Proceedings of the 69th Annual Convention of the American Association of Equine Practitioners

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ACKNOWLEDGMENTS
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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

2024	25th Resort Symposium	Guanacaste, Costa Rica	January 22–24
2025	26th Resort Symposium	Maui, Hawai'i	January 20–22
2024	Focus on Field Practice	Fort Collins, Colorado	August 1–3
2025	Foundational Skills in Equine Practice	Tucson, Arizona (TBC)	Winter (TBC)
2024	70th Annual Convention	Orlando, Florida	December 7–11
2025	71st Annual Convention	Denver, Colorado	December 6–10
2026	72nd Annual Convention	Las Vegas, Nevada	December 6–10

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 2023 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 141 papers were submitted for the 57 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 over 50 members of the SREC to create the best possible program for the AAEP membership. Many volunteer hours were spent putting together the 2023 program, so please thank them for all their hard work creating this program for you.

From Your President

American Association of Equine Practitioners
4075 Iron Works Parkway • Lexington, KY 40511
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Dear AAEP Members, Family, and Friends:

Howdy! Welcome to beautiful San Diego, California and the 69th Annual Convention of the American Association of Equine Practitioners (AAEP).

It is my pleasure to share an engaging, enlightening educational program chaired by your President-Elect, Dr. Katie Garrett, and the Educational Programs Committee (EPC). A special tip of the hat to Dr. Garrett and her EPC co-chairs, Drs. Erin Contino and Luke Bass and the tireless efforts of this committee and the Scientific Review and Editorial Committee. The AAEP is unique in our editorial rigor that includes all invited and submitted papers prior to presentation. While peer review may not be a standard at all continuing education events, it is paramount to the success and knowledge of the horse doctor, and the AAEP values this process tremendously.

While we will be presenting the state-of-the-art of equine veterinary science, you will also find a blend of practical knowledge and experience featured in the table topics, round tables, sunrise sessions, wellness, and business sessions.

Maintaining a balance of scientific and practical information has always been a high priority for the EPC. The way information is shared has changed over time and I think you will find a response to the requests to enhance the convention with more small group sessions, online access to education, and improved member technology with the AAEP On The Go App.

In case you do miss a session, convention recordings will be available to those who register for the convention, either in person or virtual. The recordings will be available indefinitely, and CE will be available till the end of 2024.

The Trade Show is also scheduled for you this year to see the latest technology, equine products, medications, diagnostics and more in the three-day opening period. You will note a longer lunchtime so that you don't have to worry about missing a valuable lecture and getting around to visiting the vendors and Educational Partners.

The association has been very focused on the Commission on Equine Veterinary Sustainability over the past three years. Hopefully, you have been following the growing body of work being performed by the five subcommittees: Students, Internships, Practice Culture, Emergency Duty, and Compensation. Updates, tool kits, case studies, best practices, and more will be rolled out throughout the convention as we seek to change the numbers and support a thriving next generation of horse doctors. I hope you will consider being the change you wish to see in the profession as the Commission only realizes change when we make improvements to our individual lives, practices, classrooms, laboratories, offices, and trucks.

One of the most important aspects of the annual convention is the opportunity for connection and networking among colleagues. Explore the many social opportunities, alumni receptions, California-style Vet Story Night and the After Party on Saturday night.

Educate yourselves! Enjoy camaraderie! Encourage each other!

Iron Sharpens Iron



Rob Franklin, DVM, DACVIM
AAEP 2023 President

Raising the Standard in Horse Health

From the Program Chair and President-Elect

American Association of Equine Practitioners
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Hello and welcome to San Diego! Hopefully you will find a little bit of everything at this convention: education, social activities, roundtable discussions, and time to catch up with friends.

First, I want to extend my thanks to the members of the Scientific Review and Editorial Committee and Educational Programs Committee for their hard work putting together the educational program not only for this convention, but for the other AAEP educational programs offered throughout the year. An extra special thank you goes to Dr. Erin Contino and Dr. Luke Bass, the chairperson and vice-chairperson of the Educational Programs Committee for their leadership during a very busy year. I'd also like to recognize the AAEP staff as well as the Board of Directors for their hard work throughout the year, as well as the AAEP Educational Partners, Media Partners, and many sponsors for making this meeting possible.

I want to make sure to highlight some of the work of the AAEP's Commission on Equine Veterinary Sustainability. Although the Commission was formed just over one year ago, the subcommittees (Compensation, Internships, Practice Culture, Emergency Coverage, and Students) have already produced great work with more to come. The overarching goal of the commission is to understand the current challenges facing equine practitioners and to create and provide resources to help meet these difficult realities. Initial work focused on understanding the problems, but we have progressed to rolling out solutions. I encourage you to attend some of the Commission programming at this convention, including round table sessions for each subcommittee on Wednesday afternoon, a Friday afternoon session titled "I Am Change," an ethics panel on Saturday morning, and various table topics throughout the convention. We also have a variety of resources available online with more being added all the time. (scan the QR code to access).

Some highlights of the convention include:

- A keynote address by Cassandra Worthy who will be talking to us about discovering enthusiasm for change.
- The Milne Lecture, this year given by Dr. Pat McCue on equine reproduction at a new time on Thursday afternoon.
- Lunchtime chats in the trade show where you can eat with colleagues who share your interests in both veterinary and non-veterinary topics.
- The new Burst session, featuring dynamic 5-minute presentations on a wide variety of practical topics.
- A variety of opportunities for socializing, including the Opening Reception on Wednesday, the trade show reception on Thursday, alumni receptions on Friday, and the After Party on Saturday.
- If you'd like to get some exercise in, we have morning exercise programs Friday and Saturday.

Finally, don't forget that your registration includes access to the virtual convention as well. You can watch all the main sessions at your convenience after the convention (and still earn CE credits until the end of the year), so don't worry if you can't get to every session in person in San Diego. A selection of table topics will be presented live the week after the convention as part of the virtual convention also.

Have a wonderful meeting!

Sincerely,

Katie Garrett, DVM, DACVS
2023 Program Chair and President-Elect

Raising the Standard in Horse Health

2023 AAEP Board of Directors

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2023 AAEP Awards

Distinguished Life Member – Dr. Kenton Morgan
Awarded to a member in recognition of their outstanding contributions to the association throughout their career.

Distinguished Educator Award (Academia) – Dr. Michelle Barton
Awarded to an individual educator who by his or her actions and commitment has demonstrated a significant impact on the development and training of equine practitioners.

Distinguished Educator Award (Mentor) – Dr. Ryland Edwards, III
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 – Dr. Julie Wilson
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.

General Guidelines for All Papers
70th AAEP Convention
Orlando, Florida
December 7–11

ALL papers must be submitted online

https://www.abstractscorecard.com/cfp/submit/login.asp?EventKey=WFRZSOAH

by March 15, 2024, 3:00 p.m. E.T.

ALL papers must be submitted online by March 15, 2024, 3:00 p.m. E.T. Under no circumstances will submissions received after the deadline be considered or reviewed. ALL deadlines must be followed to have the published proceedings available at the meeting.

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, ≤ 300 word abstracts, and Business papers can be found in their respective sections.

Formatting and Style:

- 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".

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 footnotes.

Dosages, weights and measures 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)

Section Headings:

Please refer to the specific guidelines for your paper to see required section headings.

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:

i. Declaration of Ethics
ii. Conflicts of Interest
iii. Funding/Material/Technical Support

General acknowledgment considerations:

- 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.
- All submissions should cite levels of evidence-based medicine.

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

Conflicts of Interest:

- 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. (This includes ownership, employment, consultancy arrangements, or service as an officer or board member.) The submitting author is required to confirm whether they or any co-authors listed have any actual or potential conflicts of interest, and to provide details during the online submission process. It is the submitting author's responsibility to ensure that all authors adhere to this policy.

Example of COI Statement:
Dr. John Doe has no conflicts 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.

Funding Sources:

- Authors are expected to acknowledge all sources of funding or support for the work described and to disclose to the review committee 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 of the paper.

References:

References should conform to JAVMA's guidelines.

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:

1. Auer JA, Martens RJ, Williams EH. Periosteal deformities in foals. *Am J Vet Res* 1982;181:459–466.
2. 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:

1. Turner AS, McIlwraith CW. *Techniques in large animal surgery*. Philadelphia: Lea and Febiger, 1982;186–191.
2. Banks P, Bartley W, Birt LM. *The biochemistry of the tissues 2nd ed*. London: John Wiley & Sons, 1968;24.
3. Devlin TM, ed. *Textbook of biochemistry with clinical correlations*. New York: John Wiley & Sons, 1982;14–36.

Chapter in a book:

1. Axelrod B. Glycolysis. In: Greenberg DM, ed. *Metabolic pathways, vol 1. 3rd ed.* New York: Academic Press, 1967;112–145.
2. 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:

1. Divers TJ. Acute renal failure in horses and cattle, in *Proceedings*. 3rd Am Coll Vet Int Med Forum 1985;93–95.
2. 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:

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

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

c. Smith AB. Unpublished data. January 1990.

Product and Equipment Names:

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 (city, state, and 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:

- 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.

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 and Medical Devices:

To be considered for selection in 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 (2005). 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 abstract.

An exception to this policy will be made for abstracts 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 be reviewed by an individual with expertise in this area. The individual will then make a recommendation to the SREC about the suitability of the submission for potential inclusion in the program.

Scientific Papers: Guidelines for Authors 70th AAEP Convention Orlando, Florida December 7–11

ALL papers must be submitted online by March 15, 2024, 3:00 p.m. E.T.

Please make sure you have reviewed the General Guidelines.

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

The quality of the Scientific Paper will determine the selection. Missing data or proposed, but not completed, procedures will exclude the Scientific 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 Guidelines and should be no fewer than 600 words, with no upper word limit.

Section Headings:

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

1. Paper Title
2. Take Home Message
3. Introduction
4. Materials and Methods
5. Results
6. Discussion
7. Acknowledgments
   i. Declaration of Ethics
   ii. Conflicts of Interest
   iii. Funding/Material/Technical Support
8. References

Paper Title:

The title should clearly identify the technique or procedure that will be presented.

> Example:
> An Investigation of Regions Desensitized Following Intra-articular Analgesia of the Coffin Joint

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)

> 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 & Methods:

The Materials and Methods 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:

The Results section should include 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:

In the Discussion section, 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.

Acknowledgments:

i. Declaration of Ethics
ii. Conflicts of Interest
iii. Funding/Material/Technical Support

Full instructions for Acknowledgments can be found in the General Guidelines.

References:

References should conform to JAVMA's guidelines.

Full instructions for References can be found in the General Guidelines.

The "How to" Paper: Guidelines for Authors 70th AAEP Convention Orlando, Florida December 7–11

ALL papers must be submitted online by March 15, 2024, 3:00 p.m. E.T.

Please make sure you have reviewed the General Guidelines.

"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 should be formatted as described in the General Guidelines and should be no fewer than 600 words, with no upper word limit.

Section Headings:

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

1. Paper Title
2. Take Home Message
3. Introduction
4. Materials and Methods
5. Results
6. Discussion
7. Acknowledgments
   i. Declaration of Ethics
   ii. Conflicts of Interest
   iii. Funding/Material/Technical Support
8. References

Paper Title:

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

Take Home Message:

Example:
How to Obtain Diagnostic Dental Radiographs

This should be a concise summary of the main conclusion and should be no longer than two or three sentences (approximately 50 words)

Example:
This paper will help practitioners improve their skills in dental radiography, which will improve recognition of radiographic signs of dental and paradental pathology.

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 & Methods:

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 footnotes.

Results:

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.

Discussion:

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.

Acknowledgments:

i. Declaration of Ethics
ii. Conflicts of Interest
iii. Funding/Material/Technical Support

Full instructions for Acknowledgments can be found in the General Guidelines.

References:

References should conform to JAVMA's guidelines.

Full instructions for References can be found in the General Guidelines.

Review Paper: Guidelines for Authors 70th AAEP Convention Orlando, Florida December 7–11

ALL papers must be submitted online by March 15, 2024, 3:00 p.m. E.T.

Please make sure you have reviewed the General Guidelines.

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 be formatted as described in the General Guidelines and should be no fewer than 600 words, with no upper word limit. The content of review articles should be organized with headings and subheadings that provide a logical flow to the material presented.

Section Headings:

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

1. Paper Title
2. Take Home Message
3. Introduction
4. Review of Topic/Information
5. Discussion
6. Acknowledgments
   i. Declaration of Ethics
   ii. Conflicts of Interest
   iii. Funding/Material/Technical Support
7. References

Paper Title:

The paper should be titled "Review of Some Subject" and should clearly identify the topic that will be presented.

Example:
Review of Upper Respiratory Dysfunction in Horses During High-Speed Exercise

Take Home Message:

A "Take Home Message" should be provided that summarizes the practical application of the information for the practitioner. This should be a concise summary of the main conclusion and should be no longer than two or three sentences (approximately 50 words).

Example:
There are many upper respiratory conditions that can impact a horse's performance during high-speed exercise. Differentiating between these conditions allows for the most appropriate treatment and optimizes outcome.

Introduction:

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. 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.

Review of Topic/Information:

Review of significant published information should be included here. Agreement and disagreement within the subject matter should be identified along with the strengths and limitations of the information sources. Subheadings can be used within this section to break down the material, as appropriate. Reference should be made to the authors who generally support the opinions stated.

Discussion:

In the Discussion section, the author can give their personal views or commentary of the reviewed topic/information. The author's perspective, including their 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.

Acknowledgments:

i. Declaration of Ethics
ii. Conflicts of Interest
iii. Funding/Material/Technical Support

Full instructions for Acknowledgments can be found in the General Guidelines.

References:

References should conform to JAVMA's guidelines.

Full instructions for References can be found in the General Guidelines.

Abstracts ≤300 words: Guidelines for Authors *For those who intend to publish in a refereed journal* 70th AAEP Convention Orlando, Florida December 7–11

ALL papers must be submitted online by March 15, 2024, 3:00 p.m. E.T.

Please make sure you have reviewed the General Guidelines.

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 should be ≤300 words. These "abbreviated abstracts" should follow a structured format with the same headings (see below) as the full-length scientific paper. Please be aware that the Take Home Message is included in the total word count. The abbreviated abstract does not need references, but appropriate acknowledgments should be included. Note this abbreviated abstract is not applicable to Review, How-to, or In-Depth Papers. **A 1500-word long paper** conforming to the General Guidelines 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. 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 the refereed journal. These submitted abbreviated abstracts should be identified with the words "RESEARCH ABSTRACT" at the end of the title.

Guidelines for Abstracts

- Abstracts should be ≤300 words. They can be longer; however, this is dependent on the journal in which the author wishes to submit the full paper. Journals differ in what they consider to be "prior publication", e.g., *Equine Veterinary Journal* (EVJ) currently will allow an author to submit an abstract up to 1000 words whereas some journals allow fewer words. It is the author's responsibility to contact the respective journal to discuss their prior-publication criteria so that their accepted abbreviated abstract will not jeopardize their publication in the refereed journal.

Section Headings:

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

1. Paper Title
2. Take Home Message
3. Introduction
4. Materials and Methods
5. Results
6. Discussion
7. Acknowledgments
   i. Declaration of Ethics
   ii. Conflicts of Interest
   iii. Funding/Material/Technical Support
8. References are required for the full paper but not the abstract

Paper Title:

The title should clearly identify the technique or procedure that will be presented.

Example:
An Investigation of Regions Desensitized Following Intra-articular Analgesia of the Coffin Joint

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)

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 & Methods:

The Materials and Methods 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 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:

The Results section should include actual results with numbers and data. 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 [CI]) in addition to the results of hypothesis testing. If the data can be well represented with a graph or figure, these are encouraged. 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:

In the Discussion section, 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.

Acknowledgments:

i. Declaration of Ethics
ii. Conflicts of Interest
iii. Funding/Material/Technical Support

Full instructions for Acknowledgments can be found in the General Guidelines.

References:

References are required for the full paper but not the abstract.

A full paper must be included with all abstracts to be considered for the program.

Business and Practice Life Papers: Guidelines for Authors 70th AAEP Convention Orlando, Florida December 7-11

ALL papers must be submitted online by March 15, 2024, 3:00 p.m. E.T.

Please make sure you have reviewed the General Guidelines.

The general theme for the 2024 Business of Practice Life Sessions is "Preparing for the Practice of the Future." Some 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 accepted papers are allotted a total speaking time of 20 minutes (15 minutes presentation time + 5 minutes for questions). The following topic suggestions are intended to spark ideas that relate to the theme; however, we also welcome paper submissions on any topic pertaining to the Business and/or Practice Life.

Potential Topics:

- How to pay employees more and still be profitable
- Pricing strategies
- How to manage staff and clients
- Collaboration between veterinarians and technicians
- Collaboration with boundaries
- Managing inventory in new age
- Utilizing technology
- Communication through technology
- Practice management software usage
- Risks for privacy and malware

Guidelines:

Failure to adhere to the following format will result in non-acceptance. It is the author's responsibility to convince the review committee 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.

Business papers should be formatted as described in the General Guidelines and should be no fewer than 600 words, with no upper word limit.

Section Headings:

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

1. Paper Title
2. Take Home Message
3. Introduction
4. Solutions
5. Results
6. Discussion
7. Acknowledgments
   i. Declaration of Ethics
   ii. Conflicts of Interest
   iii. Funding/Material/Technical Support
8. References

Paper title:

The title should clearly identify the topic that will be presented.

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).

Example:
Breaking the Silence: Disclosing Medical Errors

Introduction:

Significant published work should be acknowledged in the Introduction. 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.

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.

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:

i. Declaration of Ethics
ii. Conflicts of Interest
iii. Funding/Material/Technical Support

Full instructions for Acknowledgments can be found in the General Guidelines.

References:

References should conform to JAVMA's guidelines.

Full instructions for References can be found in the General Guidelines.

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Historical Perspectives in Equine Reproduction: Pioneers in the Age of Discovery

Patrick M. McCue, DVM, PhD, DACT

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1. Introduction

Equine veterinarians today have the distinct advantage of practicing in an era in which most of the basic physiologic principles, management protocols, diagnostic techniques, and therapeutic procedures are well established. A debt of gratitude is owed to the research scientists and clinicians that laid the foundation for modern equine practice. Sir Isaac Newton noted in 1675, "If I have seen further, it is by standing on the shoulders of giants." The goals of this lecture are to present some of the great discoveries and advancements in the field of equine reproduction over the past 5 to 8 decades and honor those who changed the course of equine reproductive practice. Their collective contributions enhanced the knowledge of reproductive physiology and provided the framework for reproductive management, diagnostic techniques, and therapeutic protocols used today. The lecture will cover the following areas of historical relevance: reproductive evaluation, reproductive endocrinology, mare management, hormone therapy, pregnancy determination, pregnancy physiology, reproductive pathology, and assisted reproduction.

2. Reproductive Evaluation of the Mare

Transrectal Palpation of the Reproductive Tract

Descriptions of transrectal palpations date back to the late 1920s and 1930s.[1–3] Perhaps the first description of transrectal palpation of the ovaries of mares throughout the estrous cycle and early pregnancy was that of Aitken in 1926.[1] The description of the manual palpation technique presented by Day in 1939 is as accurate today as it was when published over 80 years ago.[3] Manual palpation of the reproductive tract of the mare is an important clinical skill that is often underappreciated by veterinary students. Manual palpation can identify features of the tract that cannot be detected by ultrasonography, including tone in the uterus and cervix, softness of an ovarian follicle, and sensitivity of the ovary to touch and pressure after ovulation.

Transrectal Ultrasonography of the Reproductive Tract

Equine reproductive practice was forever altered following the first description of diagnostic ultrasonography for the reproductive evaluation of mares.[4] The authors described the transrectal ultrasonographic appearance of large preovulatory follicles, young corpora lutea, and more mature corpora lutea. It was noted that the largest follicle stopped growing 1 day prior to ovulation and that the follicle destined to ovulate could be identified as the largest follicle 6 days prior to ovulation. They hypothesized that the interval to ovulation could be estimated based on the size of the largest follicle. A flurry of publications followed, which outlined the clinical use of ultrasound to

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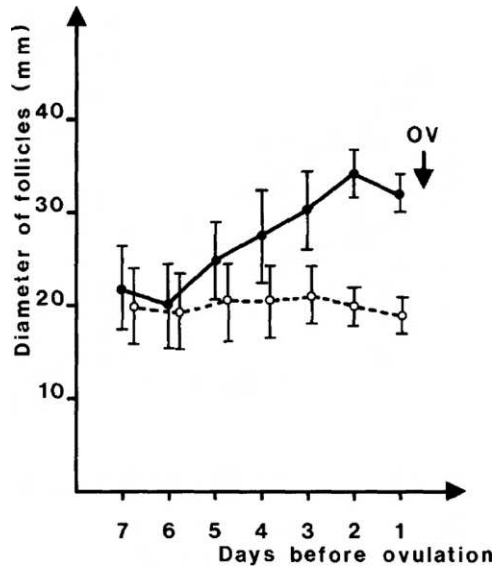


Fig. 1. Diameter of the largest (black circles) and second largest follicles (white circles) measured by ultrasound during the preovulatory phase of the estrous cycle of the mare (from Palmer and Driancourt, 1980).[4] OV, ovulation.

monitor the estrous cycle, detect early pregnancies and twins, identify pregnancy loss, and diagnose abnormalities of the reproductive tract (Fig. 1).[5–8] An early treatise on the use of ultrasound in the reproductive management of mares and specifically the origin, development, and management of twins was published in 1986.[9] A textbook titled *Equine Diagnostic Ultrasonography* was published in 1998 and covered a broad range of diagnostic ultrasound topics including reproduction, musculoskeletal, cardiovascular, respiratory, abdominal, and neonatal examinations.[10] A few of the current clinical uses for ultrasound in clinical equine practice are listed in Table 1.

