.
- The surgeon sat cranio-laterally to the limb during the procedure and used one hand to direct the scope while the other hand was used to hold/stabilize the limb. Thus, the 360° sterile draping is recommended.
- A routine tenoscopic approach through the proximolateral recess of the carpal sheath (3 cm proximal to the distal radial physis) was performed.[14] In this case, a blunt obturator was used to enter the sheath perpendicular to the limb and then tenoscopic evaluation was carried out.
- A 65-mm long-needle arthroscope and a 2.4-mm outer-diameter cannula was used in anticipation of the higher torque needed to explore the intertendinous recess. A pressure infusion bag was used to ensure joint distention during the procedure.
- The sheath was injected with 250 mg of gentamicin at the end of the procedure. The incision was left unsutured and the limb was routinely bandaged for 4 to 5 days. After this period, horses returned to paddock turnout.

Scapulohumeral Joint

- Horses were placed slightly outside of the stocks to prevent interference with the stocks' frame.
- After a first scrub of the shoulder region, skin and subcutis were anesthetized using a line block proximal to the joint with lidocaine hydrochloride 2%. Next, the SH joint was anesthetized and distended with 20 mL of mepivacaine hydrochloride 2% diluted in 25 mL of an isotonic solution via a cranio-lateral approach with a 18-G spinal needle.
- No draping was used for this joint and the surgeon stood cranio-laterally to the limb during the procedure (Fig. 3E).
- A routine cranio-lateral approach to the SH joint was performed.[14] To facilitate joint entry, the needle used for joint anesthesia and distension was left in place and the cannula and a blunt obturator were directed in the same direction until joint entry.
- A 100-mm long-needle arthroscope and a 2.4-mm outer-diameter cannula was used in anticipation of the higher torque needed to explore this joint. A pressure infusion bag was used to ensure joint distention during the procedure.
- The joint was injected with 250 mg of gentamicin at the end of the procedure. The incision was left unsutured and a sterile adhesive bandage was applied for 24 to 48 hours. Horses were kept in stall rest for 2 to 3 days after the procedure before being turned out in a small paddock.

3. Results

Metacarpo/Tarsophalangeal Joint (Dorsal Recess)

Eight females and 13 geldings, from 1.7 to 11 years of age (mean, 4.5 years; median, 4 years) of different breeds (12 Warmbloods, 4 Quarter Horses, 3 Standardbreds, 1 Friesian, and 1 Lusitano) were operated with the technique.

Dorso-proximal first phalanx fragments were found in 18 horses (24 joints, 30 fragments), fragments embedded in the distal aspect of the synovial plica in 2 horses (2 joints, 4 fragments) and a free-floating fragment believed to have come from the dorsal sagittal ridge of the third metatarsal bone (MT3) in one horse (1 joint). Fifteen of 21 horses (71%) were unilaterally affected and 6 (29%) bilaterally. Thirty-five osteochondral fragments were arthroscopically removed from 27 joints: 15/27 (56%) frontlimbs (9 right and 6 left) and 12 (44%) hindlimbs (7 right and 5 left). One solitary fragment was removed from 19/27 joints (71%) and 2 from 8 (29%) joints.

Patient preparation was approximately 60 minutes while the surgical procedure took 15 to 20 minutes for most patients. Joint visualization was considered equivalent to performing the surgery standing with a 4-mm arthroscope.

Intra-operative complications included mild fluid extravasation in two horses and one horse urinated at the end of hindlimb surgery despite urinary catheterization but did not contaminate the surgical field. Moderate movement during the procedure leading to arthroscope exit and reintroduction was seen in 5/21 horses but only in one after the technique was refined (use of a contralateral Kimzey splint for unilateral hindlimb surgeries and performing the line block just proximal to the joint recess) after the first 5 horses.

No equipment damage occurred and the arthroscopes were reused approximately 5 to 8 times (it was not necessary to reuse them more than 1 to 2 times for the other synovial structures in the study). None of the joints became septic and all arthroscopic incisions were macroscopically healed 2 days postoperatively. This was also the case for the other synovial structures investigated.

The following synovial structures were evaluated in 6 healthy medium-sized breed horses (4 mares and 2 geldings) with a mean age of 9 years old (range, 3–13) and mean weight of 450 kg (range, 380–528).