Uterine Culture

Infectious endometritis has always been a significant cause of reduced fertility in broodmares. Dimock and Snyder published one of the earlier reports on culturing the uterus of mares in 1923.[11] Caslick (1937) recognized an association between perineal conformation of mares and the probability of an ascending bacterial infection.[12] Routine culture of mares was not universally practiced until the outbreak of contagious equine metritis in England in 1977 and in the United States in 1978.[13,14] Infectious endometritis is a significant cause of reduced fertility, early pregnancy loss, and abortion in mares.

Uterine samples can be collected for microbial culture using a guarded swab,[15] low-volume lavage,[16,17] or endometrial biopsy.[18] The primary bacterial organisms associated with endometritis in mares are *Streptococcus equi* subsp. *zooepidemicus*, *Escherichia coli*, *Pseudomonas aeruginosa*, *Klebsiella pneumoniae*, and occasionally *Staphylococcus* sp. Approximately 20% to 30% of positive cultures yield growth of more than one bacterial organism. Fungal infections of the equine uterus are not common. *Candida albicans* is the most common fungal organism cultured and is often associated with older mares that have a history of chronic reproductive problems. Currently, infectious endometritis is diagnosed based on a combination of reproductive history, physical examination, transrectal ultrasonography, vaginal speculum examination, uterine culture, endometrial cytology, and, if indicated, a uterine biopsy (Fig. 2).

Endometrial Cytology

One of the earliest publications on the use of endometrial cytology for monitoring the health of the uterus was by Knudsen in 1964.[19] Cytology samples in that study were collected by manual curettage of the endometrium then applied to glass slides and stained. A correlation was noted between the presence of neutrophils in the smears and a positive microbial culture. This was followed by multiple papers in the late 1970s and early 1980s that documented the endometrial cytology of normal mares and the inflammation that occurs following mating or in association with microbial infection.[20–22] In current clinical practice, endometrial samples are collected using a single- or

Table 1. The State of Practice in Equine Reproductive Ultrasonography

Reproductive evaluation of the mare	Reproductive pathology of the mare
Monitoring follicle development	Hemorrhagic anovulatory follicles
Monitoring endometrial edema	Ovarian tumor
Prediction of impending ovulation	Endometrial cysts
Confirming ovulation	Uterine fluid
Evaluation of the corpus luteum	Reproductive issues during pregnancy
Doppler blood flow - corpus luteum, etc.	Placentitis
3D evaluation of the corpus luteum	Monitoring the high-risk mare
Early pregnancy diagnosis	Assisted reproduction of the mare
Twin detection and management	Transvaginal aspiration/Ovum pick up
Detection of pregnancy loss	Reproductive evaluation of the stallion
Fetal sexing	Testis/scrotal evaluation
Fetal biophysical profile	Testicular pathology
Estimation of gestational age of a fetus	Cryptorchid testes
Examination of the foal	Accessory sex glands

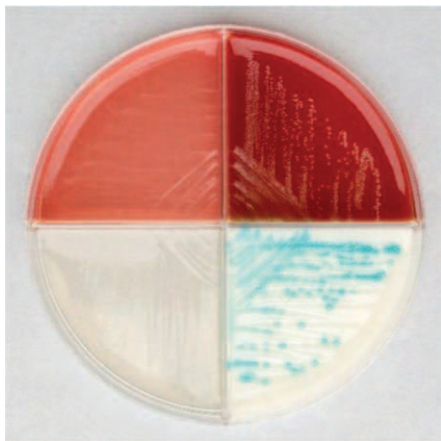


Fig. 2. Microbial culture plate of *Streptococcus equi* subsp. *zooepidemicus*. Note the presence of β-hemolysis around pinpoint white colonies in the tryptic soy agar with 5% sheep blood in the upper right quadrant and the blue colonies growing on the Gram-positive chromogenic agar in the lower right quadrant. No microbial growth is evident in MacConkey agar (upper left) or Gram-negative chromogenic agar (lower left).

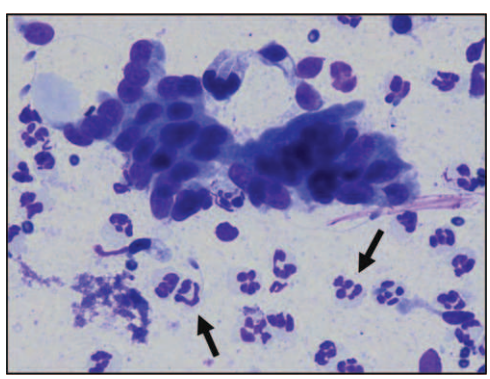


Fig. 3. Cytologic samples from the uterus of a mare showing a raft of normal uterine epithelial cells and numerous white blood cells (arrows). The cellularity of a sample should be evaluated in order for a cytology sample to be considered diagnostic quality.

double-guarded swab, guarded brush, or a low-volume lavage.[23] The cytology brush has been noted in several studies to provide a better sample of cells than the swab.[24,25] A cytologic smear can also be made from an endometrial biopsy.[26] Cytology samples are first evaluated for the presence of normal uterine endometrial cells and then evaluated for the presence and relative number of inflammatory cells (white blood cells, especially neutrophils), bacteria, fungi, and background debris (Figs. 3 and 4). A combination of uterine culture and endometrial cytology is beneficial in identifying mares with infectious endometritis.[27] In general, a positive endometrial cytology is more common than a positive uterine microbial culture, and a *Streptococcus* infection is associated with a greater degree of inflammation than a coliform infection.[11,28] Pregnancy rates are lower in mares with a positive cytology (i.e., presence of white blood cells) or a positive culture (i.e., growth of microbial

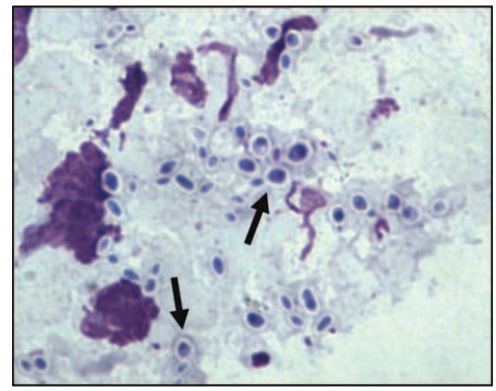


Fig. 4. Yeast (*Candida albicans*) organisms (arrows) in an endometrial cytology sample. Note the uniform cells, some with budding, and the large "halo" around the yeast organisms.

pathogens) than rates in mares with no evidence of inflammation or infection.[28]

Low-Volume Lavage

Infusion of a small volume of sterile fluid into the uterus and subsequent recovery of the fluid, termed a low-volume uterine lavage, theoretically samples the entire endometrial surface and uterine lumen. The technique was first described by Ball and colleagues (1988) and later adapted and popularized by LeBlanc and coworkers (2007).[16,17] Sterile fluid volumes utilized in the low-volume lavage technique range from 50 to 1,000 mL. If needed, effluent fluid is centrifuged in one or more 50-mL conical tubes at 400 $\times$ *g* for 10 minutes. The supernatant is discarded, and the cellular pellet is used for microbial culture, cytologic evaluation, and/or molecular diagnostic techniques for detection of inflammation or infection.[16,17,24,29]

Endometrial Biopsy

Early observations on the histology of the endometrium were made in the 1920s by Seaborn (1925), who correlated changes in the surface epithelium, endometrial glands, and lymphocyte infiltration with the stages of the estrous cycle.[30] Histologic evaluation of an endometrial biopsy sample has subsequently been used to assess the health of the endometrium and provide a prognosis for fertility and potential fecundity.[31–35] Endometrial histology has been touted as the "gold standard" for the assessment of inflammation,[29] and endometrial biopsy samples can also be used for microbial culture or cytologic evaluation.[18,36] In clinical practice, a single collected biopsy sample is generally considered to be representative of the entire endometrium. Blanchard and colleagues (1987) reported that epithelial cell height, degree of stromal and periglandular fibrosis, and lymphatic lacunae were relatively evenly distributed throughout the endometrium, while the severity of inflammation may be affected by location of the biopsy sample.[37] In some subfertile or infertile mares, collection of multiple uterine biopsy samples may be advantageous. Biopsy samples are placed into a fixative

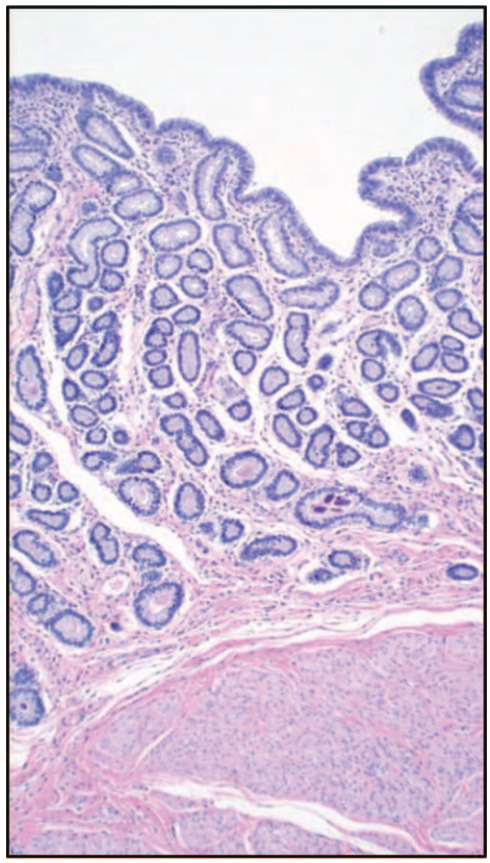


Fig. 5. Normal equine endometrium under low magnification showing the luminal epithelium and endometrial glands. The uterine lumen is at the top of the image; the muscularis is at the bottom of the image.

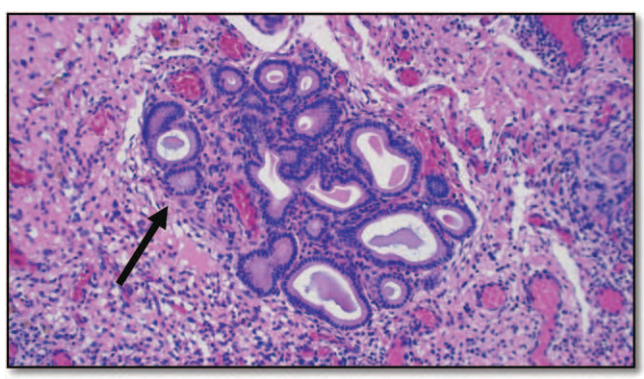


Fig. 6. Mare endometrium with a nest of dilated glands. The nest is surrounded by a thin layer of fibrosis (black arrow, high magnification).

solution (10% formalin solution or Bouin's solution) after collection and prior to histological processing. It has been noted that samples fixed in Bouin's solution retain biofilm on the surface of the endometrium better than samples fixed in formalin.[38] Endometrial biopsy samples are examined for the presence of inflammatory and degenerative changes. Inflammation is recognized by the accumulation of inflammatory cells, primarily lymphocytes, within the endometrial tissue.

Table 2. Expected Foaling Rates of Mares According to Endometrial Biopsy Grade (Modified After Kenney and Doig, 1986)[35]

Category	Degree of Endometrial Change	Expected Foaling Rate (%)
I	Absent	80–90
IIA	Mild	50–80
IIB	Moderate	10–50
III	Severe	< 10

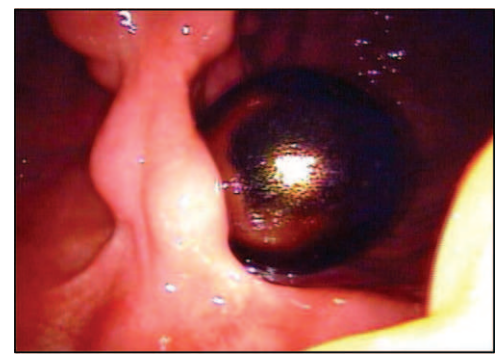


Fig. 7. Videoendoscopic image of a marble at the bifurcation of the uterus. The endoscope is just anterior to the internal cervical os, and the septum visibly separates the two uterine horns. The marble is at the base of the right horn.

Endometrial glandular degeneration is most often recognized by a deposition of collagen in the form of fibrosis around the endometrial glands. The endometrium is classified on a grading scale based on biopsy characteristics. A Grade I endometrium is essentially normal, with minimal inflammation or fibrosis (Fig. 5). A Grade III endometrium includes severe inflammatory and/or fibrotic changes (Fig. 6). Grade II is a broad category encompassing a continuum of pathologic levels between Grades I and III and is further subdivided into Grades IIA and IIB.[35] The prognosis for a mare to carry a foal to term, based on endometrial biopsy interpretation and score, is presented in Table 2.[35]

Hysteroscopy

In 1992, Allen and colleagues published a series of articles on the observations made during hysteroscopy of the normal fertile mare, subfertile mare, and pregnant mare.[39–41] Although transrectal ultrasonography along with uterine culture, cytology, and biopsy can reveal a majority of the abnormalities of the equine uterus, hysteroscopy has advantages in the detection of intrauterine adhesions, localized lesions, focal sites of infection, lymphatic cysts, retained endometrial cups, and removal of foreign bodies (Fig. 7).[42,43] The original hysteroscopic equipment used for direct visualization of the interior of the uterus was a fiberoptic endoscope,[31,44–46] whereas current state of practice utilizes digital videoendoscopic equipment.[42] Hysteroscopy has also been used in the mare for placement of spermatozoa at the utero-tubular junction,[47–49] cannulation of the oviduct for hydrotubation,[50] evaluation and

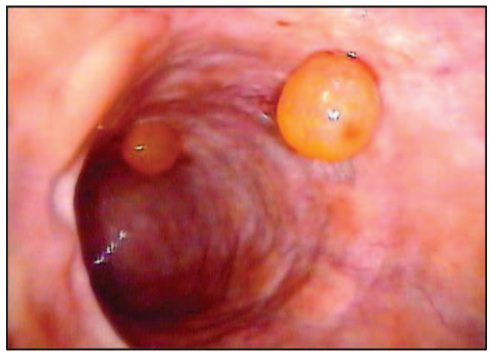


Fig. 8. Lymphatic cysts protruding into the uterine lumen viewed through a videoendoscope. The endoscope has entered one uterine horn, and the cysts are visible after insufflation of the uterus.

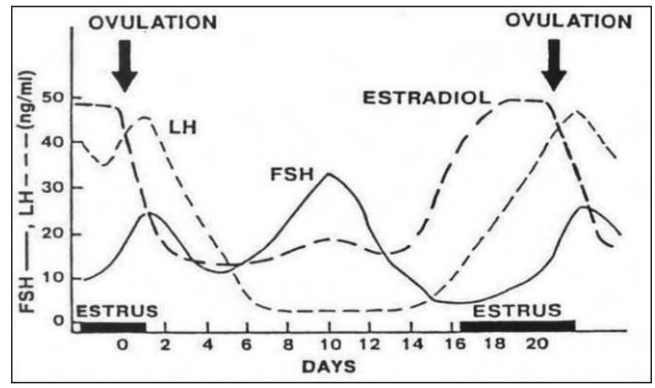


Fig. 9. Endocrine profile of follicle-stimulating hormone (FSH), luteinizing hormone (LH), and estradiol during the equine estrous cycle (adapted from Neely, 1983).[281]

laser ablation of uterine cysts (Fig. 8),[51] direct visualization of the endometrial surface, and targeted sampling of the endometrium.[52]

3. Reproductive Endocrinology

The principles of reproductive endocrinology have been investigated in a variety of species for centuries.[53] The complex interaction between anatomic structures such as the anterior pituitary and ovaries and their endocrine products was eventually defined in the early to mid-1900s. The following is a summary of early investigations into the dynamics of reproductive hormones in mares.

Follicle-Stimulating Hormone

Evans and Irvine (1975) first reported the serum concentrations of follicle-stimulating hormone (FSH) throughout the estrous cycle in mares.[54] An increase in FSH in mid-diestrus triggers development of a follicular wave that includes the follicle that will eventually become dominant during the subsequent estrus (Fig. 9). FSH is important in stimulation of follicular growth, stimulation of estradiol production by granulosa cells, and induction of synthesis of luteinizing hormone (LH) receptors on granulosa cells. Secretion of FSH from the anterior pituitary is primarily regulated by negative feedback inhibition by inhibin and estradiol produced by granulosa cells of the developing dominant follicle, as well as positive feedback by activin.

Luteinizing Hormone

Multiple studies have reported the concentration of LH in the blood of mares throughout the estrous cycle beginning in the early to mid-1970s.[55–60] Of significant note was the broad surge of LH that began in mid-estrus and peaked the day of ovulation or the day after ovulation (Fig. 9). The broad peak and time of peak concentration contrasts with the relatively short surge of LH that occurs 24 to 48 hours prior to ovulation in other species. Production of LH is stimulated by an increase in gonadotropin-releasing hormone (GnRH) pulse frequency and enhanced by positive feedback from estradiol produced by the developing dominant follicle. Secretion of LH is inhibited by progesterone produced by the corpus luteum. LH is important in the female for stimulation of estradiol production by granulosa cells, maturation of the dominant follicle, stimulation of ovulation, and maintenance of the corpus luteum.

Estradiol

Changes in concentrations of estradiol-17β (estradiol) in the blood of mares throughout the estrous cycle were initially reported in the early 1970s.[57,61,62] It was noted that concentration of estradiol peaked 1 to 2 days prior to ovulation and subsequently declined as the time of ovulation approached (Fig. 9). Estradiol, in the absence of progesterone, stimulates formation of edema within the endometrium. The degree of edema is correlated with the changes in plasma concentrations of estradiol.[63,64] In addition, estradiol is responsible for induction of behavioral estrus, relaxation of the cervix, increase in the character and volume of uterine secretions, and upregulation of pituitary LH release.

Progesterone

Concentration of progesterone in the blood of nonpregnant and pregnant mares was first reported by Short in 1959.[65] In the 1970s, several publications reported the concentration and pattern of progesterone secretion during the equine estrous cycle.[66–70] The authors noted that concentration of progesterone began to increase within 24 hours after ovulation, reached peak concentrations approximately 5 days after ovulation, and then slowly declined until luteolysis occurred 12 to 14 days after ovulation (Fig. 10). Progesterone is responsible for blocking the expression of behavioral estrus, altering the secretion and development of endometrial glands, closure of the cervix, maintenance of pregnancy, and a variety of other nonreproductive physiologic processes.

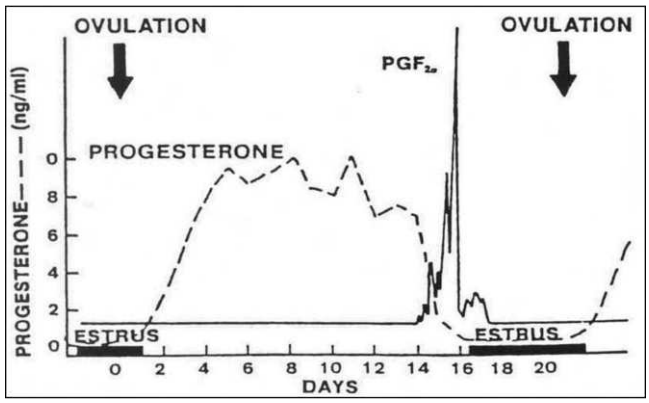


Fig. 10. Endocrine profile of progesterone and prostaglandin F2α ($PGF_{2\alpha}$) during the equine estrous cycle (adapted from Neely, 1983).[281]

Prostaglandin F2α

Development of a radioimmunoassay for prostaglandin F2α or the primary metabolite of prostaglandin opened a new avenue for research in the late 1970s and 1980s.[70–74] It was noted that pulsatile release of prostaglandin F2α from the endometrium occurred 12 to 14 days after ovulation in the nonpregnant mare. The secretion of prostaglandins resulted in destruction of the corpus luteum (luteolysis). Ginther and First (1971), followed by Squires and colleagues (1974), noted that complete hysterectomy in mares during diestrus resulted in persistence of the corpus luteum,[70,75] confirming that the uterus is the source of prostaglandins in the mare. In another study, restriction of the ability of an equine embryo to migrate through the entire uterine lumen resulted in luteolysis.[76] This confirmed that the entire endometrium contributes to the release of prostaglandins and that prostaglandins produced in the uterine horn contralateral to the location of the corpus luteum traveled through the systemic circulation to cause luteolysis.

Inhibin

Plasma concentrations of inhibin during the equine estrous cycle were first reported by Roser and colleagues,[77] whereas the inhibin assay in current use was developed by Conley and coworkers.[78] The primary clinical use of inhibin assays is as a marker for granulosa cell tumors of the ovary.[79,80] Approximately 80% to 85% of mares with histologically confirmed granulosa cell tumors have an elevated concentration of inhibin in peripheral blood.[78,80,81]

Anti-Müllerian Hormone

Anti-Müllerian hormone (AMH) is a dimeric glycoprotein hormone produced by granulosa cells of ovarian follicles and Sertoli cells of the testis. AMH was first discovered by Jost in 1947 as the factor that suppresses the development of the Müllerian duct during fetal development in males.[82] AMH has been evaluated as a biomarker for the ovarian follicular reserve in mares,[83] as an indicator of the presence of a granulosa cell tumor,[84] and as a marker for the presence of testicular tissue in potentially cryptorchid horses.[85]



Fig. 11. Equilume light mask with a blue light applied only to the right eye.