Middle Carpal and Radiocarpal Joints

Arthroscopy of the RC joint was performed on all horses (3 left and 3 right forelimbs), whereas arthroscopy of the MC (first joint evaluated) was only carried out on the first 3 horses (2 left and 1 right forelimbs). Mild weight-bearing movements during the procedure transiently limited visualization of the caudal aspect of the weight-bearing surface of the bones in the MC joint. This made thorough MC joint evaluation time consuming, which subjectively affected procedure tolerability/movement during RC arthroscopy. Thus, for the following three horses it was decided to explore only one joint and the RC joint was chosen.

For both joints, most IA structures were completely visible from the dorsolateral approaches (radiocarpal joint [RCj] mean dorsolateral visualization score: 2.75 and middle carpal joint [MCj]: 2.83) while they were mainly completely to subcompletely visualized from the dorsomedial approaches (RCj mean dorsomedial visualization score: 2.28 and MCj: 2.12). Despite the superior scores for the dorsolateral approaches, both arthroscopic approaches are recommended for a thorough joint evaluation.

Mean ± SD arthroscopic times for the RCj and MCj were 6.24 ± 1 minute and 9.75 ± 1.75 minute, respectively. Splint wear was well tolerated by all horses. The procedure was considered feasible with only minor complications (mild hemarthrosis in 1/6 and mild iatrogenic damage in 2/6) associated to the technique other than movement. Moderate limb movement occurred in 2 of the 3 first horses where both joints were evaluated during the same procedure.

Tarsocrural Joint

A mean visualization score of 2.53 was obtained for the dorsal arthroscopic approaches (2.69 for the dorsolateral [first approach performed] and 2.38 for the dorsomedial approach [second approach performed]) while only a mean score of 1.88 was obtained for the plantarolateral approach (third approach performed). The main visualization limitation for the dorsolateral approach was partial to subcomplete visualization of the medial malleolus and short medial collateral ligament thereby, thorough evaluation of the dorsal joint recesses requires both arthroscopic approaches.

The lower scores for the dorsomedial and plantarolateral approaches were associated with the presence of profuse hemarthrosis and therefore, limited visualization in 3/6 horses during the dorsomedial approach. The dorsomedial vasculature was damaged during the initial arthroscopic approach in one horse and due to movement (cannula exit and reintroduction) in the two other horses. Additionally, residual deep digital flexor tendon tension prevented arthroscopic evaluation of the plantaromedial structures in one horse. No other complications were seen during the preoperative or post-operative period.

Mean ± SD arthroscopic time to perform the dorsolateral, dorsomedial, and plantarolateral approaches were 2.57 ± 0.65 minutes, 2.55 ± 1.10 minutes, and 5.06 ± 2.05 minutes, respectively.

All 6 horses tolerated the splint and base during the procedure. Nonetheless, 2 horses were shorter and did not require the splint base to achieve a 90° of tarsal flexion.

Carpal Sheath

The procedure allowed complete visibility of most proximal carpal sheath structures up to the carpometacarpal joint level. Nonetheless, visualization of the intertendinous recess was partial in most horses (4/6) due to remaining flexor tendon tension in standing horses. The splint was well tolerated by all horses (6/6) but placement of the splinted limb on the splint base resulted in occasional drastic limb movement during the procedure in one horse. Mean tenoscopic time was 7 ± 3 minutes.

Besides the aforementioned movement in one horse, only mild complications were found: mild and transient intrathecal bleeding in 3/6 horses, mild-to-moderate fluid extravasation in 3/6 horses, and mild cannula bending while accessing the tight intertendinous recess in 2/6 horses.

Scapulohumeral Joint

Joint distraction and limb adduction without joint collapse is not possible in the standing horse, and therefore it was anticipated that the medial aspect of the joint would not be visible.

The joint was arthroscopically accessed on the first attempt in all but one case (2 attempts). The glenoid rim up to 2 cm medially, humeral head and synovial membrane were completely visualized centro-laterally in all cases and caudo-laterally in 3/6. The visualization of the most caudal aspect of the joint was partial in three cases. Visualization of the cranial aspect of the glenoid rim and glenoid notch was partial in two and three cases, respectively, and complete in the remaining cases.