4. Mare Management

Artificial Photoperiod

A discovery that altered the housing and management of broodmares was the recognition of the effect of photoperiod on the annual cyclicity of mares and the subsequent development of artificial photoperiod protocols. The original research into the effect of photoperiod on ovarian function was carried out at the Animal Research Station in Cambridge,[86] and later by researchers in Kentucky,[87] Florida,[88] France,[89] and other locations from the late 1960s through the 1980s. Artificial lighting programs are now standard on many equine breeding facilities to advance the first ovulation of the year. The technology has progressed from stall or paddock lights to "wearable" sources of light to advance the first ovulation of the season (Fig. 11).[90,91] Collectively, these studies provided evidence that artificial photoperiod programs should begin by approximately December 1 in the Northern Hemisphere, that 3 or more hours of artificial light exposure should be added beginning at dusk, that a fluorescent light or 100- to 200-W incandescent light in a 12 $\times$ 12-ft stall provides sufficient light intensity, and that the interval from onset of light therapy to first ovulation is 60 to 75 days. In addition, Palmer and colleagues (1982) provided evidence that exposure of mares to a 1-hour pulse of light 9.5 to 10.5 hours after the onset of darkness was also effective in advancing the onset of the breeding season.[89]

Caslick Procedure

The relationship between the conformation/function of the vulva/vestibulo-vaginal fold and the reproductive health of the mare was established in the 1920s and 1930s.[92–94] In his landmark 1937 paper, Dr. E.A. Caslick discussed his clinical observations on the relationship between perineal anatomy, "wind-sucking," and uterine health.[95] It was noted that perineal injuries, poor conformation, and poor muscular tone or function of the vulva of both open mares and

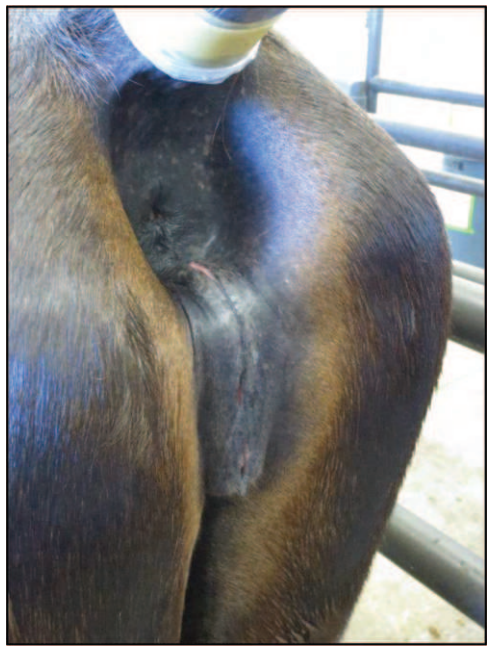


Fig. 12. Poor perineal anatomy of an aged broodmare. The dorsal aspect of the vulva has formed a horizontal shelf above the brim of the pelvis.

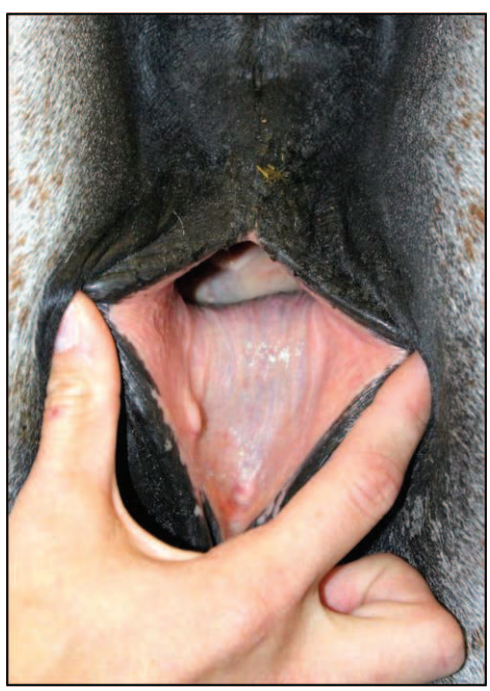


Fig. 13. Poor muscular tone of the vulva. This leads to aspiration of air and microbial contamination of the reproductive tract.

postpartum mares all lead to aspiration of air and microorganisms into the reproductive tract resulting in uterine infections and infertility (Figs. 12 and 13). The author further commented that the healthy mare vulva should lie at an angle of about 80° from vertical and the dorsal commissure should be above the floor of the pelvic girdle. Dr. Caslick then described the procedure to prevent "wind-sucking," which entailed surgically closing the dorsal aspect of the vulva to a level 0.5 inch below the floor of the pelvic girdle. This simple procedure, which now bears his name, has stood the test of time for prevention of aspiration of air into the reproductive tract, thereby reducing microbial contamination and maintaining fertility in mares with perineal issues. Other clinicians have subsequently extended the original observations on the relationship between vulva conformation and fertility in mares.[95]

Kerosene Therapy

Another historical therapeutic procedure worthy of mention is the use of kerosene infusion into the uterus as a "chemical curettage" in the management of chronically infertile mares. The technique was first applied by Dr. Charlie Roberts, an equine veterinarian in New Zealand, more than 50 years ago. The effect of kerosene treatment on the endometrium and on pregnancy rates was evaluated by Bracher and colleagues (1991).[96] The authors noted that infusion of kerosene into the uterus resulted in severe acute inflammation of short duration. After treatment and endometrial healing, inflammation levels were decreased, and debris had been eliminated from a portion of the endometrial glands. In addition, pregnancy rates after kerosene infusion for mares with Grade II and Grade III uterine biopsies were 50% and 82%, respectively. Kerosene infusion is currently used in clinical equine practice as a "nontraditional" therapy for mares with low fertility.[97]

5. Hormone Therapy

Human Chorionic Gonadotropin

The initial use of human chorionic gonadotropin (hCG) for induction of ovulation in mares has been attributed to workers in Russia in the 1930s.[98] Day (1939) described the hormonal induction of ovulation in the mare using commercial preparations of gonadotrophic hormones extracted from urine or serum of pregnant mares.[3] The "gonadotrophic hormones" present in pregnant mares would eventually be termed pregnant mare serum gonadotropin (PMSG) and later equine chorionic gonadotropin (eCG). Later, the efficacy of hCG in induction of ovulation in mares was reported by Loy and Hughes (1966).[99] The average interval from hCG administration to ovulation is approximately 36 hours, and approximately 85% to 90% of mares ovulate within 48 hours after administration. Repeated administration of hCG was shown to be associated with development of antibodies and a decrease in efficacy at inducing a timed ovulation.[100]

Gonadotropin-Releasing Hormone

Evans and Irvine (1977) were the first to report the use of GnRH to stimulate follicular development, maturation, and ovulation of mares.[101] Agonists of GnRH were developed as an alternative to hCG for hormonal induction of ovulation.[102,103] Currently, deslorelin and

Table 3. Historical Biological Tests for Pregnancy Determination in the Mare

Type of Test	Hormone	Method	Reference
Biological	Equine chorionic gonadotropin (serum)	Rat test	Cole and Hart (1930)[123]
		Mouse test (Aschheim-Zondek test)	Hart and Cole (1932)[124]
	Estrogen (urine)	Mouse test	Crew et al. (1931)[125]
			Miller (1934)[126]
		Capon test	Greenwood and Blyth (1934)[127]

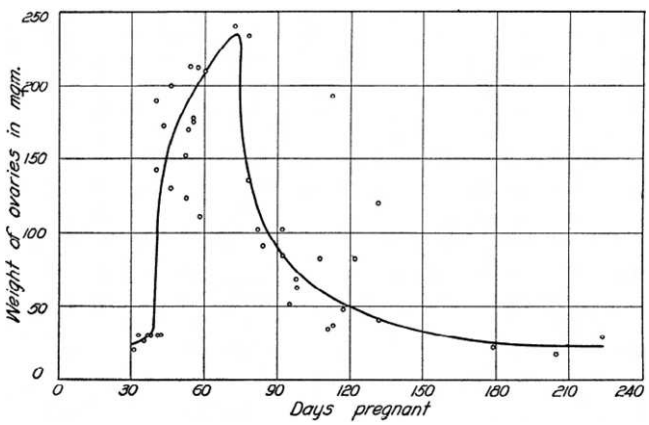


Fig. 14. Ovarian weight of immature rats injected with serum from mares at various days of pregnancy.[123]

histrelin are in common use for induction of ovulation of a dominant follicle in a mare in estrus.[104] The average interval from deslorelin or histrelin administration to ovulation is approximately 40 to 42 hours, and approximately 90% to 95% of mares ovulate within 48 hours after administration.

Prostaglandins

The discovery that prostaglandin $F_{2\alpha}$ from the endometrium was responsible for destruction of the corpus luteum in sheep led to the evaluation of exogenous prostaglandins for therapeutic use in horses.[105–107] Prior to the availability of natural prostaglandins or prostaglandin analogues, treatment for prolonged diestrus in mares consisted of intrauterine infusion of unbuffered saline.[108–111] Regression of a persistent corpus luteum after saline infusion was attributed to either the acidity of the saline causing inflammation or the introduction of bacteria causing inflammation with subsequent release of endogenous prostaglandin from the endometrium. The commercial availability of prostaglandins led to treatment protocols for short-cycling, estrous synchronization, termination of early pregnancy, evacuation of uterine fluid, and much later stimulation of maternal behavior in postpartum mares or nurse mares.

Other Hormones

A host of other hormones have been used therapeutically for reproductive management of mares, including altrenogest,[112] progesterone,[113] estradiol-17β,[114,115] oxytocin,[116] dopamine antagonists,[117] prostaglandin E2,[118] and prostaglandin E1 (misoprostol).[119]

6. Pregnancy

Pregnancy Examination – Behavioral Assessment

Early descriptions of indications of potential pregnancy in mares noted cessation of heat periods, changes in temperament, and eventually enlargement of the abdomen and ballottement of the foal through the flank.[120,121] However, it was noted that some pregnant mares will still show heat and stand to be mated and that some nonpregnant mares will fail to return to estrus after mating. Consequently, other methods to determine pregnancy status were investigated throughout the early and mid-1900s.

Pregnancy Examination – Biological Tests for PMSG

It was during the 1930s and 1940s that biological and chemical tests were developed to diagnose pregnancy in mares based on the presence and concentrations of PMSG (currently termed eCG) and estrogens in serum and urine (Table 3).[122–126] Cole and Hart (1930) utilized immature rats to detect the presence and biologic activity of what was presumed at the time to be an "anterior hypophyseal sex maturing hormone" in the serum of pregnant mares.[122] A positive reaction was first detected on day 37 to 42 of pregnancy, and the reaction abated by day 120 after breeding (Fig. 14). The test was based on the Aschheim-Zondek test used to detect a factor that was eventually identified as hCG in the urine of pregnant women.[127] The test was considered positive if ovarian enlargement, follicle development, ovulation, or corpora lutea were identified or if the uterus was enlarged in the immature mice. The changes in the reproductive tract of the immature mice were caused by the presence of PMSG/eCG. In 1943, the source of PMSG (eCG) was identified as cells migrating from the chorionic girdle of the embryo that invade the endometrium of the mare.[128] Other biological tests for PMSG/eCG followed, including the Friedman (rabbit) test and the male toad test.[129,130]

Pregnancy Examination – Laboratory Tests for PMSG

Hemagglutination-inhibition assays were used to measure the concentration of PMSG in the serum of pregnant mares (Figs. 15 and 16).[131,132] Concentrations of PMSG increased in serum between 35 and 41 days of gestation, peaked around 60 to

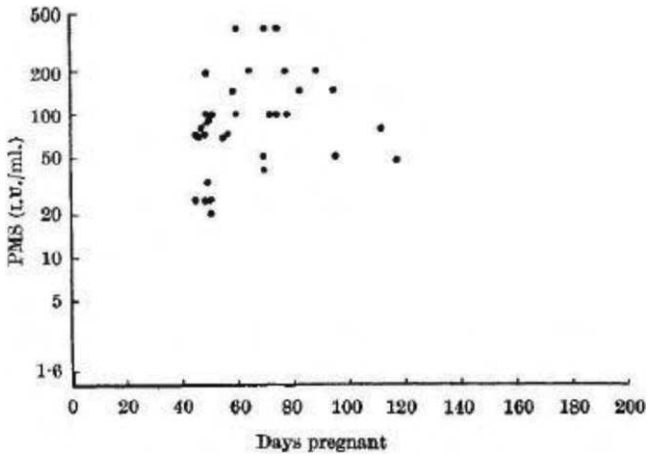


Fig. 15. Immunological activity of PMSG in pregnant mares (Wide and Wide, 1963).[132] PMS, pregnant mare serum.

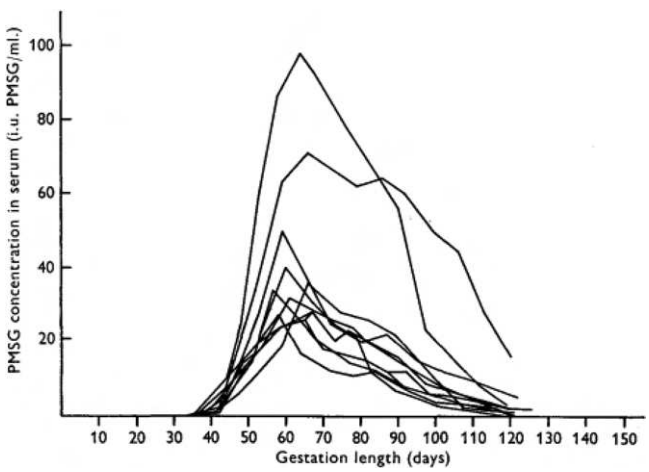


Fig. 16. Serum concentrations of pregnant mare serum gonadotropin (PMSG) in the serum of 10 pregnant Thoroughbred mares as determined by a hemagglutination-inhibition assay in pregnant mares.[133]

65 days, and disappeared by 120 to 130 days of gestation. Results of the hemagglutination-inhibition studies confirmed the early bioassay work of Cole and Hart.[122] In 1969, a commercial test for pregnancy in the mare, called the MIP test, was developed based on the original hemagglutination-inhibition assay (Fig. 17).[133,134] The test was touted as accurate between days 41 and 130 of pregnancy. Clinical challenges with the test included false negative tests if performed prior to endometrial cup formation or after cup regression and false positive tests if fetal loss occurred after cup formation. Current methods to determine the concentrations of eCG include radioimmunoassay[135] and enzyme-linked immunoabsorbent assay.[136]

Pregnancy Examination – Biological Tests for Estrogens

Another bioassay for assessment of pregnancy in the mare was based on an increase in estrogens during

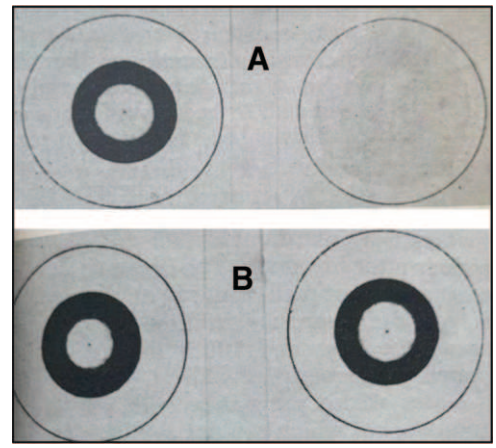


Fig. 17. A, Negative MIP test, with an internal control on the left and hemagglutination on the right characterized by a flat layer of cells at the base of the test tube. B, Positive MIP test showing an inhibition of agglutination and a ring of cells at the base of the right test tube.[134]

pregnancy. Initial work in the early 1930s by Crew and coworkers,[124] Hart and Cole,[123] and Miller[125] utilized immature rats or mice ("the mouse test") in which 3- to 4-week-old mice were oophorectomized or ovariohysterectomized and eventually received injections of serum or urine from potentially pregnant mares. A smear from the vagina was collected 36 hours after the last injection and evaluated cytologically. Full cornification of the epithelial cells was considered indicative of pregnancy. The test was highly accurate when used for mares at least 60 days in gestation. A second biological assay for determination of pregnancy in the mare was "the Capon test."[126] The assay used castrated Brown Leghorn chickens from which a patch of feathers had been removed from the breast area. As new feathers began to grow, the fowl received injections of prepared mare urine in the pectoral muscles for 2 consecutive days. The new developing feathers were subsequently examined, and presence of a red pigment was considered as a positive test for "œstrin" (estrogen).

Pregnancy Examination – Chemical Tests for Estrogens

Chemical tests to determine estrogen concentration in urine samples were also used to determine pregnancy status of mares. Cuboni[137] and Kobler[138] validated tests for estrogens in urine that were able to detect pregnancy after 100 to 110 days of gestation in mares.[137–139]

Pregnancy Examination – Laboratory Tests for Estrogens

Current laboratory techniques for assessment of estrogen concentrations in pregnant mares include radioimmunoassay[61] and enzyme immunoassay.[140] The increase in urinary estrogens in mares after 90 days of gestation is the basis for "at-home" tests that are commercially available.

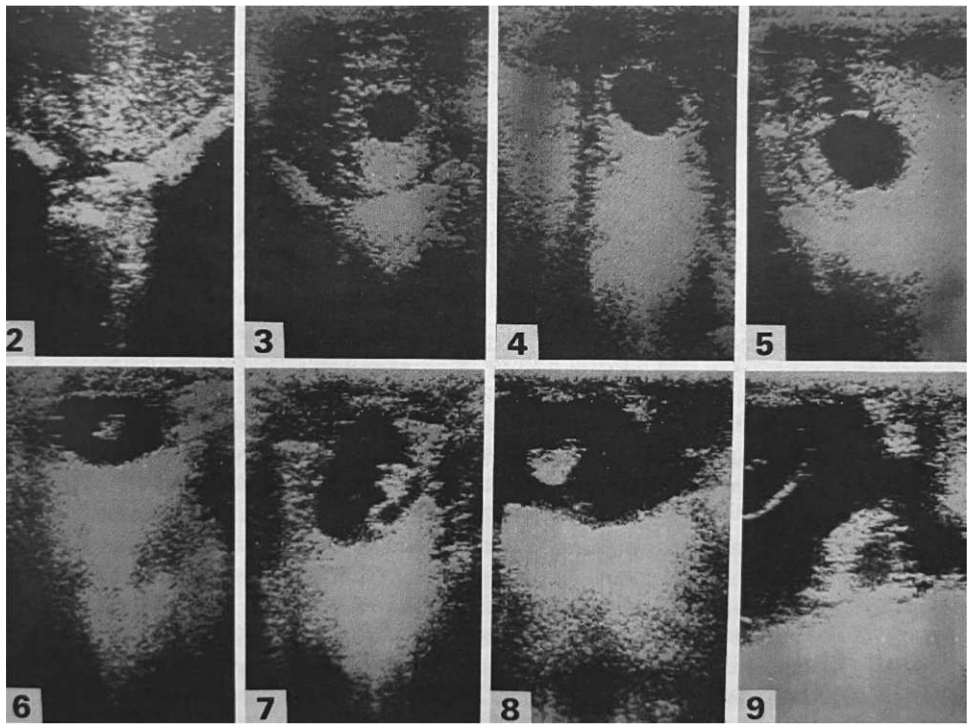


Fig. 18. Ultrasound images of the uterus of a nonpregnant mare (upper left) and various stages of pregnancy (from Simpson et al., 1982). Image 2, Uterus of a nonpregnant mare; Image 3, Day 15 pregnancy; Image 4, Day 18 pregnancy; Image 5, Day 23 pregnancy; Image 6, Day 28 pregnancy; Image 7, Day 36 pregnancy; Image 8, Day 45 pregnancy; Image 9, Day 61 pregnancy.

Pregnancy Examination – Vaginal Examination

In the early 1900s, it was not uncommon to perform a vaginal examination, either with a speculum or by hand, to determine the stage of the estrous cycle or determination of pregnancy.[92,141] Signs of pregnancy included closure of the external cervical os and a "uterine seal." The uterine seal was described as a white or grayish white, exceedingly gummy secretion with the consistency and character of white library paste.[92]

Pregnancy Examination – Transrectal Palpation

Manual palpation of the reproductive tract per rectum was historically utilized for pregnancy determination prior to the advent of ultrasonography.[92,120,121,142] In 1924, Dimock and Caslick noted that most pregnancy exams were performed between 4 and 7 months of gestation.[92] It was recommended that the mare be "fasted for at least 24 hours before the examination" and restrained with either hobbles or with a twitch and one foreleg held up. By 1936, transrectal pregnancy exams were being performed "any time from 30 days following conception" with a high percentage of accuracy.[120] A diagnosis of pregnancy by palpation was based on detection of a bulge in the ventral aspect of the uterus, typically at the base of one uterine horn, and the presence of increased uterine and cervical tone. Authors noted that the assessment of pregnancy status by transrectal palpation was easier in maiden, open, or barren mares than postfoaling mares. Limitations to transrectal palpation for pregnancy include the inability to accurately diagnose early pregnancy status and an inability to detect and manage twins early in gestation.

Pregnancy Examination – Transrectal Ultrasonography

Pregnancy examination in mares changed dramatically with the introduction of ultrasonography into veterinary medicine. Palmer and Driancourt (1980) were the first to report the use of ultrasonography in the detection of early pregnancy in mares.[4] The authors noted that a 10- to 15-mm embryonic vesicle could be visualized at the base of one horn 14 days postovulation. An increase in the diameter of the embryonic vesicle was observed from 14 to 20 days, and an embryo was observed within the vesicle between 25 and 30 days postovulation. Subsequently, numerous other publications confirmed the use of ultrasound in early pregnancy diagnosis, detection and management of twins, and diagnosis of pregnancy loss (Fig. 18).[6,7]

Unfertilized Oocytes

In the mare, only viable embryos traverse through the isthmus and uterotubular junction and descend into the uterus.[143–146] Unfertilized oocytes are retained in the oviduct near the junction of the ampulla and isthmus. This finding is clinically relevant in that, when an unfertilized oocyte is recovered during an embryo flush, it is generally in the presence of a viable embryo and likely passively traversed through the oviductal isthmus and uterotubular junction along with the embryo that produced prostaglandin E2 (PGE2; Fig.