Arthroscopic evaluation took a mean time of 7 minutes (ranging from 5 to 10 minutes). Arthroscope manipulation and maneuverability was considered easy in all instances and all horses tolerated the procedure well without any undesirable movements. Fluid extravasation was encountered in all cases, being mild in 5 cases and moderate in one. Mild iatrogenic cartilage damage during trocar penetration was seen in 2 horses; however, no lesions were identifiable when horses were euthanized 8 months later for reasons unrelated to the project.

Representative arthroscopic and tenoscopic images of all the synovial structures explored are shown in Fig. 4.

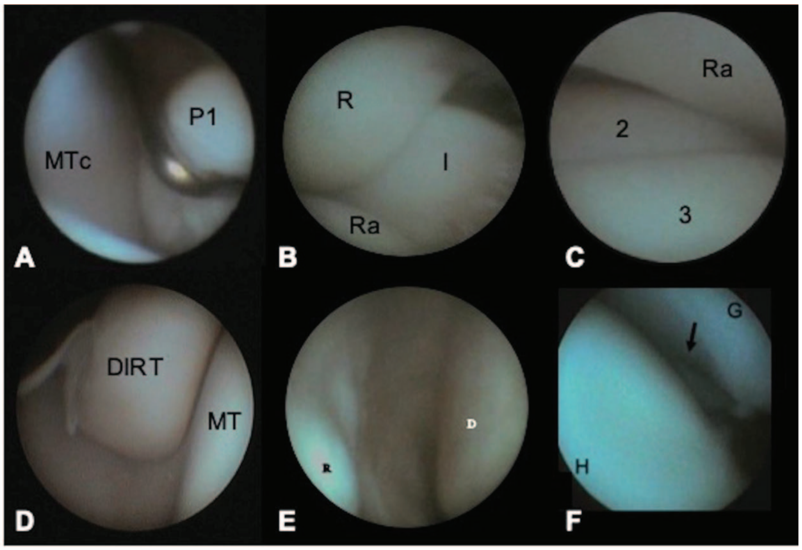

Fig. 4. Representative arthroscopic and tenoscopic images of the metacarpophalangeal joint (A), radiocarpal (B), middle carpal (C), tarsocrural (D), carpal sheath (E), and scapulohumeral joints (F).

4. Discussion

The mortality rate associated with GA has been reported to be approximately 1% in horses. Additionally, other perianesthetic risks are also prevalent and remain significantly higher in horses than in other species.[9] Nonetheless, GA is required to perform arthroscopy and advanced imaging in most instances due to the size and temperament of horses. Moreover, traditional imaging has a limited diagnostic accuracy in certain regions (i.e., shoulder), yields a moderate diagnostic rate for certain articular lesions and does not offer information regarding cartilage health.[4,14,15] For example, radiography and ultrasonography still miss a percentage of intra-articular soft-tissue injuries and osteochondrosis dissecans lesions in the tarsus, especially for osteochondrosis lesions at the level of the medial malleolus (sensitivity of 71% and 83%, respectively).[7,8] In the carpus, some lesions such as nonmarginal osteochondral fragments, cartilage damage, and palmar intercarpal ligament tearing can be radiographically silent and difficult to diagnose preoperatively.[16–18] Lastly, a definitive diagnosis for soft-tissue pathologies involving the carpal sheath require an expert ultrasonographer and tenoscopy remains the gold standard for diagnostics.[19] Thus, the use of standing arthroscopic techniques for diagnostic purposes will eliminate the risks associated with GA and may improve the diagnostic rate before a treatment is pursued. Additionally, good characterization of the lesions will provide clients with a more accurate prognosis before pursuing surgery and will help veterinarians with surgical planning. Finally, the technique could also be used as a second-look arthroscopic technique for clinical or research purposes.

The techniques reported offered a quick, safe, and reliable diagnostic evaluation of the investigated synovial structures but as for other diagnostic techniques, they are not exempt of limitations. General and specific limitations and tips are discussed below.