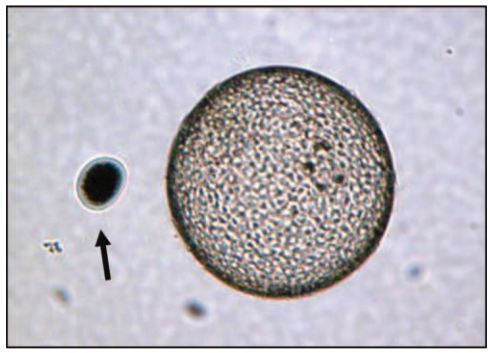


Fig. 19. A small unfertilized oocyte (arrow) recovered from the uterus of a mare along with an expanded blastocyst stage embryo. Equine embryos are spherical and roll during handling or manipulation, while unfertilized oocytes are flat and do not roll.

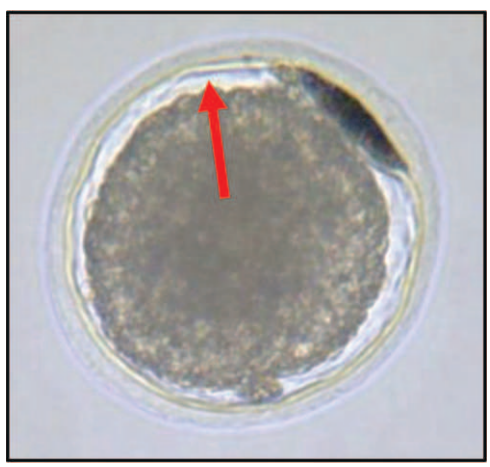


Fig. 20. Early blastocyst stage embryo with a capsule visible beneath the zona pellucida (arrow).

19). It is exceedingly rare to recover just an unfertilized oocyte in the recovered fluid during an embryo flush procedure in mares. Equine embryos must produce PGE2 to pass through the oviductal isthmus and uterotubular junction into the uterus.[147] Nonviable embryos and unfertilized oocytes are retained in the oviduct as they do not produce PGE2.

Embryo Migration

In 1983, Ginther used repeated ultrasound examinations of early pregnant mares to discover that an equine embryo "migrates" throughout the entire uterine lumen multiple times per day until it "fixes" in position on day 16 of pregnancy.[148] Fixation usually occurs at the base of one of the uterine horns. Embryo migration is a critical aspect of maternal recognition of pregnancy in the mare.[76] Restriction of embryo migration will result in release of prostaglandin F2α from the restricted area and lysis of the corpus luteum.

Embryonic Capsule

In vivo produced embryos develop an acellular glycoprotein capsule, synthesized by embryonic trophoblast



Fig. 21. Expanded blastocyst embryo. The zona pellucida had been shed and the capsule is visible surrounding the embryo (arrow). Note that this embryo has slightly shrunk away from the capsule.

cells with contributions from the uterine environment.[149] The capsule develops beneath the zona pellucida and is the only membrane surrounding the embryo after the zona pellucida is shed as the embryo expands (Figs. 20 and 21). The capsule provides physical protection and maintenance of a spherical shape and facilitates migration of the embryo through the uterus.[150] Rupture of the capsule is responsible for the distinctive "pop" that is detected during manual reduction of a twin embryo. Loss of the capsule at approximately 21 to 22 days of gestation results in a change of shape of the embryo from spherical to irregular. Empty trophoblastic vesicles maintain their shape due to the continued presence of a capsule.[151]

Endometrial Cups and Equine Chorionic Gonadotropin

A series of clinical observations and scientific discoveries, dispersed over a 70-year period, led to the current understanding of one of the most unique phenomena of reproductive endocrinology of any domestic mammal: equine endometrial cup formation.[282] The saga began in 1897 when J.C. Ewart of Edinburgh first described a unique whitish band, which he described as a "girdle," encircling the day 35 equine embryo (Fig. 22).[152] In 1912, an anatomist in Germany reported on the presence of raised cup-like structures that formed a discontinuous ring around the base of the pregnant uterine horn.[153] In 1930, Cole and Hart, working at the University of California, Davis, discovered that the serum of mares between 40 and 150 days of gestation stimulated dramatic uterine enlargement and follicular growth in immature rats.[122] The "gonad-stimulating hormone," as it was referred to in the 1930s, was later termed PMSG and is currently known as eCG. In 1934, Catchpole and Lyons reported that the source of the gonadotropin in the serum of pregnant mares was the allantochorion of the fetus.[154] Cole and Goss, in 1943, determined that the elusive origin of the gonadotropin

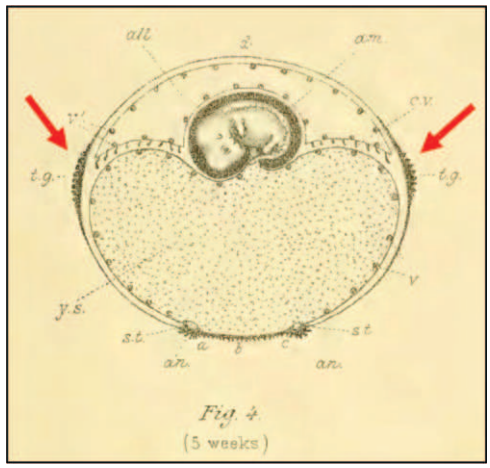


Fig. 22. Drawing of an equine embryo at week 5 (35 days) of gestation (from Ewart, 1897).[153] Red arrows indicate the chorionic girdle.

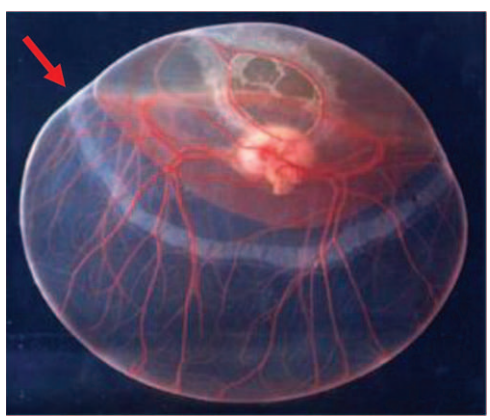


Fig. 23. Photograph of an equine embryo at 34 days of gestation (from Antczak et al., 2013).[282] The chorionic girdle is indicated by the red arrow.

was the endometrial cups (Cole and Goss, 1943).[156] Van Niekerk (1965) observed that the chorionic girdle (Fig. 23) disappeared from the surface of the embryo after 35 days of gestation.[155] At that time, it was not known that trophoblast cells from the chorionic girdle leave the embryo, invade the endometrium, and eventually form the endometrial cups. Allen and Moor (1972) eventually deduced that PMSG/eCG was produced by the fetal-origin endometrial cups and that the hormone ultimately enters the maternal circulation.[156] In summary, endometrial cups begin to form at approximately 35 days of gestation and regress between 130 and 150 days of pregnancy. Once formed, endometrial cups will continue to persist and produce eCG even if the mare loses her pregnancy (Fig. 24). Understanding the relationship between duration of pregnancy, presence of endometrial cups, and production of eCG is critical in the reproductive management of mares. Mares that lose their pregnancy after endometrial cup formation will often not resume normal ovarian function again during that breeding season.

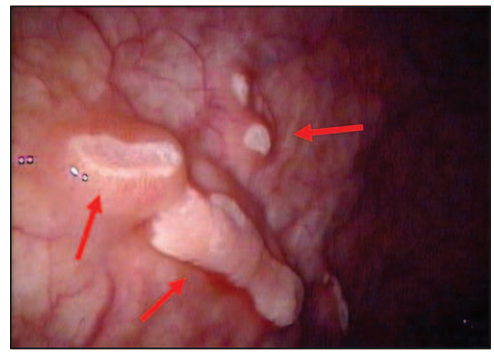


Fig. 24. Videoendoscopic view of endometrial cups (red arrows) in a mare that lost her pregnancy at 60 days of gestation.

In addition, persistence of the endometrial cups for the duration of pregnancy and even after foaling has been described.[157]

Progesterone and Progestins

Production of large quantities of eCG is associated with formation of secondary corpora lutea and a resurgence of blood progesterone levels in the mare (Fig. 25). The presence of secondary corpora lutea in the pregnant mare was first noted by Cole and others in 1931 in necropsy specimens[158] and later reported by Amoroso and colleagues in 1948[159] and Bain in 1957.[160] Cole and colleagues categorized pregnancy in the mare into 4 periods relative to ovarian function.[158]

- **Period 1**. Extends from conception to approximately 40 days of gestation. Only the corpus luteum of pregnancy is present, and the "ovarian stimulating hormone" (PMSG/eCG) is not present.
- **Period 2**. Extends from 40 days to 150 days of gestation. Multiple follicles and luteal structures are present in the ovaries. The ovarian stimulating hormone is present in high concentrations.
- **Period 3**. Extends from 150 days to late stages of pregnancy. All corpora lutea have regressed and large follicles are absent. The ovarian stimulating hormone is now absent.
- **Period 4**. Near the end of pregnancy. No corpora lutea, only small follicles present. Oestrin (estrogen) is present in high concentration in the blood.

In 1959, Short reported on the presence of progesterone during the early stages of pregnancy in association with the primary and accessory corpora lutea, as well as the absence of detectable progesterone during the later stages of pregnancy (120 to 310 days).[65] He noted that the shift or changeover from ovarian support of pregnancy to placental support appears to occur during the 4th or 5th month of gestation. Recently, Conley described the production of progestins throughout pregnancy of the mare.[161] The author confirmed that progesterone was produced by the primary corpus luteum and supplemental corpora lutea

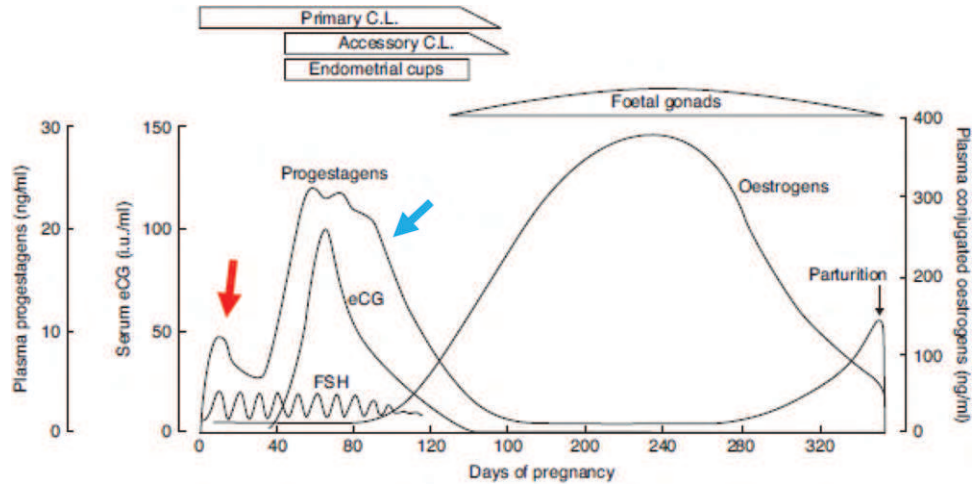


Fig. 25. Reproductive endocrinology of the pregnant mare, showing the progesterone produced by the primary corpus luteum (CL; red arrow) and the increase in blood progesterone after the formation of secondary or accessory corpora lutea (blue arrow; adapted from Allen, 2005).[283] eCG, equine chorionic gonadotropin; FSH, follicle-stimulating hormone.

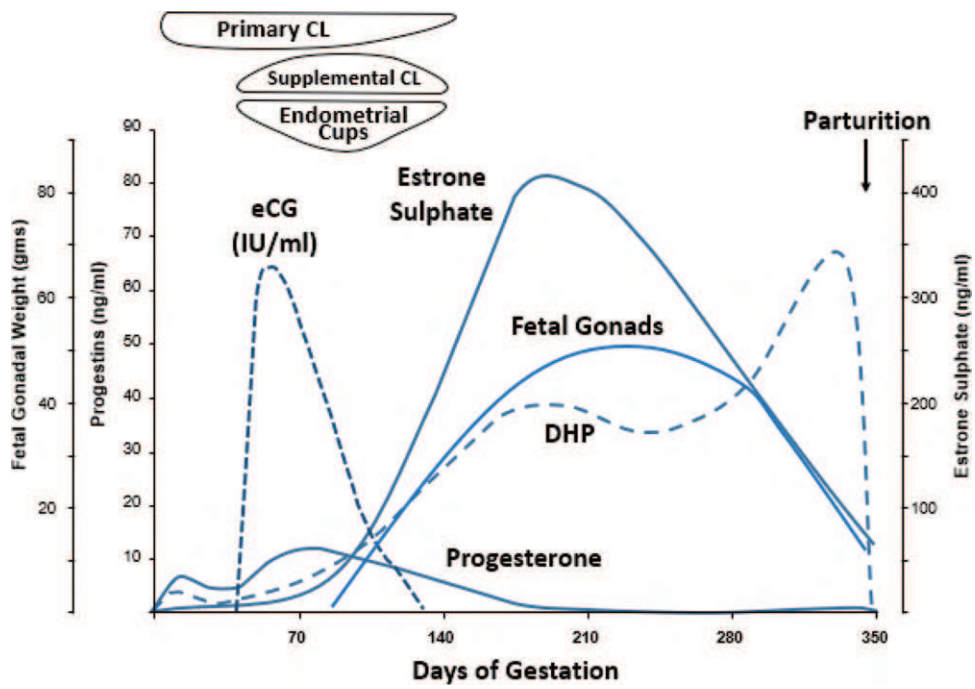


Fig. 26. Reproductive endocrinology of the pregnant mare showing the relative production of progesterone and dihydroprogesterone (DHP) throughout gestation (from Conley, with permission). CL, corpus luteum; eCG, equine chorionic gonadotropin.

from the ovaries in the first few months of pregnancy. However, after week 12 (~84 days) of pregnancy, the plasma concentration of progesterone declines, whereas the concentration of dihydroprogesterone, produced by the placenta, continues to increase and exceeds the concentration of progesterone by week 16 (~112 days; Fig. 26). This crossover defines the *luteo-placental shift* in pregnane synthesis in which pregnancy support switches from ovarian to primarily placental. In addition, this work confirms why concentrations of progesterone measured by radioimmunoassay are low in normal mid- to late gestation in mares. At that point, the equine pregnancy is being supported by progestins that are not detected in most commercial radioimmunoassays.

Estrogens

In a remarkable study in 1933 involving assessment of gonads from 300 male and female equine fetuses, Cole and colleagues noted that the size of the fetal gonads of both sexes increased dramatically during midgestation.[162] The researchers noted that fetal gonadal development occurred after the disappearance of the "gonad-stimulating hormone" (PMSG/eCG) in maternal blood and after the regression in size of the

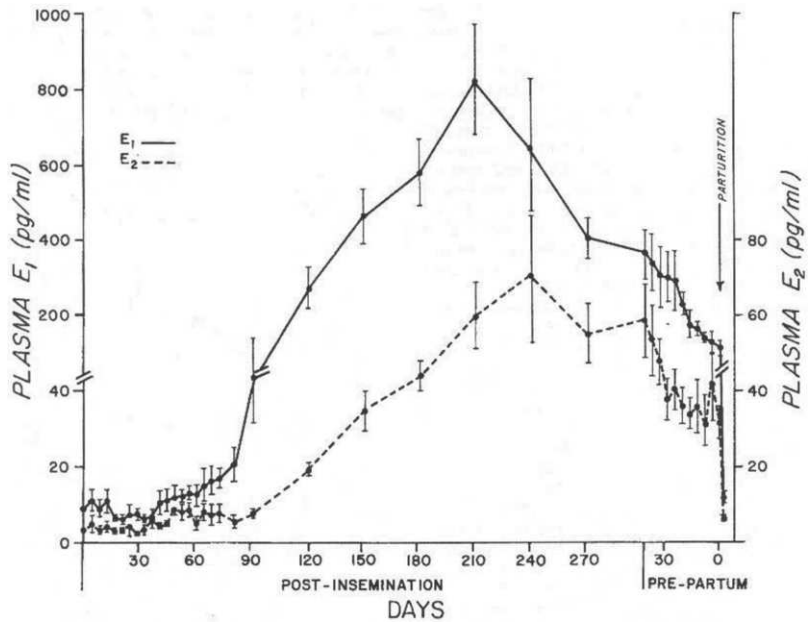


Fig. 27. Concentrations of estrone (E1) and estradiol (E2) during pregnancy in the mare.[61]

maternal ovaries. It was also reported that oestrin (estrogen) concentrations increased in urine of the mare during the second half of pregnancy.[162] A correlation was noted between the development of the fetal gonads and the oestrin content of maternal urine. The highest concentration of oestrin in urine was reached at approximately the same time as maximum development of the fetal gonads. Furthermore, a decrease in oestrin was coincidental with regression of fetal gonads in late gestation. Since the ovaries of mares in the last trimester of pregnancy are "fibrous structures" void of large follicles,[158] and ovariectomy at 200 days of gestation did not eliminate oestrin from maternal blood, Hart and Cole theorized that the source of oestrin in late pregnancy was fetal gonads and/or fetal placenta.[163] Decades later, endocrine studies confirmed that a large increase in estrogens begins after day 55 of pregnancy, the source of which is the feto-placental unit (Fig. 27).[61,164] Estrogen concentrations reach peak levels by day 210 to 240 and then gradually decline over the remainder of gestation.[61]

7. Ovariectomy Studies

Several ovariectomy studies were performed over the years to determine the source of hormones responsible for the maintenance of pregnancy in mares. In 1934, Hart and Cole reported that ovariectomy of a mare at 200 days of gestation did not result in pregnancy loss and did not remove the source of estrogen in late gestation.[163] The source of estrogen was subsequently presumed to be the fetal gonads or the fetal placenta. In another study, ovariectomy at day 150 of gestation did not result in pregnancy loss.[165] Holtan and colleagues reported that ovariectomy between 25 and 45 days postovulation resulted in pregnancy loss in all mares.[166] Daily administration of 100 mg of progesterone following ovariectomy at 25 days resulted in maintenance of pregnancy. Ovariectomy performed between 50 and 70 days only resulted in pregnancy loss in 45% of mares even though plasma progesterone declined precipitously in all mares. No pregnancies were lost after ovariectomy at 140 or 210 days of gestation.

An increase in plasma progesterone above baseline (> 1 ng/mL), presumably of placental origin, was noted at 90 days of gestation in ovariectomized pregnant mares maintained on altrenogest.[167] In another study, embryos were transferred into ovariectomized mares supplemented with altrenogest.[168] Pregnancy was maintained in the ovariectomized mares when altrenogest treatment was administered until day 100 before treatment was discontinued. Collectively, the ovariectomy studies confirm that the ovary is responsible for production of progesterone and support of pregnancy in early pregnancy. An alternative source of progestins, the fetal-placental unit, begins to provide progestin support for maintenance of pregnancy beginning at 50 to 70 days of gestation. Results of the ovariectomy studies correlate with the dihydroprogesterone study noted above.[161]

8. Reproductive Pathology

Ovarian Tumors

In 1924, Dimock and Caslick reported one case of an ovarian tumor in 420 mares examined by necropsy.[92] The mare had one enlarged ovary, and the opposite ovary was "one-fourth normal size and very hard". Undoubtedly the enlarged ovary was a granulosa cell tumor. The granulosa cell tumor is the most common ovarian tumor of the mare.[79,169,170] The clinical presentation, behavioral characteristics, pathologic changes, and hormonal secretory patterns of mares



Fig. 28. Ultrasound image of a large multicystic granulosa cell tumor.

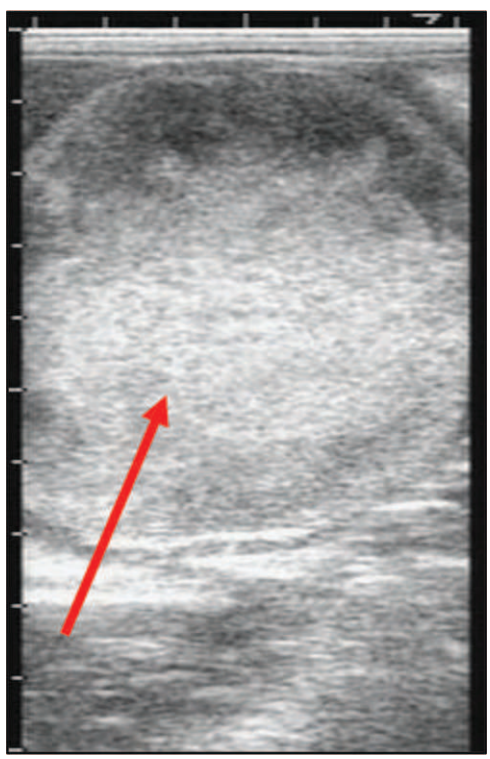


Fig. 29. Ultrasonographic image of a hemorrhagic anovulatory follicle. Unclotted blood (arrow) has filled the lumen of the follicle.

with granulosa cell tumors were described in the mid-1970s.[171–173] The ultrasound characteristics of the affected ovary and the contralateral ovary were subsequently reported.[174–176] The affected ovary is typically enlarged and has a multicystic appearance on ultrasound (Fig. 28), while the contralateral ovary is small and inactive. The use of endocrine markers such as inhibin, AMH, and testosterone for the identification and differentiation of mares with granulosa or granulosa-theca cell tumors have been reported.[78,80,177] Granulosa cell tumors are usually associated with an increase in plasma inhibin and AMH concentrations, while granulosa-theca cell tumors typically exhibit increased levels of testosterone as well as inhibin and AMH.

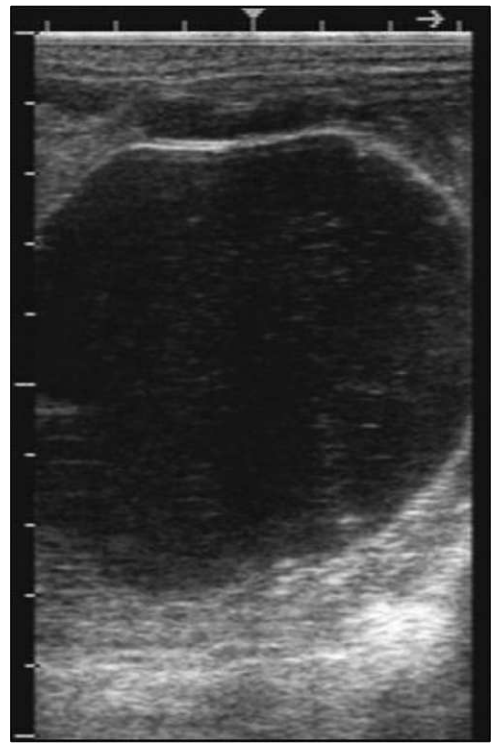


Fig. 30. Ultrasound image of a persistent anovulatory follicle.

Anovulatory Follicles

The presence of "cystic ovaries," failure of mares in behavioral estrus to ovulate, and abnormalities of the equine estrous cycle have been described since the 1930s and 1940s.[94,141,178] Ovulation failure has been reported to occur more frequently in older mares and during the late summer and fall.[179,180] The incidence rate, endocrine profiles, ultrasound characteristics, and morphology of anovulatory follicles have been described.[180–183] Unfortunately, cause(s) of ovulation failure in the mare have not been determined. In addition, a mare may exhibit failure of ovulation during more than one estrous within a given breeding season.

Two main types of anovulatory follicles have been characterized.[180] Hemorrhagic anovulatory follicles comprise 85% of anovulatory follicles (Fig. 29). Hemorrhage into the lumen of the dominant follicle is eventually followed by luteinization and high levels of progesterone in peripheral blood. Administration of prostaglandins, once the structure has fully luteinized 9 to 10 days after initial recognition, will result in luteolysis and a return to estrus. Occasionally, more than one dose of prostaglandins is needed to cause complete regression of the luteal structure. Persistent anovulatory follicles comprise 15% of anovulatory follicles (Fig. 30). With a persistent anovulatory follicle, hemorrhage does not occur into the follicle lumen and the follicle becomes atretic and will slowly regress over time. Historically, it was recommended to remove the fluid from the cystic structure by a procedure referred to as "tapping" or "puncturing."[94] In

current practice, an atretic anovulatory follicle is allowed to regress spontaneously. Administration of prostaglandins is not effective due to lack of luteal tissue. Usually another follicular wave will occur, and another dominant follicle will emerge.

Persistent Corpus Luteum

The average lifespan of the corpus luteum of the nonpregnant mare was reported to be 12 days.[183] Nonpregnant mares may spontaneously exhibit prolonged periods of behavioral diestrus that last for approximately 2 months.[184] The syndrome of persistence of the corpus luteum, associated with a prolonged elevation in plasma progesterone concentration, was subsequently characterized by Stabenfeldt and coworkers.[185] Causes of persistent corpus luteum development in mares include insufficient release of prostaglandins from the endometrium, ovulations late in diestrus, pregnancy loss after maternal recognition of pregnancy, and severe endometrial pathology (i.e., pyometra).[186,187] Regression of a persistent corpus luteum can be induced by infusion of saline into the uterine lumen to stimulate endogenous prostaglandin release[188–190] or systemic administration of exogenous prostaglandins.[190–193]

Blocked Oviducts

Gelatinous masses containing fibroblast cells may occlude the lumen of the oviduct and prevent sperm from reaching the site of fertilization or prevent an embryo from reaching the uterus.[194–196] Oviductal masses are typically located at the ampullary-isthmic junction. Diagnosis of oviductal blockage using starch granules, fluorescent microspheres, or beads is challenging, and therefore oviductal blockage is often a diagnosis of exclusion.[197–199] Treatment protocols for presumptive oviductal blockage have included surgical oviductal flushing,[200,201] laparoscopic application of PGE2 to the oviductal surface,[202,203] hysteroscopic hydrotubation,[50,204] and topical application of PGE1 at the utero-tubal junction via deep horn infusion.[205]

Endometritis

A transient inflammatory response in the endometrium is an inevitable consequence of mating by either natural service or artificial insemination. Evidence indicates that most of the endometritis is due to an antigenic response to the presence of spermatozoa.[205] This mating-induced inflammatory response may develop into a pathologic condition in older susceptible mares that cannot physically clear fluid and inflammatory products from their uterus.[206,207] An impairment of physical clearance of fluid, inflammatory by-products, and bacteria is one of the main factors involved in susceptibility to persistent endometritis.[206] Persistent breeding-induced endometritis may be associated with decreased fertility and possibly premature luteolysis. Current management and treatment protocols include timed mating or insemination, uterine lavage, administration of ecbolic agents or anti-inflammatory medications, immunomodulators, and intrauterine infusion of biologics such as platelet-rich plasma and stem cells.[208,209]

Infectious endometritis due to bacterial or fungal pathogens is also associated with reduced fertility and economic loss. In 1924, Dimock and Caslick reported a high incidence of uterine infections in Thoroughbred mares (151 out of 420 mares).[92] Most infections were due to *Streptococcus genitalium* (now *Streptococcus equi* subsp. *zooepidemicus*) and were primarily due to bacteria entering the uterine cavity through the external genital canal.[94] Dimock and Snyder (1924) noted that uterine infection with *Streptococcus* caused a greater inflammatory response than the presence of other microorganisms.[11] Mares harboring *Streptococcus* infections were noted to frequently abort, and foals carried to term were often stillborn or died at birth or within the first few days of life.[11] It was further noted that *Streptococcus* is often the principle infectious agent associated with navel ill, joint ill, peritonitis, and septicemia in young foals. In 1928, Dimock and Edwards noted that 36% of barren mares were infected and 24% of infections were due to *Streptococcus genitalium*.[93] The main factors predisposing mares to uterine infections include contamination at breeding, pooling of urine in the anterior vagina and uterus, trauma from parturition or breeding, retained placenta, failure of prompt uterine involution after foaling, and failure of natural uterine defense mechanisms.[92,93,210–212] Poor perineal conformation, decreased muscular tone of the vulva, and cranial displacement of the anal sphincter may lead to aspiration of air, fecal material, and bacteria into the reproductive tract. The most common bacterial organisms cultured from mares with infectious endometritis are *Streptococcus equi* subsp. *zooepidemicus*, *Escherichia coli*, *Pseudomonas aeruginosa*, *Klebsiella pneumoniae*, and *Staphylococcus aureus*.[213] The most common fungal organisms cultured are the yeast *Candida albicans* and the hyphate fungus *Aspergillus fumigatus*. The general principles of a treatment regimen are to remove the source of infection, aid in physical clearance of the uterus, eliminate pathogenic organisms by local infusion with antimicrobial agents or systemic therapy, reduce inflammation, and reduce future contamination by enhanced reproductive management.

Biological Therapy for Endometritis

A variety of biological therapies have been administered to mares to prevent or treat endometritis. Intrauterine infusion of autologous plasma as a treatment for endometritis was first reported by Asbury in 1984.[214] Several reports followed on the efficacy of intrauterine plasma for treatment of endometritis and a means to enhance pregnancy rates.[215–219] Platelet-rich plasma was first reported as a therapy for the prevention of mating-induced endometritis by Metcalf and coworkers in 2012.[220] Subsequently, a multitude of studies have described the efficacy of platelet-rich plasma in mitigating mating-induced endometritis and as a therapy for bacterial endometritis in mares.[221–225] Other biologics

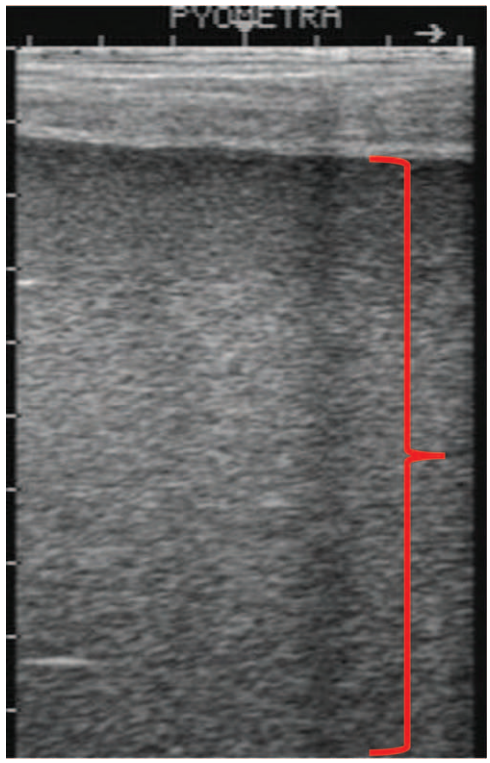


Fig. 31. Ultrasound image of the uterus of a mare with a large volume of echogenic fluid in her uterus. *Streptococcus equi* subsp. *zooepidemicus* was cultured from the uterus.

used in the treatment of endometritis include colostrum,[226] mycobacterium cell wall extract,[227–229] autologous conditioned serum,[230,231] stem cells,[231–233] amnionic microvesicles,[234] platelet lysate,[235] and other therapies.[209,236]

Pyometra

Pyometra is uncommon in mares.[92] The term pyometra in horses refers to the chronic accumulation of a large volume of inflammatory fluid within the uterine lumen secondary to bacterial infection (Fig. 31).[237,238] An open pyometra refers to cases where the cervix is patent and a chronic or intermittent cervical or vaginal discharge is present (Fig. 32). In contrast, a closed pyometra implies that the cervix is not patent (i.e., closed or adhered shut), in which case there is no vaginal discharge despite accumulation of a large quantity of fluid in the uterus. Severe degeneration of the endometrium in mares with a pyometra may result in persistence of the corpus luteum secondary to insufficient production of prostaglandins to cause luteolysis.[239] Affected mares are usually not systemically ill as the infection is localized to the endometrium and uterine lumen.[238] Prognosis for complete resolution and future fertility is guarded to poor. Administration of prostaglandins to lyse the corpus luteum, followed by uterine lavage and administration of ecbolic agents such as oxytocin or prostaglandins, and either local or systemic administration of antibiotics can achieve short-term or temporary resolution, but unfortunately the condition often returns within a few

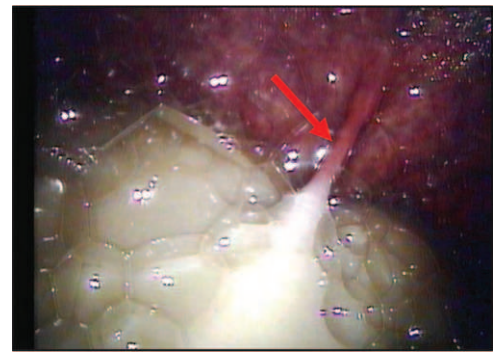


Fig. 32. Purulent debris covering the external os of the cervix of a mare with open pyometra. The red arrow indicates the dorsal frenulum of the cervix.



Fig. 33. Retained tip of the non-gravid horn of the chorioallantoic membrane that had been retained.

days or weeks.[240] Salvage procedures include ovariohysterectomy,[241–245] hysterectomy only,[246] ovariectomy only,[247] hysteropexy,[248] cervical wedge resection,[249,250] and application of a cervical stent.[251]

Retained Fetal Membranes

Retention of the fetal membranes is the most common abnormality of the postpartum mare, with written descriptions dating back decades.[252–254] Current consensus is that fetal membranes are considered abnormally retained in the mare if not passed by 3 hours postfoaling.[255] A mare may retain the entire chorioallantoic membrane, the entire non-gravid horn of the chorioallantoic membrane, or just the tip of the non-gravid horn of the chorioallantoic membrane (Fig. 33). The incidence rate of fetal membrane retention has been reported to be 2% to 10% of all foalings.[256] Risk factors for development include breed, advanced age, abortion, dystocia, obstetrical manipulation, placentitis, hydrops conditions, Cesarean surgery, induction of labor, previous history of retained placenta, and fescue toxicosis.[257–259] Friesian mares have a high breed incidence of retained placenta, and affected mares may have a lower serum calcium level than mares that do not retain their placenta.[260,261] Sequelae of retained fetal membranes include metritis, peritonitis, laminitis, and possibly uterine prolapse. Therapy includes manual

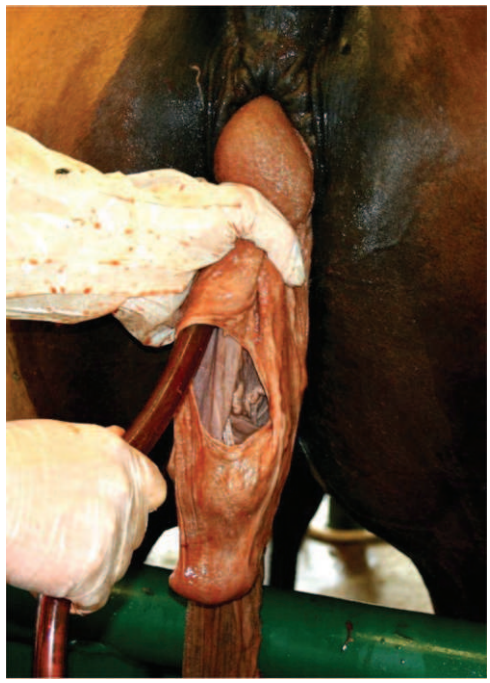


Fig. 34. A stomach tube has been passed into the allantoic cavity, which was subsequently filled with water to promote passage of the retained chorioallantoic membrane.



Fig. 35. Insertion of a stallion catheter into an umbilical vessel prior to infusion of water to promote passage of the retained chorioallantoic membrane.

removal,[262–264] administration of oxytocin,[256,265] infusion of water into the allantoic cavity (Burn's technique; Fig. 34),[266] injection of collagenase into an umbilical artery,[267] and infusion of water into an umbilical blood vessel (Fig. 35).[268] Additional therapy may be indicated depending on the health status of the mare. Manual removal or forced extraction of a retained fetal membrane is controversial and has even been suggested to be contraindicated.[255,256,269]

9. Assisted Reproduction

Artificial insemination in the mare has apparently been practiced for hundreds of years, with the first recorded insemination occurring in 1322.[270,271] In contrast, embryo transfer and other advanced assisted reproductive techniques in mares are much more recent in origin. The first report of successful mammalian embryo transfer was in rabbits and performed in Cambridge, England, by Walter Heape in 1891.[272] The era of equine embryo transfer began in 1972 with a report of reciprocal inter-species transfer of horse, donkey, mule, or hinny zygotes collected from and transferred back into mares or donkeys.[273]

Table 4. Progression of Assisted Reproduction Techniques Approved by the American Quarter Horse Association

Reproductive Management Technique	Approval Year
Live cover only	Prior to 1958
Artificial insemination (AI) permitted	1958
Embryo transfer approved; allowed one foal registered/mare/year	1980
AI with cooled-transported semen approved	1997
AI with frozen semen approved	2001
Registration of multiple foals approved	2003
Sperm, embryos, and oocytes from foals born in 2015 or after can only be used for 2 calendar years following death	2015

The first live foal produced by embryo transfer was reported in 1974.[274] Successful cryopreservation of an equine embryo that resulted in a live foal was first reported in 1982.[275] The birth of the first foal produced by in vitro fertilization was recorded in 1991.[276] The first foal produced from intracytoplasmic sperm injection was noted in 1996.[277] The first equids produced by nuclear transfer or cloning were reported in 2003.[278,279] A recent breakthrough in in vitro fertilization was reported by Felix and coworkers in 2022.[280] The authors noted that prolonged preincubation of sperm with penicillamine, hypotaurine, and epinephrine for 22 hours prior to coincubation with cumulus-oocyte complexes yielded high fertilization rates and high blastocyst development rates. The technique ultimately led to the birth of 3 live foals after in vitro fertilization. The progression of breed registration approval of assisted reproductive techniques, from the perspective of the American Quarter Horse Association, is presented in Table 4.

10. Summary

The current state of practice in equine reproduction has clearly been built upon the foundation laid by equine researchers and clinical veterinarians over the past 50 years or more. It is hoped that this discourse on research, discovery, and innovation will encourage current and future generations of veterinarians and equine scientists to continue to contribute to the advancement of knowledge in the field of equine reproduction.

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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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How to Improve Early Embryonic Loss

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1. Introduction

Early embryonic loss (EEL) refers to losses occurring in the period from fertilization until 40 days of pregnancy.[1] The estimated incidence of embryonic loss in normal mares between fertilization and day 50 is approximately 18%.[2] A higher incidence of EEL (16–20%) has been observed for in vitro produced embryos, especially in the first 28 days of gestation, which is the time of development of the embryo proper.[2] In subfertile mares, the corresponding estimate for embryonic loss between fertilization and day 50 is 80%, with most embryonic losses occurring before day 14.[3] A high rate of EEL in mares may be related to age, oocyte abnormalities, embryonic defects, or the oviductal or uterine environment. Other factors include stress, twinning, hormonal deficiencies, ergot alkaloid toxicity, or ingestion of tent caterpillar setae causing mare reproductive loss syndrome.[4–6] A study of 3,740 mares with confirmed pregnancies showed that early and late pregnancy loss increased with the age of the mare.[7] Resorption rate, but not abortion rate, increased with parity.[7] Breed had no effect on pregnancy loss.[7] Reproductive status was not linked with embryonic death frequency; however, pregnancy loss rate increased if the mare became pregnant during foal heat.[7] Similar resorption rates were observed across different stallions, and risk of pregnancy loss decreased steadily as pregnancy progressed.[7] From a clinical perspective, determination of the potential cause for pregnancy loss allows for management and treatment practices to be implemented to help maintain the pregnancy and development of the foal to parturition. Strategies to improve pregnancy maintenance and viability will be discussed.

2. Oocyte Quality

There are decreased pregnancy rates and an increased rate of embryonic loss associated with aged oocytes.[8] The initial work in this area was done to determine the effect of age on the viability of oocytes from young and old mares (6–10 and 20 years, respectively).[8] Oocytes from young mares resulted in significantly more embryonic vesicles than old mares (92% and 31%, respectively).[9] This research confirmed that an age-associated decline in oocyte quality is a primary factor in reduced fertility in the old mare. Further studies identified that oocyte quality decreases due to mitochondrial function and potentially the change of the follicular milieu surrounding and nourishing the oocyte.[8] Increasing maternal age was associated with a reduction in the reproductive efficiency of all breeding techniques except ovum pick up (OPU), intracytoplasmic sperm injection (ICSI), and embryo transfer.[10] This may be due to most of the maturation of the primordial follicle oocytes being in vitro after OPU, reducing the influence of age-related maternal maturation factors, thus making OPU/ICSI a viable option for increasing fertility in older mares.[10] Another factor that influences oocyte quality, follicular milieu, and the developing embryo is excess weight or obesity in the mare.[11] Mares with equine metabolic syndrome have increased concentrations of insulin and leptin, inflammatory cytokines, tumor necrosis factor α, and interleukin-1 β and decreased concentrations of

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adiponectin in their follicular fluid.[12] However, the extent to which these alterations impact the conceptus and offspring still needs to be determined.[12]

What can be done to influence oocyte quality and thereby embryonic development? Dietary supplementation of a complex of nutrients with n-3 fatty acids and antioxidants when given to older mares has been shown to improve oocyte metabolic function and embryo blastocyst development, compared to other grain-based supplementation.[13] While the anti-inflammatory effects of omega 3 might combat an age-related increase in the inflammatory response in older mares, which components of the supplements are key to improvement needs to be determined so that there can be practical application. Different omega 3 fatty acid supplements on the market have promoted the improvement of a mare's fertility. Unfortunately, scientific studies are lacking. Early diagnosis and treatment of metabolic disease may aid in normalizing and improving oocyte quality and the follicular fluid milieu.[12] As few other studies have been done to specifically identify treatments that can improve the quality of oocytes, one method presented by the author could be increasing blood flow to the ovaries. Studies have shown increased ovarian and uterine blood flow with increased serum progesterone levels when cycling nonpregnant mares are treated with acetylsalicylic acid (ASA).[14] ASA at 2,500 mg twice daily improved uterine and ovarian perfusion and increased plasma progesterone concentrations.[14] This could potentially influence the quality of the oocyte and improve the uterine environment for the developing embryo. Another recommendation, emphasized above, may be the use of ICSI or gamete intrafallopian transfer, which provide a better environment for fertilization and growth by removing as many negative factors as possible.

3. Embryonic Development and Uterine Synchrony

Rapid embryonic growth, unimpeded conceptus mobility, and presence of an acellular capsule at the time of maternal recognition of pregnancy are prerequisites to pregnancy maintenance. Adequate size or growth of the conceptus is essential for maternal recognition of pregnancy.[15,16] Growth retardation and inappropriate development is considered a major reason for EEL in mares.[15] In contrast, larger vesicles at day 15 to 16 postovulation appear to positively correlate with pregnancy maintenance.[2] Changes within the oocyte elicit decreased embryonic growth and development rates, leading to asynchrony of the embryo with regard to days postovulation of the endometrium. Lysis of the corpus luteum associated with failure of maternal recognition of pregnancy can lead to early embryonic death.[17,18] Embryonic loss prior to day 20 has been identified in vesicles that were too small for days of age or failed to fix. In these mares, serum progesterone was lower at 12, 15, and 18 days.[16] In addition, by day 10, the embryo secretes estradiol, which acts locally on the endometrium and likely plays an important role, like progesterone, in the production of endometrial gland histiotroph.[16] Embryonic estrogens locally enhance endometrial vascularity and potentially promote conceptus development.[16] Unfortunately, it is not possible to measure estradiol produced by the conceptus in peripheral blood in early pregnancy, and therefore it is unknown if low estradiol is a factor in EEL when compared to the low progesterone. When a small or growth-retarded embryo is identified on ultrasonography at day 14 of gestation, it may already be too late. The corpus luteum production of progesterone should peak at day 6 postovulation and then plateau. Therefore, measuring serum progesterone on day 6 can potentially identify low serum levels during early pregnancy development. If there is evidence of potential or impending EEL such as uterine edema, poor uterine tone, or small embryo for days of gestation during pregnancy diagnosis by ultrasound at 12 to 14 days, serum progesterone levels are warranted.