1. Needle arthroscopy is mainly conceived for diagnostic purposes but a therapeutic use has been shown for the dorsal compartment of the fetlock and could also be possible for simple osteochondral lesions in other regions. Nevertheless, further investigations are needed before it can be recommended.
2. The needle arthroscope has a 10° lens viewing angle and the field of view is smaller. This translates to working closer to the area of interest and having a sub-complete to partial visualization for certain structures during specific arthroscopic approaches (i.e., limited visualization of the medial malleolus of the tibia from the dorsolateral approach and of some carpal structures from a contralateral arthroscopic approach). To minimize this limitation, a good arthroscopic knowledge is mandatory before attempting the technique. Also, some joints (i.e., MC, RC, and TC) will require two arthroscopic approaches to obtain a thorough joint evaluation. Lastly, the required arthroscope and console are specialized equipment and require a practice investment.
3. Fluid delivery could be a problem if an instrument portal or intense joint lavage (i.e., moderate hemarthrosis is present) is required. This could be completely or partially solved by using the 2.4-mm diameter

cannula and a peristaltic pump. Additionally, a needle can be used to allow joint lavage in cases of mild hemarthrosis or darkening of the synovial fluid. This needle can also be used to retract the synovium from the field of view as required.

4. Joint distension is usually achieved at the same time that anesthetics are delivered. Nevertheless, anesthetics can leak into the subcutis by the time of the procedure and lead to suboptimal distension. In those cases, it is recommended to redistend the joint immediately before arthroscopic entry to minimize the possibilities of iatrogenic cartilage damage.
5. A custom-made splint and a base were designed to obtain the required tarsal and carpal angle for the procedures while ensuring sterility. The current splint fits forelimbs and hindlimbs of different sizes and has a heavy and wide base to minimize horse movement during the procedure. Unfortunately, the splint is not yet commercially available and performing the procedure with other commercially available splints will likely jeopardize sterility. In contrast, the author anticipates that standing carpal sheath tenoscopy could be performed with commercially available splints without risking the sterility of the procedure.
6. Horse temperament should be taken into consideration before attempting the technique to prevent horse, personnel, or equipment damage. Anxious or unbroken horses or horses that cannot get rapidly acclimated to splint use are not good candidates. The research horses used for the experimental arthroscopies received minimal splint training before the procedures to prevent an acclimation effect. Additionally, the behavior was unknown before acquiring these horses for the studies.
7. Despite good splint tolerance, horses may move during the procedure and limit or lengthen the procedure. Several steps can be put in place to reduce/minimize this movement: 1) Appropriate sedation and analgesia. A relatively light plane is preferred to prevent animals from resting the limb to be operated on or being wobbly. 2) Local and intrasynovial anesthesia is mandatory. 3) Excellent arthroscopic knowledge is crucial to minimize procedure time. 4) Minimize the time horses wear the splint base, if required for the procedure, and therefore, they are partially weight bearing on the limb. 5) Have an assistant available to hold the limb as required and step on the wide splint base to further improve limb stability.
8. The unsutured arthroscopic portals are macroscopically healed around 2 days after the procedure and no septic synovitis have been encountered. Leaving the portals unsutured avoids a recheck appointment for suture removal, which reduces cost for clients and improves cosmetics. Nevertheless, the use of cyanoacrylate glue or wound closure strips could be used if desired.
9. When the technique was used for diagnostic purposes, horses required a short convalescence period (4 to 5 days maximum) before turnout was resumed. This period is significantly shorter than after performing therapeutic arthroscopy. Nevertheless, a therapeutic procedure may follow diagnostic needle arthroscopy in many cases.
10. No clinical cases were included for the synovial structures experimentally evaluated and therefore, further investigations are needed to determine other benefits and limitations of the technique. As clinical cases are recruited, it will be easier to determine the diagnostic accuracy of the technique for the different pathologies and synovial structures.
11. MC/MTP joint: Standing arthroscopy of the MC/MTP joint for diagnostics or for removal of simple dorsal osteochondral fragments is undoubtfully beneficial for horses. However, many surgeons still prefer to do the technique under GA due to concerns regarding surgeon position during the procedure, equipment damage, or familiarity with the technique. The reported technique is safe for horses and personnel and in case of damage, needle arthroscopes are significantly cheaper than a traditional 4-mm arthroscope. Nonetheless, equipment damage is rare to occur with either arthroscope. The author found that the learning curve for the technique was not steep and the MC/MTP joint is likely a good starting point for surgeons willing to initiate on standing arthroscopy. The landmarks and intra-articular structures of the MC/MTP joint are simple to identify for surgeons already familiar with traditional arthroscopic techniques.
12. MC/RC joints: Horses only tolerate partial weight bearing on a forelimb for a very limited time. Thus, moderate movement occurred in 2/3 horses when both joints were performed at the same time and only the RC joint was evaluated for the remaining 3 horses. It is recommended to explore one joint at a time to minimize limb flexion time and movement and therefore, increase procedure tolerability. Nevertheless, it is uncommon that both joints will need to be evaluated in clinical cases. For most clinical scenarios, it is recommended that both dorsal approaches be performed for a thor-