What can be done to aid embryonic growth and potentially improve survivability? Supplementation with exogenous progestogens can be used to increase uterine tone and replace the potentially decreased levels associated with luteolysis. ASA increases both uterine and ovarian perfusion in cycling nonpregnant mares.[14] The increase in uterine and ovarian blood flow has been attributed to the inhibition of platelet cyclooxygenase, which results in inhibition of the synthesis of thromboxane A_2, and thus facilitates platelet aggregation and vasoconstriction. Another rheostatic agent, pentoxifylline, has anti-inflammatory properties that have been used extensively in clinical situations of placentitis, endotoxemia, laminitis, and other systemic illnesses to increase perfusion to the microvasculature. The use of pentoxifylline to increase blood flow to the microcirculation of the uterus has been extrapolated from other systemic models and therefore can be used in similar situations as ASA, but by a different mechanism of action. The rationale behind using either of these drugs is that increasing uterine blood flow potentially improves histiotroph production, which may improve growth of the embryonic vesicle, allowing it to survive and catch up to the expected size for gestation. Supplementation with estradiol in addition to progesterone in the form of compounded progesterone and estradiol 17/(P + E) has been suggested as a possible treatment protocol; however, caution should be taken as this may not be an appropriate solution as administration of exogenous estrogen in early pregnancy results in partial regression of luteal function without complete luteolysis.[16]

4. Endometritis

Progesterone together with 5α -pregnanes is secreted by the corpus luteum and induces the production of endometrial histiotroph, which is responsible for conceptus nutrition until placenta formation. It has been postulated that decreased progesterone either due to

luteal insufficiency or to early luteolysis from intrauterine inflammation may be a cause of early embryonic loss. Uterine inflammation and infection with chronic underlying endometritis may not be identified until embryonic loss occurs and further diagnostics are done. Endometrial culture, cytology, and biopsy can help identify the presence of excessive mucus, acute or chronic inflammatory cells, bacteria, and fungi. However, if a causative agent is not identified, more in-depth diagnostics can be performed, to include intrauterine infusion with N-acetylcysteine, misoprostol, bActivate, biofilm disruptors, and kerosene in combination with low volume lavage, culture, and cytology.[19–23] If there is a lack of evidence of an inflammatory or infectious cause of luteolysis, primary luteal insufficiency may be suggested. With subsequent confirmation by serum progesterone values of < 4 ng/dL, supplementation with exogenous progestins at day 6 postovulation may be indicated. While a serum progesterone level of < 4 ng/dL on day 6 postovulation was identified in 11% of mares in a recent study, only when serum progesterone levels were < 2.5 ng/dL did there appear to be a decrease in pregnancy rates.[18]

What can be done to reduce endometritis and low endogenous progesterone? Once underlying endometritis due to an infectious process, poor perineal conformation, cervical defect, or vesiculo-vaginal reflux is identified, appropriate treatment can be initiated. With resolution of the endometritis, pregnancy should be achieved and maintained given all else is normal. If inflammation persists due to chronicity of disease, with no evident etiology, anti-inflammatories or immune modulators can be utilized pre- or postbreeding. These may include dexamethasone, platelet-rich or -poor plasma, mycobacterium cell wall fraction, or propionibacterium acnes.[24–26]

Treatment options during early pregnancy can consist of firocoxib, ASA, or pentoxifylline. Firocoxib has been identified to not affect early embryonic mobility, unlike flunixin meglumine or meloxicam, and can help with persistent inflammation when administered postbreeding or postovulation.[27] The effects of ASA and pentoxifylline on embryonic mobility have not been determined.

5. Chronic Degenerative Endometrial Changes

In addition to producing an environment hostile to embryonic growth, chronic endometritis also promotes and enhances the development and severity of endometrial fibrosis.[28] Endometrial biopsy score is an accepted marker of uterine health and predicted fertility.[28,29] Biopsy, however, can be used to give a predictive index not only for carrying a foal to term but also for direct therapeutic interventions depending on the pathology identified. More than one sample from different areas of the uterus should be obtained to verify the quantity of degenerative changes.[30] Abnormal areas can be identified by hysteroscopic examination or randomly taken from each horn using an alligator biopsy instrument. The endometrium is classified according to the presence of inflammation (type and severity), endometrial gland density, periglandular fibrosis and nesting, cystic glandular distension, lymphatic lacunae and angiopathies, or angiosclerotic changes.[28,31] As the number and severity of pathologies increases, so does the classification category, and the potential of carrying a foal to term decreases. Category I has little or no pathologic changes, with an 80% to 90% foaling rate. Category IIA has slight to moderate diffuse superficial inflammatory changes, infrequent fibrotic changes, or mild fibrotic nesting; the lymphatic lacunae have a 50% to 80% rate of carrying to term. Category IIB consists of widespread diffuse, moderately severe inflammation; there are more extensive fibrotic changes of individual glands with increased nesting, leading to a 10% to 50% expected foaling rate. Category III has widespread, diffuse, severe inflammation with extensive fibrosis and nesting.[31] Unfortunately, the Kenny-Doig classification system described above does not take into account the amount of lymphatic stasis or endometrial angiopathies that may be present within the endometrium.[32] It is the author's opinion that consideration of these changes should be taken into account as they give insight into what damage the uterus has incurred as well as where treatments should be focused if resolution is possible and pregnancy maintenance is expected.

Endometrosis or chronic degenerative endometritis is a glandular and/or stromal fibrosis, including glandular alterations in fibrotic foci.[30] Endometrial fibrosis is progressive and irreversible and worsens with age and parity.[30] In mares with endometrosis, microcotyledon formation and their extent of development is affected. The most significant lesion in endometrial biopsies associated with this change was reduced gland density, with accompanied fetal growth retardation.[33] The relationship of chronic degenerative endometrial disease with age and parity was investigated, and it was found that maiden mares of increased age exhibited endometrial changes, indicating that age alone will be a causative factor in the development of endometrosis.[34] These authors also suggested that mares with increased parity had a higher incidence of poor endometrial quality.[32] As uterine blood flow is a dynamic process influenced by hormones, the presence of semen, and pregnancy, increased age and parity influences the severity of endometrial angiopathies.[35–37] Older maiden mares had a higher incidence of angiosclerotic changes or vascular elastosis than younger mares.[38] Degeneration of the uterine vasculature seems to be strongly associated with increased parity and is associated with decreased uterine perfusion below physiological levels found in normal mares.[39] Arterial degeneration or sclerosis also affects embryonic and fetal well-being. Reduced perfusion means decreased supply of oxygen and nutrients to the uterus and therefore the growing conceptus. If the supply of nutrients and oxygen is limited during critical growth phases, uterine growth retardation or

dysmaturity can occur. This can further manifest itself with prolonged gestation, decreased size and body weight at birth, or fetal loss.[40–42] The importance of adequate blood flow and drainage of the uterus has been further substantiated with the use of Doppler ultrasonography, which has detected differences in uterine blood perfusion in mares with varying degrees of endometrial degenerative changes.[39]

What can be done to decrease endometrial gland fibrosis and degenerative angiopathies? Very little has been identified in the literature to reduce endometrosis associated with the endometrial glands and vasculature degeneration. However, a recent study tried to determine the potential regenerative effect of mesenchymal stem cells injected directly into the endometrium of mares with endometriosis.[43,44] Sixty percent of mares showed improved biopsy scores and increased steroid receptors in the endometrium, making this potentially a new technique to improve fertility.[44] Amnion-derived products are starting to be utilized to regulate inflammation and potentially reduce fibrosis.[45] A novel product that is an amniotic-derived acellular bioscaffold has been injected into the endometrium to potentially reduce inflammation and fibrosis.[46] This has been hypothesized to replace fibrosis with healthy collagen within the endometrium. Further studies are needed to assess the benefits with pregnancy maintenance. Ozone therapy has been described in humans as having many benefits including antioxidant and angiogenic properties. The effect of ozone on endometritis and angiogenesis is starting to be scientifically studied within the mare.[47,48] A recent study in mares reported that three successive exposures of equine endometria to O_2–O_3 gas mixtures induced local angiogenesis without histological injuries.[46] Furthermore, the histomorphometry of the endometrial glands was stimulated by successive exposure to an O_2–O_3 gas mixture.[48] Further information is needed to determine if this translates into improved pregnancy and maintenance rates.

ASA has been recommended for clinical use in mares with placentitis by several authors.[49–51] ASA has been used to help improve blood flow and red blood cell malleability to try to combat placental insufficiency and maintain pregnancy.[52,53] The effect of ASA in pregnant mares was studied using two different doses, giving 5,000 mg of ASA orally from 120 days of gestation to parturition and the same until 285 days of gestation, then twice a day until parturition.[54] Its effects on uterine blood flow during gestational length was monitored by color flow and pulsed wave Doppler sonography. It has been found that 5,000 mg of ASA can enhance uterine perfusion by increasing blood flow velocity during late pregnancy, which might support ASA treatment not only in older mares with degenerative changes (endometriosis, angiosclerosis) but also in placentitis.[54] The benefit associated with the use of ASA needs further study in a larger population of abnormal pregnancies.

There are conflicting reports regarding pentoxifylline's use to increase uterine artery blood flow and improve circulatory parameters in mares with endometriosis. Although pentoxifylline is used to increase the lifespan of red blood cells and increase blood flow to areas that do not get enough (i.e., compromised capillaries), a study that looked at uterine artery blood flow parameters and placental or foal development in aged pregnant mares with endometriosis and in young, healthy mares revealed that peak systemic velocity increased in both groups within the first 30 days of treatment.[55] However, blood flow parameters in young pregnant mares were altered, resulting in larger placentas, although foal weights were unchanged. Pentoxifylline did not increase uterine artery blood flow in aged mares. The authors concluded that poor placental development associated with endometriosis could not be overcome by this drug.[55] Another study looked at pentoxifylline use in pregnant pony mares between 18 and 190 days gestation. They concluded that any benefit of administration of pentoxifylline was not mediated through enhanced uterine artery blood flow.[56] However, treatment duration was 3 days, which may have been too short to see significant changes. Further studies are warranted.

6. Endometrial Cysts

Embryonic mobility depends on local peristaltic contractions of the myometrium that are most likely induced by prostaglandins synthesized and secreted from the conceptus.[15] This mobility throughout the uterus is necessary for maternal recognition of pregnancy to occur and inhibition of endometrial prostaglandin release. Therefore, restriction of conceptus mobility to only part of the uterine lumen results in failure of pregnancy in the horse.[57] Endometrial cysts that project into the lumen of the uterus, impeding embryonic mobility, may therefore be a cause of embryonic loss. The incidence of endometrial cysts in the general mare population has been reported to be 1% to 22% and as high as 55% in subfertile and older mares.[58,59] Endometrial cysts are most prevalent in multiparous mares that have undergone fibrotic changes.

The significance of the presence of endometrial cysts is controversial.[51,60] They are a sign of an underlying problem, that of blocked lymphatics and poor uterine clearance; however, the concerns associated with them seem to be their differentiation from early embryonic vesicles, embryonic growth, and whether or not they impede the early mobility phase and therefore affect fertility.[59,61] In mares that have a few small cysts, ultrasonographic exam of the mare's uterus pre- or postbreeding to measure and map the endometrial cysts can aid in pregnancy diagnosis by comparing ultrasonographic images at time of breeding to time of pregnancy examination. Mares that have numerous clusters or multiloculated cysts may need repeat examinations before determination of a pregnancy to document increasing vesicle

size or a visible heartbeat. It has also been shown in some cases that the presence of numerous or large endometrial cysts (2.5 cm) can impede mobility of the embryonic vesicle, preventing maternal recognition of pregnancy and allowing luteolysis to occur.[59,60]Additionally, when the yolk sac or allantois contacts the cyst rather than the endometrium, absorption of nutrients may be prevented, resulting in early embryonic death.[60-63]

What can be done about endometrial cysts? Various treatment regimens include endometrial curettage, puncture by uterine biopsy punch, puncture or aspiration during hysteroscopic examination, snare electrocoagulation via hysteroscopy, repeated lavage with warm saline, or manual ablation.[60-63] Initial therapy may consist of exogenous progestagen supplementation to compensate for luteolysis due to failure of maternal recognition of pregnancy. If this is not successful, large pedunculated cysts can be removed when the mare is in heat by manually snaring the cyst. Smaller more numerous cysts are removed via hysteroscopic laser. Other treatment options may include endometrial curettage, puncture by uterine biopsy punch, puncture or aspiration during hysteroscopic examination, snare electrocoagulation via hysteroscopy, or ablation manually.[60-63] It is the author's opinion that most cysts do not cause a problem but are a sign of an underlying one. These mares are usually older with poor uterine clearance and varying degrees of fibrosis, and therefore treatment to help lymphatic drainage, improve blood flow, and combat inflammation and fibrosis is warranted in addition to cyst removal.

7. Reproductive Conformation

Understanding the above endometrial changes helps to identify the potential causes of infertility and fetal loss, allowing for strategic breeding management and treatment. It is imperative that mares be evaluated prior to the breeding season so that chronic endometritis and physical abnormalities, such as poor perineal conformation and cervical incompetence, can be treated and addressed. Uterine health requires appropriate anatomical positioning of the reproductive tract,[64–66] muco-ciliary clearance,[67,68] myometrial contractions,[69–71] and lymphatic drainage.[64] The mare's reproductive tract resides in the caudal portion of the abdomen suspended from the body wall by the broad ligaments. There are three major anatomical barriers that protect the uterine environment. These include the vulvar labia, vestibulo-vaginal fold (hymen), and cervix.[65,72] Good conformation of the vulva and the perineal body are imperative for reproductive efficiency and are too frequently overlooked. The vulva lips need to have good tone with tight closure supported by the perineal body (muscular tissue between the vulva and anus).[73] The vestibulo-vaginal seal should be maintained when the vulvar lips are parted, denying aspiration of air into the vagina. A competent cervix consisting of an internal and external os connected by a long tubular body that is tight during diestrus should prevent ingress of contamination and infection. When any of these three barriers become disrupted (through trauma, poor perineal conformation, or poor body condition), air may be intermittently or consistently aspirated into the vagina, resulting in contamination by urine or particulate matter, causing vaginitis, cervicitis, and endometritis.[73]

What can be done to decrease uterine contamination? Different procedures have been utilized for perineal reconstruction, ranging from a Caslick vulvoplasty to the Pouret or Gadd techniques, depending on the severity of pathology. Examination of the cervix for complete closure and tears should be done during diestrus when it should be tightest and most toned under heightened serum progesterone levels. Repair of cervical tears and defects aids in prevention and treatment of endometritis. Decreased duration of time from tear formation to identification and repair promotes increased pregnancy rates.[74] Recently, a procedure has been described in which the mesometria have bilateral imbrication shortening the broad ligaments and raising the uterine body and uterine horns.[75] Perineal conformation has also been documented to improve after uteropexy.[75] This procedure may therefore be beneficial in aiding uterine clearance as well as decreasing contamination of the uterus. In the author's opinion, re-establishing good perineal conformation and vulvar closure is the most important treatment for chronic endometritis and infertility, as if any degree of inflammation persists when the embryonic vesicle descends into the uterus, embryonic and future fetal loss can occur.

8. Adjunct Therapies for Pregnancy Maintenance

Traditional Chinese veterinary medicine appears to be most effective when used in conjunction with Western management in reproductive cases.[76] Acupuncture point choices and herbal medication should be based on the mare's Bian Zheng.[76] Specific points modified based on pattern assessment as well as the herbal Pregnancy Smoother or Yunnan Baiyo can aid in pregnancy maintenance.[76]

9. Conclusion

In order to maintain pregnancy and prevent early embryonic loss, a methodical approach should be taken by identifying potential problems prior to breeding and those during pregnancy by continual monitoring, especially those that may be at higher risk. If diligent intervention does not prevail, further evaluation for genetic abnormalities should be performed.

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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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Causes of Pregnancy Loss: From the Laboratory to the Clinic

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Early pregnancy loss (EPL) conceptuses found to be aneuploid (loss or gain of whole chromosome) are highly likely to be nonviable. Given this condition is commonly associated with EPL, clinically treating compromised pregnancies with progesterone or progestins should be done with caution to avoid a delay in rebreeding. Authors' addresses: Baker Institute for Animal Health, College of Veterinary Medicine, Cornell University, Ithaca, NY 14850 (de Mestre) and Department of Pathobiology and Population Sciences, Royal Veterinary College, North Mymms, UK (Lawson); e-mail: amm43@cornell.edu. *Corresponding and presenting author. © 2023 AAEP.

1. Introduction

Pregnancy loss arises due to a pathology that can originate in the mare, the stallion, the embryo/feto-placental unit itself or due to an external insult (for example, a pathogen or teratogen) that impacts one of these three entities. Therefore, pregnancy loss is an outcome, not a diagnosis, and can be very frustrating for veterinarians to manage. One needs to either preemptively diagnose the pathology prior to the loss and then initiate preventative treatment(s) or retrospectively diagnose the causative pathology to accurately inform the management of future pregnancies. Establishment of the underlying cause of pregnancy loss is often not achieved, resulting in a reliance on more generic approaches to loss prevention such as supplemental progesterone/progestins. This review will discuss the causes of equine pregnancy loss, focusing on non-infectious causes and how the veterinarian can use aspects of the recent literature to inform clinical management of the mare and communicate and manage client expectations.

2. What Incidence of Pregnancy Loss Should Be Expected?

Equine pregnancies are most likely to fail in the first two months of gestation corresponding to the period of early embryogenesis, placental development, and organogenesis. Studies of research mares estimate that approximately 20% of pregnancies are lost prior to clinical detection,[1] observed by veterinarians as mares that fail to conceive. Epidemiological studies have quantified early pregnancy loss (EPL) after clinical detection in the US and abroad, consistently reporting that 5-15% of confirmed day 14-16 pregnancies are lost prior to 42 to 65 days.[2–5] Variability in loss rates can be attributed to geographical variation, breed, management, and inherent characteristics of each cohort. Specific examples of mare, pregnancy, stallion, and external risk factors are reviewed elsewhere.[6] Breeding method has been found to have a significant impact on EPL, with

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natural mating, artificial insemination, and artificial insemination combined with embryo flush and transfer all having a similar and lower incidence of early pregnancy loss (4.5–6%) when compared with pregnancies established using cryopreserved in vitro generated embryos (13%).[7]

The incidence of pregnancy loss beyond the first two months is also geographically variable and ranges between 5 and 15%.[2,3,8] Risk factors for pregnancy loss beyond day 70 are distinct from those associated with early pregnancy. The greatest risk factor for abortion is the mare having two or more previous abortions, but surprisingly, not mare age or status.[9] These results concur with other studies that show advancing maternal age is an important factor for embryo mortality in early gestation[10] but more likely impacts fetal morbidity (not mortality) in mid to late gestation.[11]

3. Causes of Pregnancy Loss

The underlying causes of pregnancy loss are heterogenous in nature. Ultimately most cases will be attributed to a primary pathology of the mare (such as endometrial pathology, endocrine function, immunopathology, and oocyte characteristics) or the embryo/feto-placental unit (inherited via the germline from the stallion or mare or acquired during development). In both cases, defects could be intrinsic to the tissue or alternatively the response of that tissue to environmental exposures such as pathogens and contaminants. While individual stallions can have a higher incidence of early pregnancy loss, several multivariable studies have shown, at the cohort level, the stallion contribution to variability in risk is not significant or low.[4,10,12]

4. Pregnancy Loss Prior to 70 Days

Genetic variants in equine pregnancies are more commonly associated with pregnancy loss in the first 70 days of gestation. Broadly, there are three main mechanisms by which genetic variants can impact the outcome of a pregnancy. The genetic characteristics of the mare can influence the environment she provides for the developing conceptus, the embryo can inherit lethal genetic variants via the germline (mare and stallion), or the embryo can acquire lethal variants in the early stages of development. Clinically, if a genetic cause of pregnancy loss is suspected, understanding these different types of genetic influences will be key to implementing the optimal clinical management as they do differ, with each discussed below.

Aneuploidy of the Conceptus Genome

The most common described genetic variant associated with equine early pregnancy loss is aneuploidy, the gain (trisomy) or loss (monosomy) of an entire chromosome. The horse has 31 pairs of autosomes, with aneuploidy associated of equine chromosomes 1, 4, 15, 20, combined 23/24, 26, 27, 30, and 31 all linked with lethality in the first two months of gestation.[13] It is worth noting that monosomies of some of the larger chromosomes are yet to be identified, perhaps suggesting these are lethal prior to clinical detection and may well be revealed once routine testing of equine blastocysts is established. Monosomies have never been reported in viable individuals in any species, including the horse. Trisomies found in failed pregnancies are also unique, with the exception of trisomy 30, which has also been described rarely in liveborn foals.[13,14] It is plausible that an extra copy of chromosome 30 can result in multiple outcomes (pregnancy loss or developmental disorders of the foal). Alternatively, the identification of Trisomy 30 in the lost pregnancy could be incidental. In a study that screened 55 primarily Thoroughbred clinical cases of EPL, aneuploidy of chromosomes 1-31 was identified in 11/55 (20%) feto-placental units, making it the most common cause of EPL described to date. To put the incidence in clinical context, just 13 liveborn foals have been described in the literature that are associated with aneuploidy of the small chromosomes, and wide scale screening of group sizes of 500 or more horses only identified three mosaic aneuploidies (i.e., the aneuploidy was only in some of the screened cells for that horse, not all of them).[14] Most aneuploid liveborn foals are euthanized at a young age due to developmental pathologies.[15–17]

Aneuploidy arises due to errors in gametogenesis (maternal or paternal gametes) or during early embryonic development, both reviewed elsewhere.[6] The balance of evidence currently available points towards maternal gametogenesis as the greatest contributor to equine aneuploid conceptuses, similar to what is observed in women.[6] Advanced maternal age is associated with increased incidence of aneuploidy of equine oocytes. Studies have found 56% of oocytes from older mares compared with 16% in younger mares are aneuploid.[18] It is important to note, aneuploid pregnancy losses can still be found in younger mares with 6/11 autosomal aneuploid EPLs described by Shilton et al.[13] identified in mares aged 10 years or younger.