ough joint evaluation. This is also recommended for traditional carpal arthroscopy under GA.[14]

13. TC joint: The dorsolateral approach is safe and allowed an exhaustive evaluation of the joint except for the medial malleolus and the short medial collateral ligament. Thus, it is possible to perform only this approach unless concerns are focused on the most medial aspect of the joint or a thorough joint evaluation is desired. Profuse hemarthrosis was a significant complication when the dorsomedial approach was performed. This was mostly related to reintroduction of the arthroscope after the horse has moved (2/3 horses). At this point, the dorsomedial vasculature may have rolled under the original incision and the surgeon inadvertently punctured it. Thus, critical attention is required while performing the original dorsomedial approach or reintroducing the cannula to avoid the saphenous vein and its branches. Alternatively, a larger incision could be performed to clearly determine the absence of vasculature before cannula introduction.
14. Carpal sheath: This technique offered a thorough evaluation of the proximal sheath structures, where pathology tends to occur, except the intertendinous recess (partial evaluation in 4/6 and complete in 2/6). This was associated with residual tendon tension during the standing procedure, which could potentially be resolved by having the limb held by an assistant while the practitoner explores the region. Evaluation of the intertendionus region is important to detect tearing of the superficial digital flexor tendon accessory ligament. Nevertheless, all reported cases with this lesion have also been tenoscopically identified medial to craniomedial to the deep digital flexor tendon and this technique has the potential to identify them at this location.[20]
15. Scapulohumeral joint: This technique did not offers thorough a joint evaluation as arthroscopy under GA does because it was impossible to obtain joint distraction and limb adduction with the animal standing. Nonetheless, the craniolateral, centrolateral, and caudolateral aspect of the glenoid rim and the humeral head are visible and pathology can be identified at this level. The technique described does not identify some conditions involving the SH joint but the simplicity of the procedure should encourage surgeons to use it due to its diagnostic potential. The technique is very similar to performing an SH joint injection. Moreover, the technique could also be used as a screening tool to better select surgical candidates.

5. Conclusion

The described techniques mainly offer an alternative diagnostic tool for a subset of cases where traditional imaging modalities are unrewarding or fail to obtain a definitive diagnosis. Additionally, it may be useful for horses where an accurate prognosis is required before arthroscopic treatment under GA is pursued (cartilage evaluation and extent of cartilage and soft-tissue damage). Lastly, the technique has the potential to be used as a second-look arthroscopic technique to monitor healing/damage in clinical and research settings. Further investigations are needed to determine its applicability in clinical cases as joint visualization, limb movement, and splint tolerance may be challenging in horses with pathology.

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Declaration of Ethics

The Author has adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

There is an agreement between the University of Montreal and the orthotics center Topmed to seek the commercialization of the custom-made splint and base in the near future. The author is one of the co-inventors of the splint.

References and Footnotes

1. Clegg P. Clinical insights: Recent developments in equine articular disease (2016–2018). *Equine Vet J* 2018;50:705–707.
2. Declercq J, Martens A, Maes D, et al. Dorsoproximal proximal phalanx osteochondral fragmentation in 117 Warmblood horses. *Vet Comp Orthop Traumatol* 2009;22:1–6.
3. Hinz A, Fischer AT. Comparison of the accuracy of radiography and ultrasonography for detection of articular lesions in horses. *Vet Surg* 2011;(40):881–885.
4. Denoix JM. Ultrasonographic examination of joints, a revolution in equine locomotor pathology. *Bull Acad Vét France* 2099;162:313–325.
5. Von Engelhardt LV, Lahner M, Klussmann A, et al. Arthroscopy vs. MRI for a detailed assessment of cartilage disease in osteoarthritis: Diagnostic value of MRI in clinical practice. *BMC Musculoskelet Disord* 2010;11:75.
6. Greet TRC. Arthroscopy: A chance to cut or cure? *Equine Vet J* 1991;23:151–152.
7. Relave F, Meulyzer M, Alexander K, et al. Comparison of radiography and ultrasonography to detect osteochondrosis lesions in the tarsocrural joint: A prospective study. *Equine Vet J* 2009;41:34–40.
8. Barker WHJ, Smith MRW, Minshall GJ, et al. Soft tissue injuries of the tarsocrural joint: A retrospective analysis of 30

cases evaluated arthroscopically. *Equine Vet J* 2013;45: 435–441.
9. Senior JM. Morbidity, mortality, and risk of general anesthesia in horses. *Vet Clin North Am Equine Pract* 2013;(1): 1–18.
10. Elce YA, Richardson DW. Arthroscopic removal of dorsoproximal chip fractures of the proximal phalanx in standing horses. *Vet Surg* 2002;31:195–200.
11. Frisbie DD, Barrett MF, McIlwraith CW, et al. Diagnostic stifle joint arthroscopy using a needle arthroscope in standing horses. *Vet Surg* 2014;43:12–18.
12. Bonilla AG. Standing needle arthroscopy of the metacarpophalangeal and metatarsophalangeal joint for removal of dorsal osteochondral fragmentation in 21 horses. *Vet Comp Orthop Traumatol* 2019;32:420–426.
13. Deirmengian CA, Dines JS, Vernace JV, et al. Use of a small-bore needle arthroscope to diagnose intra-articular knee pathology: Comparison with magnetic resonance imaging. *Am J Orthop (Belle Mead NJ*) 2018;47(2).
14. McIlwraith CW, Nixon AJ, Wright IM. *Diagnostic and surgical arthroscopy in the horse.* 4th ed. St. Louis, MO: Elsevier; 2015; 19.
15. Redding WR, Pease AP. Imaging of the shoulder. *Equine Vet Educ* 2010;22:199–209.
16. Graham RJTY, Rosanowski SM, McIlwraith CW. A 10-year study of arthroscopic surgery in racing Thouroughbreds and Quarterhorses with osteochondral fragmentation of the carpus. *Equine Vet J* 2020;52:225–231.
17. Beinlich CP, Nixon AJ. Prevalence and response to surgical treatment of lateral palmar intercarpal ligament avulsion in horses: 37 cases (1990–2001). *J Am Vet Med Assoc* 2005; 226:760–766.
18. Kannegieter NJ, Burbidge HM. Correlation between radiographic and arthroscopic findings in the equine carpus. *Australian Vet J* 1990;67:132–133.
19. Jorgensen JS, Stewart AA, Stewart MC, et al. Ultrasonographic examination of the caudal structures of the distal antebrachium in the horse. *Equine Vet Educ* 2010;22:146–155.
20. Minshall GJ, Wright IM. Diagnosis and treatment of intrathecal tears of the accessory ligament of the superficial digital flexor. *Equine Vet J* 2015;47:48–53.

[a]BioVision Technologies, 17301 W Colfax Ave., #305, Golden, CO 80401.
[b]Kimzey, Inc., 164 Kentucky Ave., Woodland, CA 95695.
[c]Masterflex L/S series, Easy-load II, Cole-Parmer Canada Company, Canada.

Computed Tomographic Assessment of Brain Damage by Various Firearms to Determine Euthanasia Efficacy of Horses

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Computed tomography showed consistent damage to the cerebrum, cerebellum, and brainstem in equine cadaver heads shot by the included firearm-ammunition combinations by using a novel aiming point. Authors' addresses: Department of Surgical Sciences, School of Veterinary Medicine (Lund, Waller, Brounts); Department of Biostatistics and Medical Informatics (Hetzel), University of Wisconsin, Madison, WI 53706; Irongate Equine Clinic, 1848 Waldorf Blvd., Madison, WI 53719 (Ketover); e-mail: jrlund@uwalumni.com. *Corresponding and presenting author.