Aneuploid pregnancies present clinically with a diverse range of pathologies, likely relating to which chromosome is affected. They have been linked with pregnancy losses ranging from gestation day 14 through 60. Only one of the twelve clinical aneuploid pregnancies described was found to be anembryonic. Other pathologies observed included marked edema and vascular defects and mismatch in developmental features of the fetus.[6,13] More recently, a case series of fetal cystic hygroma associated with equine pregnancy losses occurring between days 52 and 75 days were reported.[18,19] This condition is associated with aneuploidy in human conceptuses, but whether this is the case in the horse is still not known. Cystic hygroma can be detected via ultrasound and grossly after expulsion of the fetus (Fig. 1).[19] Cases present with a fetus with abnormal quantities of fluid initially in the neck region and later expanding to the abdomen (ascites) and pelvic limbs (Fig. 1D).

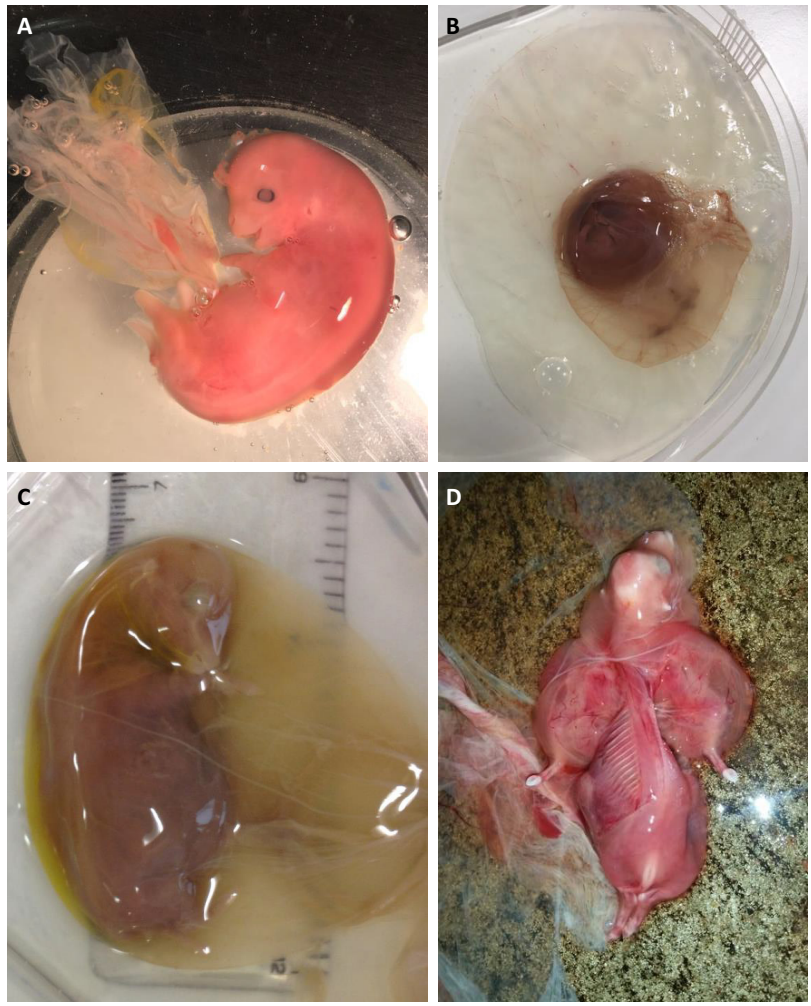


Fig. 1. Examples of gross presentation of clinical cases of EPL flushed from the uterus of Thoroughbred mares at gestation age 42 days (A), 41 days (B), 68 days (C) and a case of fetal cystic hygroma flushed from an embryo transfer recipient mare at gestation age 59 days (D). Photos from Equine Pregnancy Laboratory archive, (A–C) and generously provided by Dr. Santiago Martinez Zuviria (D).

There are currently limited options available to the clinician to avoid aneuploid pregnancies in naturally mated mares as it can only be diagnosed retrospectively using tissue from the conceptus. Recent studies have shown the validity of using DNA based screening over karyotyping for diagnosis of aneuploidy, providing advantages to the clinician as DNA is more readily isolated from autolytic tissues with viable dividing cells required for karyotyping. Due to the lethality of these variants, the best clinical outcome for the mare is to have the pregnancy lost as soon as possible so she can be rebred. Therefore, veterinarians are advised to consider carefully whether it is worth attempts to prolong a compromised pregnancy. In the case of embryo transfer, there are further options available to the clinician to prevent aneuploid embryos, although these are in their infancy in the horse. Embryos can be screened prior to transfer using a trophectoderm biopsy and only diploid blastocysts transferred to the recipient mare. Based on work in other species, it is important to note that ploidy status of one to two cells is not always reflective of chromosome number in all cells and can lead to false positives due to apoptosis of the aneuploid cell or detection of mosaic pregnancies with the aneuploidy restricted to certain tissue regions or compartments.

Translocations in the Mare Genome

Translocations are the breaking and fusing of chromosome segments between non-homologous chromosomes. Translocations involving the mare's genome have been found to increase the risk of that individual suffering recurrent EPL. Translocations are significantly less common variants when compared with aneuploidy, with just 13 mares identified in the literature in a recent review by two laboratories that regularly perform equine karyotyping screening.[14] In all cases the translocations were identified in the mare's genome, not that of the conceptus. The gametes that form in these mares can be unbalanced, leading to an imbalanced embryo genome, which is thought to lead in turn to a non-viable pregnancy. Less commonly, mares with a translocation can produce balanced gametes, which may then lead to a viable offspring. Veterinarians are advised to screen mares

for the presence of translocations when mares present with multiple EPLs and/or infertility. Diagnosis by qualified laboratories usually requires submission of 10 ml of peripheral blood in sodium or lithium heparin and EDTA. Owners of mares carrying these variants should be carefully counseled both of the likelihood of persistent untreatable subfertility/EPL but also the chance of an occasional live foal that will likely carry the variant. To date, no widespread screening of EPL conceptus tissue for translocations has been reported, so whether this condition can also arise in early embryonic development is not known.

Progesterone Concentration in Early Pregnancy

The importance of progesterone levels for pregnancy maintenance is incredibly well established, but the role of progesterone levels in pregnancy loss remains controversial. Luteal insufficiency in early pregnancy is categorically a cause of pregnancy loss, and these cases clearly benefit from progestin supplementation,[20] yet an old but well cited study suggested luteal insufficiency was uncommon.[21] A more recent study of closely-followed research mares found 6/11 singleton pregnancies were lost following luteolysis,[22] leading the field to ask again what role progesterone has in EPL. This interest in luteal insufficiency has been surpassed to some extent by studies assessing more nuanced effects of altered levels of progesterone on early pregnancy and focusing on the quality of the initial rise in progesterone following ovulation. What has been difficult to establish is a level of serum progesterone that is predictive of pregnancy loss. Progesterone levels of less than 4.3 ng/ml at day 5 postovulation are associated with a decreased pregnancy rate at day 14 when compared with progesterone levels 4.3 ng/ml and greater.[23] Further, there was no benefit for pregnancy rates at day 14 of higher levels of progesterone at day 5 post ovulation (5.8-7.6 or > 7.6 ng/ml compared with levels of 4.3 to 5.7 ng/ml).[23] Experimental models of subphysiological levels of progesterone from day 3 to 15 have demonstrated detrimental effects on endometrial function[24,25] as well as early embryonic organ development and placental growth.[25–27] Later stages of pregnancy now need to be assessed to determine if these detrimental changes lead to fetal morbidity or mortality. Further, empirical data has not been generated that shows progesterone supplementation (such as altrenogest) in the absence of absolute luteal insufficiency reduces the risk of EPL.

Endometrial Disease Associated with Early Pregnancy Loss

Endometrial bacterial infections[28] are associated with EPL prior to clinical detection and 5 to 16% of EPLs lost between days 15 and 65 of pregnancy.[3,29,30] This stresses the need to clinically monitor and manage endometritis to prevent EPL, particularly for those losses occurring prior to clinical detection. Endometrial degeneration can also lead to a compromised endometrial environment detrimental to embryonic development. Two independent risk factor studies have linked endometrial cysts to an increased risk of EPL.[10,31] The cysts may directly compromise the implantation and nutrition of the embryo or alternatively reflect other degenerative changes to the endometrium, reviewed elsewhere.[32] Interestingly, multiple risk factor studies have failed to link uterine treatments or presence of uterine fluid after cover with risk of EPL,[10,12] nor does the usage of treatments that target the endometrium align with the proportion of cases associated with endometrial disease.[3,30,33] Clearly, new diagnostics are urgently needed to better differentiate mares that warrant treatments that target and improve endometrial health and reduce a reliance on antimicrobials.

5. Pregnancy Loss Between Gestation Days 70 and Parturition

While in some cases clinical signs such as premature mammary gland development or discharge from the vulva precede abortion, in most instances the mare exhibits no indication of a failing pregnancy. The gold standard approach for clinical management of cases of abortion is the submission of the placenta and fetus (+/− mare serum) to a laboratory for diagnosis of the underlying cause. The limitation of field diagnosis was recently quantified in the context of nocardioform placentitis, where it was found 20% of mares recruited as controls were subsequently diagnosed as norcardioform placentitis by the laboratory and 18% of recruited placentitis mares were diagnosed by the pathologist to be free of nocardioform associated disease.[34] A recent UK study on the outcomes of Thoroughbred pregnancies after day 70 of gestation observed that only 62% of abortions were submitted for diagnostic investigation of any kind, and of those undergoing postmortem examination, 19% remained undiagnosed.[8] Hampering diagnostic submission was the absence of any abortus material in a third of these cases, ushering the question as to what causes abortion in these cases. Laboratory submission reports in the US paint an even more frustrating picture, with 70% of abortion and stillbirth submissions failing to have a cause attributed, despite placental tissue being submitted alongside the fetus in 77% of cases.[35] A lack of diagnosis, however, is not a failure of a post-mortem examination. The absence of identification of an infectious agent and inflammatory lesions provides valuable information to the attending veterinarian regarding the management of the mare and herd following an abortion.

Multiple studies describe the proportion of laboratory submissions ascribed to different causes of abortion and stillbirth;[29,35–38] however, a continued challenge of interpreting and comparing the data in these reports is that it is proportional. This means that the figures are relative to the other submitted causes. Therefore, for example, in areas with a high incidence of infectious causes of pregnancy loss, the relative percentage of other causes will be consequentially decreased. A more reliable way to compare the causes of pregnancy loss between equine populations is to study the causes at a cohort level, namely the percentage of all pregnancies that fail due to a

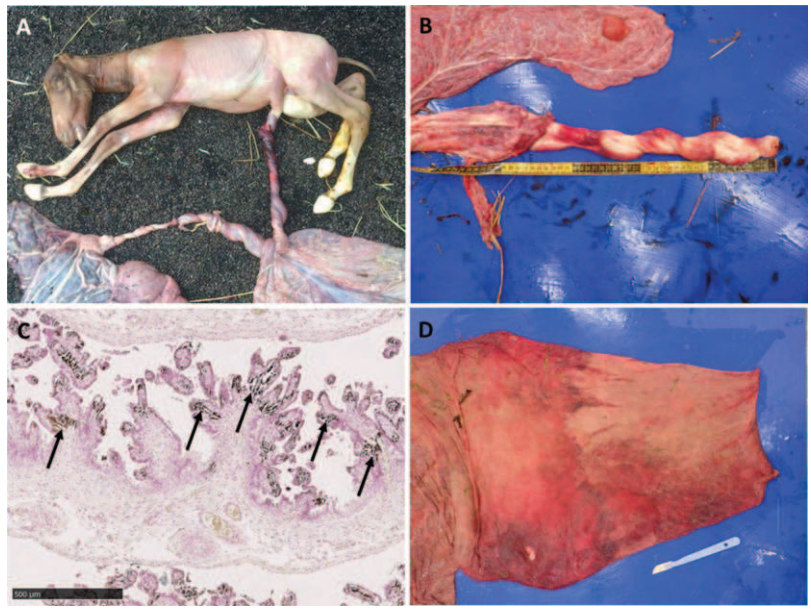


Fig. 2. A, Photograph of an aborted equine placenta and fetus showing excessive length of the umbilical cord, segmental reddening and twisting, B, the alternating pattern of reddened and blanched sections along the amniotic portion of the untwisted umbilical cord in a case of umbilical cord torsion abortion, and C, a histological section of equine chorioallantois stained with Von Kossa's stain depicting villous mineralization with calcium deposits; black arrows showing examples of mineralization within the section staining brown/black. Image D shows moderate ischemic necrosis of the chorioallantois at the cervical pole from an aborted equine pregnancy. Image A courtesy of Dr. F Barrelet and images B and D courtesy of Dr. A Foote.

particular cause as opposed to just those that fail and are submitted for postmortem examination. This allows for accurate comparison of figures between distinct populations and regions over time, enabling veterinarians and other stakeholders the ability to monitor the effects of interventions and other factors.

Noninfectious causes of pregnancy loss after day 70 of gestation include those inherent to the developing pregnancy (i.e., excessive torsion of the umbilical cord, twinning, genetic variants, dystocia arising from malformation/malpresentation, long cord with ischaemic necrosis) or those arising through the dam such as maternal disease or toxin ingestion (such as fescue toxicity leading to premature placental separation and expulsion of the pregnancy). Finally, there are those assigned as non-infectious but undiagnosed, which account for up to 65.4% of abortions and stillbirths.[35] One suggestion is that a more comprehensive investigation may be warranted in these cases,[35] or the possibility that a novel pathogen might be present which is not part of the routine screening of the laboratory; however, with an absence of lesions there is only a finite indication for continued investigation.

Umbilical Cord Torsion

Abortion can occur when there is excessive torsion of the umbilical cord, leading to vascular obstruction, fetal demise, and expulsion of the pregnancy by the mare (Fig. 2A). Until recently, umbilical cord torsion (UCT) abortion was seen to be a problem primarily affecting the UK equine population, accounting for 1.5% of all day 70 pregnancies and 44% of the pregnancy losses submitted for postmortem investigation.[8] However, the most recent analysis of laboratory submissions in California reported UCT to be the most common noninfectious cause of abortion and stillbirth in their population, although at levels almost 10-fold lower than the UK, at 4.4%.[35] The reason for this stark geographic variation in the proportion of UCTs remains unclear and will require direct comparisons of cohorts as opposed to laboratory submissions.

It is worth remembering that observing twists in the umbilical cord is not diagnostic of UCT with 5 and 6 twists normal in Thoroughbred/Standardbred and Warmblood pregnancies respectively.[39] Failed pregnancies tend to show mild to moderate autolytic changes and a congested fetus with hemorrhagic thoracic and or peritoneal effusions.[29,38,40] Once untwisted, pathologists look for an alternating pattern of reddened and blanched/constricted portions along the umbilical cord,[40] as shown in Fig 2B. Cord pathology tends to be focused on the amniotic portion of the umbilical cord with edema, surface intimal tears, or "stretch marks," urachal dilations and excessive length all associated with UCT.[29,37,40,41] It should be noted that excessive amniotic length is not a required diagnostic feature with cord lengths within the normal range observed in cases of UCT. Histological analysis often reveals mineralization of the stroma and chorioallantoic blood vessels (Fig 2C), as well as villous core degeneration.[36,40] To date there have only been limited, descriptive studies of UCT abortions; therefore, further research is warranted to ascertain diagnostic criteria that can be universally accepted. Only then can the risk factors and interventions to prevent the occurrence of UCT abortions be explored.

A second diagnosis of mid- to late-term pregnancy loss involving the umbilical cord that warrants attention is that of cervical pole necrosis, associated with excessive umbilical cord length. Fifty-seven cases of cervical pole necrosis were diagnosed by the University of Kentucky Veterinary Diagnostic Laboratory between 2013 and 2022, accounting for under 2% of their submissions.[42] Although cervical pole necrosis is currently an idiopathic cause of abortion and perinatal morbidity, excessive umbilical cord length does seem to be associated with the disease.[42] Pathogenesis is hypothesized to arise from necrosis of the chorioallantois (Fig 2D) following detachment, or as a result of an ischemic insult likely from vascular compromise due to excessive umbilical cord length.[40] Fetal hypoxia and/or catastrophic rupture of the necrosed fetal membranes are most likely the terminal cause of the pregnancy failing. Like UCT, further research into cervical pole necrosis is warranted to better understand the risk factors and pathology of this condition.

Non-Infectious Placental Disease

Pregnancy failure due to non-infectious placental disease was the second highest diagnosed cause of pregnancy loss in a cohort of day 70 pregnancies in the UK, accounting for 11.2% of investigated losses and an incidence risk of 0.4% of all pregnancies.[8] The lesions or pathologies noted in this category of loss included placental edema, villous atrophy, mineralization of the chorioallantois, and ischaemic necrosis not associated with umbilical pathology or infectious agents. Comparatively, non-infectious placental disease only accounted for 0.7% of the lab submissions out of the California Animal Health and Food Safety Laboratory System over the last 32 years.[35] Further work is needed to understand the etiology of these lesions and to reach a consensus on what constitutes sufficient pathology to be ascribed as the cause of loss.

Twinning

In the most recent studies on the causes of abortion and stillbirth in the US and the UK, twinning was a rare[35] or absent[8] diagnosis of loss, supporting the notion that early ultrasound examination and reduction have largely abolished this cause of pregnancy failure. It is worth noting, however, that in less intensively managed equine populations twinning is still a significant cause of abortion.[43] Further, an increasing number of monozygotic multiple pregnancies are being reported in the equine literature, representing 1.6% of in vitro produced embryos in one study.[44] The exact reason monozygotic twins develop is not known. In human embryos, it has been reported to be associated with intracytoplasmic sperm injection (ICSI).[45] Other plausible explanations may be suboptimal culture conditions or embryo cryopreservation.[45]

Genetics Variants Causing Lethality in Late Pregnancy

There are two single nucleotide polymorphisms (SNPs) reported in the equine literature associated with lethality in utero and/or immediately following parturition.[6,46,47] While these are not common causes of abortion and stillbirth, they can present as a problem for farms if carriers are bred to one another. Clinical management of breeding mares who are known carriers of these SNPs can be rewarding, as pregnancy loss attributed to these SNPs can be avoided with mating of carrier mares to non-carrier stallions. Should mating of carrier mares and carrier stallions occur, this would result in 25% of fetuses/foals being homozygous for the mutation, 25% free of the mutation, and 50% carriers of the mutation. For non-Thoroughbred breeds, pregnancy loss can be avoided when mating two carriers using embryo recovery combined with pre-implantation genetic testing (trophectoderm biopsy) that allows selection and subsequent transfer of just the 25% of embryos that fail to carry the mutation.

Fragile Foal Syndrome (FFS), initially described as Warmblood Fragile Foal Syndrome as it was first identified in a Warmblood,[46] is a monogenic disorder with an autosomal inheritance of a single missense mutation (c.2032G>A) in the gene procollagen-lysine, 2-oxoglutarate 5-dioxygenase 1 (*PLOD1*). To date, clinical cases of pregnancy loss associated with this mutation have only been reported in the literature in Warmbloods[48] and the Thoroughbred.[49] This breed distribution is likely to expand in the future with carriers of the mutation identified in other breeds including American Sports Pony (1/12 tested), Haflinger (2/48), and Knabstrupper (3/46).[50] Phenotypically, fetuses/foals homozygous for the mutation die in utero or are euthanized shortly after delivery. Stillbirth is the most common presentation, with the 11/14 cases in one study presenting after 320 days[48] but abortion observed as early as 9 months of gestation. Fetal pathology results from a disruption of collagen biosynthesis and includes significant open skin defects at the level of the deep dermis/subcutaneous fascia that are present at parturition, distal limb laxity or contracture and spinal scoliosis. In some cases, incomplete closure of the abdominal wall was noted.[48,49]

Congenital hydrocephalus is a clinical condition reported across multiple breeds associated with abortion, stillbirth, or perinatal death. Phenotypically it is well characterized in Friesian foals as of the internal or communicative type involving dilation of all four ventricles, a decreased ratio of white to grey matter, and likely arising due to stenosis of the jugular foramen.[51] While the condition has been reported widely across breeds for many decades, more recently in Friesians and Belgium drafts, it has been directly linked to a mutation in β-1,3-N-acetylgalactosaminyltransferase 2 (*B3GALNT2*) gene.[47] In these two breeds, affected foals are either aborted from 7 months gestation, present as stillborn, or are euthanized immediately following birth.[52,53] Studies of Friesian populations in Mexico and Netherlands indicate a 10–17% carrier frequency for the mutation, possibly explaining the higher clinical presentation of the condition in this breed. It is plausible, like FFS, the mutation is present in other breeds at a lower frequency, so clinicians

should keep an open mind when considering whether congenital hydrocephalus in other breeds is associated with this mutation.