1. Introduction

Disposal of equine carcasses euthanized with pentobarbital is becoming increasingly restricted. Pentobarbital-tainted dog food has led to decreased acceptance of equine cadavers by rendering facilities. Research has indicated that there is limited degradation of pentobarbital over a yearlong period when composting carcasses of equines euthanized with pentobarbital. There is also an increased general awareness of the role veterinarians play in protecting the natural environment and wildlife. These conditions have led to a need for additional knowledge regarding alternative euthanasia methods.

2. Materials and Methods

The authors conducted computed tomography studies of 53 equine cadaver heads that had been shot with 1 of 6 firearm-ammunition combinations by using a novel anatomical aiming point where the 2 temporalis muscles form an inverted V. The scans were evaluated for damage to the cerebrum, cerebellum, brainstem, and spinal cord.

3. Results

Consistent damage was caused to the cerebrum, cerebellum, and brainstem of equine cadaver heads with each of the firearm-ammunition combinations. There was statistically different types of damage caused by the firearm-ammunition combinations.

4. Discussion

The firearms and ammunition combinations examined in this study using a novel aiming point are reasonable options for equine euthanasia.

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Research Abstract—for more information, contact the corresponding author

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Declaration of Ethics

The Authors have adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Authors have no conflicts of interest.

Evaluation of the Local and Systemic Inflammatory Response to Anthelmintic Therapy: Is Killing Encysted Parasites Better?

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In clinically healthy horses, the proinflammatory responses are minimal following macrocyclic lactone treatment; however, they are lowest in the horses treated with moxidectin and highest in the untreated controls. Further work is needed to elucidate the importance of these processes in horses with larval cyathostominosis. Authors' addresses: Maxwell H. Gluck Equine Research Center, Department of Veterinary Science, University of Kentucky, Lexington, KY 40503 (Steuer, Barker, Scoggin, Page, Adams, Nielsen); Lexar Laboratories, 3221 Summit Square Pl #100, Lexington, KY 40509 (Stewart); Veterinary Diagnostic Laboratory, Department of Veterinary Science, University of Kentucky, Lexington, KY 40511 (Loynachan); e-mail: ashley.steuer@uky.edu. *Corresponding and presenting author.

1. Introduction

Cyathostomins are pervasive parasites of horses. In rare cases, mass excystment of larvae can lead to life-threatening disease. Anthelmintic treatment can target both the adults in the large intestine and/or the encysted larvae. Anthelmintics that are adulticidal only, such as ivermectin, have been implicated in cyathostomin disease. However, concerns have been raised that killing larvae while encysted within the mucosal walls could lead to adverse reactions as well.

2. Materials and Methods

This study evaluated the local and systemic inflammatory reaction to two different macrocyclic lactones: moxidectin, which is both adulticidal and larvicidal, and ivermectin, which is adulticidal only. Briefly, 36 horses were allocated into one of 3 groups: moxidectin treated, ivermectin treated, and an untreated control group. Half the horses from each group were euthanized at 2 weeks posttreatment, and the other half at 5 weeks posttreatment. Weekly blood samples were collected throughout the study for gene expression evaluation. Tissue samples were collected from the cecum, ventral, and dorsal colon for histopathology and gene expression at the 2 and 5 weeks posttreatment.

3. Results

Of the three groups, the moxidectin-treated group had a significantly lower proinflammatory response,

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followed by the ivermectin-treated group, and then the untreated controls.

4. Discussion

The data suggest that removal of cyathostomins will reduce the proinflammatory response associated with infections. In conclusion, proinflammatory reactions to anthelmintic treatment was minimal, but lowest for moxidectin-treated horses. Further work is needed to elucidate the exact mechanisms involved with the regulation of worm burdens and worm expulsion.

Acknowledgments

Finding Source

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Declaration of Ethics

The Authors have adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

The Authors have no conflicts of interest.

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