Infectious Causes of Mid- and Late-Pregnancy Loss

Infectious causes of abortion and stillbirth can be grouped into bacterial, viral, fungal, or mixed. At the forefront of most clinicians' minds when discussing infectious causes of pregnancy loss will be placentitis and equine herpesvirus 1 (EHV-1). Placentitis, inflammation of the placenta, is a symptom rather than a diagnosis of the cause of pregnancy loss. Attribution of the inciting cause is important due to the different treatment and management strategies dependent on the infectious agent. In a recent scoping review, EHV-1 was the most frequently published on cause of mid- and late-term pregnancy loss for every decade since 1960.[54] However, although EHV-1 is a highly researched cause of abortion and stillbirth, the incidence is relatively low, accounting for 4.6% of a Californian laboratory' submissions[35] and 0.3% of day 70 pregnancies in the UK.[8] The elevated research interest likely reflects the high stakes consequences to the wider population on the farm, with the aborted fetus and fetal membranes being a source of infection to other pregnant mares, as opposed to the relative risk of individual occurrence. Nevertheless, vaccination and appropriate herd management are warranted to mitigate risk of loss and to continue to prevent EHV-1 contributing more significantly in the future.[55,56] Current AAEP guidelines are for pregnant mares to receive an inactivated EHV-1 vaccine at five, seven and nine months of gestation.[a]

The most recent report of the diagnoses of laboratory submissions reported single agent bacterial infections (primarily *Streptococcus* spp. at 7.2% and *Leptospira* spp. at 1.0%) to be the most common diagnosis of pregnancy loss in a US population, accounting for 11.8% of submissions.[35] Of these infections, placentitis was the most commonly characterized gross lesion.[35] Similarly, in the UK, 9% of laboratory submissions of abortus/stillbirth material received between 2013 and 2017 were associated with infectious placentitis.[8] However, these figures may not be a true reflection of what is happening on farms, with a cohort study of Thoroughbred pregnancies in the UK observing only 0.3% of day 70 pregnancies failed due to infectious placentitis.[8] A further study of UK Thoroughbred mares found 4.9% of pregnancies were clinically diagnosed with placentitis by a veterinarian,[33] and none of these cases aborted, suggesting in that population at least, it is more a disease of pregnancy rather than necessarily a major contributor to abortion. The fact that ascending bacterial placentitis is one of the few causes of abortion and stillbirth that can be diagnosed premortem makes it an ideal candidate for research due to the possibility of understanding the etiology and providing opportunities for preventative treatments.

Equine viral arteritis (EVA) can cause abortion in mares, and in some instances produces abortion storms with multiple animals rapidly compromised.[57,58] While not a significant cause of loss in the equine population, accounting for 0.2% of laboratory submissions over the last 32 years,[35] EVA does have a high morbidity rate, leading to 71% of mares aborting following exposure in one study.[59] Knowledge of the EVA status of both the mare and covering stallion is important, allowing for implementation of the correct protocols following AAEP Vaccination Guidelines.[a,60,61]

In addition to the aforementioned infectious causes, leptospirosis, chlamydial, and Nocardioform placentitis have garnered the attention of the scientific community over the last three decades.[54] Interestingly, to date, there have been no published reports of chlamydial abortion occurring in the US, likely reflecting the native avian population. However, given the zoonotic nature of the disease, continued monitoring is warranted, and there could be merit in assessing archived abortion material to confirm this belief.[62] Leptospirosis, on the other hand, is a more common cause of abortion and stillbirth, showing both geographical and temporal variation. Infection is via exposure to urine, contaminated water sources, or infected aborted material. As with EHV, diagnosis of leptospiral abortion allows for correct management of the mare following loss, minimizing the risk of infection to other pregnant mares. An approved vaccination for the prevention of leptospirosis due to *Leptospira interrogans* serovar *pomona* is available with the schedule and details available via the AAEP vaccination guidelines.[a]

Nocardioform placentitis is another disease exhibiting both temporal and geographic variation.[34,63,64] It is thought to arise through infection by gram-positive branching actinomycetes, primarily *Amycolatopsis* spp., *Crossiella equi*, or *Streptomyces* spp.; however, the exact pathogenesis remains elusive.[63,65,66] Although the chorionic surface of the placenta tends to exhibit a classic brown/tan mucoid material at the ventral portion of the base of the horns and body, gross field analysis is not always reliable. In a recent study, a considerable proportion of cases were missed or misdiagnosed,[34] supporting the necessity for additional histopathology at a diagnostic laboratory on abortus/stillbirth tissues. While the pathogenesis of the disease is currently unknown, prevention is not possible. Empirical implementation of antimicrobial therapy is recommended; however, there is limited evidence that any of the current treatments are effective in preventing abortion.

6. Conclusion

The most common cause of pregnancy loss in the first two months of gestation is autosomal aneuploidy, with current evidence suggesting it primarily originates in maternal meiosis. Autosomal aneuploid pregnancies are non-viable, and most are lost within the first two months of gestation. Active management to reduce the chance of an aneuploid embryo is possible in embryo transfer programs but not in naturally mated mares. Management of mares to promote optimal endometrial health remains an important priority

for veterinarians, but it should be noted that endometrial disease is likely to contribute to approximately 15-30% of cases of EPL in well managed mares, and other causes should therefore be carefully considered. There is growing evidence for more nuanced effects of sub-physiological levels of progesterone, although equally an absence of evidence that shows progesterone supplementation is beneficial in preventing early pregnancy loss.

In mid- to late-pregnancy, it is important to remember that placentitis is a symptom of inflammation of the placenta, and attribution of the inciting cause is key to both clinical management and monitoring of infectious disease outbreaks. While abortion associated with EHV-1 infection rightly remains an intense focus of the research community due to the devastating effects it can have after an abortion storm, EHV-1 infection is only responsible for a very small proportion of cases of abortions seen by veterinarians in many jurisdictions. Umbilical cord torsion is a significant contributor to non-infectious causes of abortion not only in the UK but also in the US. Submission of abortus material remains the gold standard of diagnosing the underlying cause of pregnancy loss. Genetic causes are also relevant to mid- to late-pregnancy loss, although their relative contribution is significantly lower when compared with the first two months of gestation.

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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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Ultrasonographic Monitoring of the Equine Fetus and Its Fetal Membranes After 100 Days of Gestation

Catherine Renaudin, DVM, DECAR

Ultrasonography is a noninvasive, rewarding tool to assess the fetus and its fetal membranes after 100 days of gestation. The transrectal approach allows the clinician to determine fetal presentation, biometry, activity, fluid echogenicity, bone maturation, length and echotexture of the cervix, and the cervix's apposition to the chorioallantois, as well as to diagnose ascending placentitis. The transabdominal approach is best to assess the presence of twins, fetal fluid amount, fetal heart rate, and nonascending placentitis and is used to confirm fetal presentation and biometry (measurements of anatomic segments of the fetus by ultrasound). Author's address: University of California – Davis, School of Veterinary Medicine, One Shields Avenue, Davis, CA 95616; e-mail: cdrenaudin@ucdavis.edu. © 2023 AAEP.

1. Introduction

Traditionally, once mares are confirmed pregnant between 25 and 45 days of gestation with a single viable embryo/fetus, and potentially rechecked at 60 to 70 days for fetal gender determination, no additional ultrasound examination is performed before parturition. It is only when complications arise, or signs of impending abortion are observed, that pregnant mares are re-examined. The objective of this paper is to present a practical step-by-step protocol on how to monitor the equine fetus and its fetal membranes using ultrasonography after 100 days of gestation. Examination of the placenta, diagnosis of placentitis, examination of the cervix, and assessment of fetal well-being, growth, and bone maturation will be described in detail, using a combination of the transrectal and transabdominal ultrasound approaches.

2. Ultrasonographic Examination of the Placenta

The transrectal approach allows examination of the most caudal area of the placenta cranial to the cervix. It is the gold standard approach to diagnose ascending placentitis, which is the most common type of placentitis in the mare. The transabdominal approach allows examination of part of the body and horns of the placenta. It is the best approach to diagnose nonascending placentitis that is most commonly caused by Nocardia and leptospirosis.

Transrectal Approach: Diagnosis of Ascending Placentitis

After transrectal palpation, the 5.0- to 7.5-MHz linear transducer is positioned at the cervico-placental junction 2.5 to 5 cm cranial to the internal os.[1,2] An image of the fetal fluids, the dorsal and ventral aspects of the uterine body, and a vascular space (branch of the

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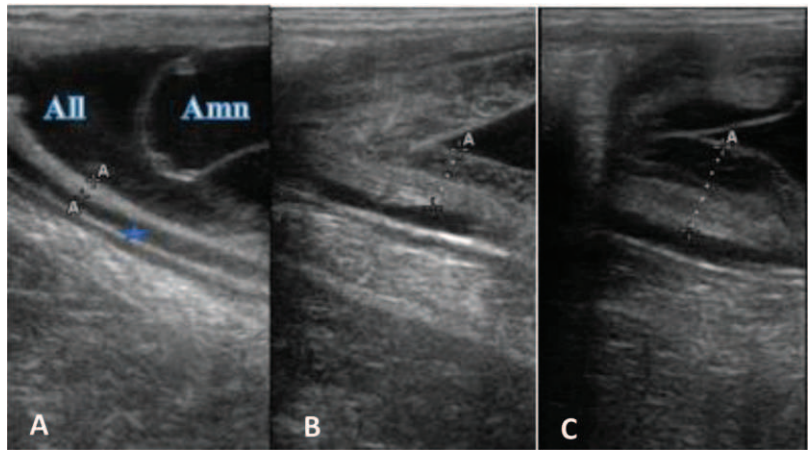


Fig. 1. Transrectal ultrasound images of the placenta at the cervico-placental junction (cranial is to the right and caudal is to the left of the image). A, Normal placenta at 108 days of gestation. The uterus and chorioallantois are indistinguishable and CTUP measured between A+ is within normal limit (4 mm). B, Normal placenta at 334 days of gestation. The uterus and chorioallantois are distinguishable and CTUP is within normal limit (12 mm between A+). C, Abnormal placenta at 288 days of gestation with excessive chorioallantoic edema and increased CTUP (17.9 mm between A+). All, allantoic fluid; Amn, amniotic fluid. The blue star indicates vascular space.

uterine artery) should be obtained (Fig. 1A). If the vascular space is not well imaged, the transducer is moved laterally until a major vessel is visible. Placental contact should then be assessed, and the combined thickness of the uterus and placenta (CTUP) should be measured.[1,2] The chorioallantois (CA) and uterus should be in contact and are always indistinguishable from each other, except after 280 to 300 days of gestation when the chorioallantois becomes edematous (Fig 1B). Chorioallantoic edema is slight if present around 280 days of gestation and gradually increases to heavy around term. The CTUP is measured from the ventral aspect of the uterine body, with one cursor placed on the border of the uterus in contact with the dorsal vessel margin and the other cursor on the border of the chorioallantois in contact with the allantoic fluid (Fig 1).[1,2] It is important that the amniotic membrane is away from the CA and not included when measuring the CTUP. Allantoic vessels can be prominent in some mares and should not be included in the CTUP measurement. The axis of the measurement should be perpendicular to the axis of the ventral part of the uterine body.[1,2] Three measurements from 2 to 3 different images should be taken, and the mean CTUP should then be calculated. In normal light breed pregnancies, the mean CTUP plateaus around 4 mm between 4 and 9 months of gestation and then increases by 1.5 to 2 mm each month.[1,2] There appears to be small variations in normal CTUP between most breeds (Quarter Horses/light breed,[1] Thoroughbred,[3,4] Warmblood,[5,6] Criollo,[7] and Standardbred[8]). In draft horses, CTUP values are significantly higher than in any other breed, reaching 15 mm late in pregnancy.[9] In most breeds, measurements established for Quarter Horses can be used as a guideline. Increased CTUP with or without placental separation is suggestive of placentitis in most breeds (Fig. 2).[3,10,11] In draft horses, placentitis is more frequently diagnosed when CTUP is greater than 15 mm. Detachment of the CA from the uterus is always abnormal at any stage of pregnancy and is often associated with placentitis. Early CA edema prior to 280 days of gestation or moderate to severe CA edema prior to 300 days of gestation is abnormal and may be a premonitory sign of placentitis or umbilical cord torsion (in the author's personal experience).

Transabdominal Approach: Diagnosis of Nonascending Placentitis

It is the author's preference to use the 5.0- to 7.5-MHz linear transducer to assess the uterus and placenta since the only placental parts accessible are shallow, in contact with the ventral abdomen. The CTUP is measured by placing one cursor at the border of the uterus and the other one at the border of the chorioallantois in contact with the allantoic fluid, keeping the axis of the measurement perpendicular to the axis of the uterus (Fig. 3A).[1] Measurements should be taken in all four quadrants of the placenta (right cranial, right caudal, left cranial, left caudal)[8,10] in areas where there is no fetal contact and preferentially where the placenta is not folded.[8] The average CTUP has been reported for different stages of gestation in Standardbred[8] and Quarter Horse mares.[1] In Quarter Horses, the mean CTUP measured transabdominally is inferior or equal to the one measured at the placento-cervical junction.

The same CTUP cutoff values used for ascending placentitis can be applied for the diagnosis of nonascending placentitis. Presumptive diagnosis of nocardioform placentitis can be challenging but is supported by visualization of areas of placental separation with hyperechoic exudate between the chorioallantois and the uterus, normal echogenicity of the fetal fluids in early stages, and separation

ULTRASOUND FETO-PLACENTAL EVALUATION

Mare's name: Date examination:
History: Gestation date:

Transrectal

Cervix	Long tight	Short relaxed	DIOs= DEOs=	Tight IOs: Yes No
Fetal actvity	0	1	2	3
CTUP (mm)				Mean:
Placental contact/edema	Contact: Nl Detachment		Edema: Yes No	
Allantoic fluid echogenicity	1	2	3	4
Amniotic fluid echogenicity	1	2	3	4
EyV (mm^3)	EyL =	EyD =	EyV =	Approx. age:
BPD (mm)				Approx. age:
Fetal presentation	anterior	posterior	transverse	unknown
Fetal gender	Male	Female	Unknown	
P1	L = < = >	Prox ep: Yes No	Distal ep: Yes No	
Mammary glands	Development: Yes No		Secretions: Yes No	
Vulva	Conformation: Poor Good		Discharge: Yes No	

Transabdominal

Fetal heart rate (b/mn)	HRR:		HRM:	
Fetal activity	0	1	2	3
CTUP (mm)	L caudal:	L cranial:	R caudal:	R cranial:
Placental contact (mm)	Nl Detachment	Nl Detachment	Nl Detachment	Nl Detachment
Fluid depth (mm)	AllMD =		AmnMD =	
EyV (mm^3)	EyL	EyD	EyV	Approx. age:
AortD (mm)				Approx. age:
BPD (mm)				Approx. age:
FL (mm)				Approx. age:
Fetal presentation	Anterior	Posterior		Transverse
Fetal gender	Male	Female		Unknown

Normal Activity (0 = immobile; 1 = <33% of exam; 2 = 33-66% of exam; 3 = >66% of exam)
100-250d = 2-3
250-320d = 1-3
>320d= 1-2
Normal Heart Rate
HRR: 100-250d = > 100b/mn **HRM**: 15-20b/mn more than HRR
250-300d = > 80b/mn
>300d = > 60b/mn
Grading fluid echogenicity: 4 anechoic- 1 hyperechoic
Abnormal AllMD: <4.7 cm or > 22.1 cm. **Abnormal AmnMD**: <0.8 cm or > 14.9 cm.
Abnormal CTUP:
4-9 M (91-270 d) > 7mm 10 M (271-300d) > 8mm 11 M (301-330d) > 10mm 12 M (331-340d)> 13mm

Fig. 2. Form for protocol feto-placental evaluation. DIOs, diameter internal os; DEOs, diameter external os; CTUP, combined thickness of the uterus and placenta; EyV, eye approximated volume; EyL, eye length; EyD, eye depth; BPD, biparietal diameter; P1, first phalange; Prox ep, proximal epiphysis; Distal ep, distal epiphysis; HRR, heart rate at rest; HRM, heart rate after movement; AllMD, allantoic maximum depth; AmnMD, amniotic maximum depth; AortD, aortic diameter; FL, femur length; M, month.

located at the base of the gravid horn and at the junction of the uterine body (Fig 3B).[12] If clinical signs of ascending placentitis (vulvar discharge) or signs of impending abortion (premature mammary development and secretions) are observed, an ultrasonographic placental evaluation is prompted. In apparently normal mares, monthly screening examination should be started at 7 months until term. Attempts to treat mares already showing significant clinical signs (precocious mammary development, vulvar discharge) are often disappointing as by the time there are outward clinical signs, there is often significant placental pathology.

Treatment of Placentitis

Treatment should be initiated when placentitis is first diagnosed. Standard treatment aims at stopping the spread of infection (use of broad-spectrum antibiotics: sulfadiazine/trimethoprim, penicillin G, gentamicin), controlling inflammation (use of anti-inflammatory agents: flunixin meglumine and firocoxib), maintaining uterine quiescence (use of exogenous progestins: altrenogest), and increasing blood flow to the fetus (use of pentoxifylline).[13–18] The preferred antibiotic choices for nocardioform placentitis are sulfadiazine or doxycycline. Treated mares should be evaluated weekly to biweekly to ensure that the

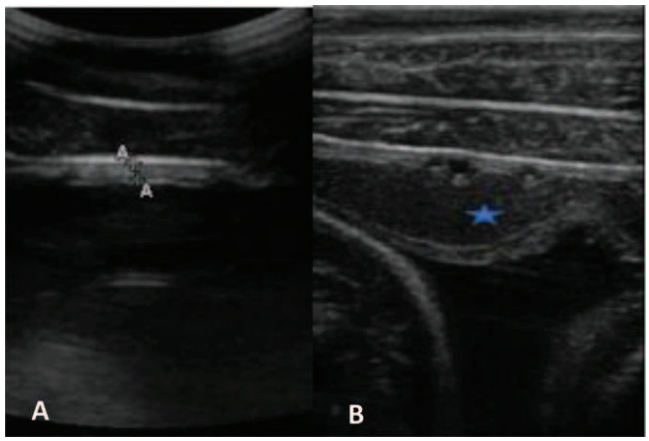


Fig. 3. Transabdominal ultrasound images of the placenta using a linear probe. A, Normal placenta. The uterus and chorioallantois are indistinguishable and CTUP is within normal limits (between A+). From top to bottom of the image, the skin and ventral abdominal muscles of the mare, uterus, chorioallantois, and allantoic fluid are seen. B, Abnormal placenta from a mare with nocardioform placentitis. The uterus and chorioallantois are distinguishable and separated by hyperechoic fluid (blue star), and CTUP is increased in the area of separation (courtesy of Dr. Maria Schnobrich).

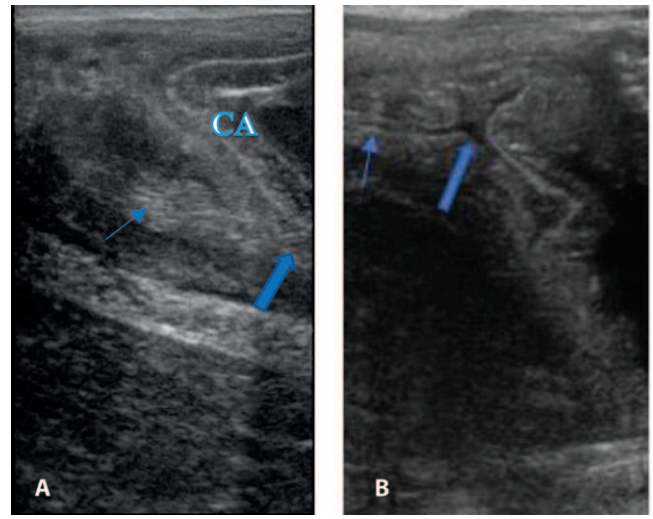


Fig. 4. A, Transrectal ultrasound image of a normal cranial cervix from a mare 323 days pregnant. The luminal striations (thin arrow) are in good apposition (thick arrow) with the chorioallantois (CA). There is no detachment at the internal os (thick arrow). B, Transrectal ultrasound image of a cranial cervix from a mare 261 days pregnant. There is disruption of the luminal striations (thin arrow) and a detachment of the chorioallantois at the internal os (thick arrow). The local detachment did not extend further later in pregnancy and had no consequence on fetal outcome but prompted follow-up ultrasound examination.

fetus has not died in utero[16] and to monitor response to treatment. Decreased CTUP or return to normal values, decreased size of fluid pocket, and decreased placental edema are indicative of positive response to treatment, while increased CTUP or increased size of fluid pocket and placental edema prompts change in treatment strategy.[4, 11]

3. Ultrasonographic Examination of the Cervix

Cervical length, internal os (IOs), external os, as well as the apposition of the IOs with the placenta should be assessed. To image the cervix, the 5.0- to 7.5-MHz transducer is placed in the rectum at the placentacervical junction and then moved caudally along the longitudinal axis of the cervix.[19] The luminal striations are characteristic of the cervix (Fig. 4A). The serosal surface is identified as a distinct hyperechoic peripheral border. Ventrally, the mucosa and muscularis are observed between the serosa and the luminal striation.

Length of the Cervix

Pregnant mares have a tight and long cervix, usually greater than 80 mm in length (greater than index-finger length). On ultrasound, a long cervix is often longer than the length of the ultrasound image. If cervical shortening occurs on a follow-up examination, it should be a concern, except close to parturition, as it can be associated with early cervical relaxation.

Diameter of the Cervix

The size of the cervix can be evaluated at three different sites (cranial, middle, and caudal), and the distance between the dorsal and ventral serosa can be measured.[19] Normal values have been established in normal pregnancies in light breed horse mares.[19] Caudal diameters tend to be smaller than cranial diameters but are comparable at months 11 and 12 of gestation, indicating full relaxation throughout the cervical canal.[19]

Apposition of the Cervical IOs with the CA

At the cranial aspect of the cervix, the cervical IOs and the chorioallantois should have a tight apposition (Fig 4A). However, slight detachment may be seen, especially close to term, and may extend caudally as seen as a thin anechoic line within the linear luminal pattern, indicating loose incompetent cranial cervix (Fig 4B). The separation should prompt follow-up ultrasound examination to assess worsening signs such as increase in size associated with or without echogenic fluid.

Echogenicity of the Cervix

Progressive changes in echotexture of the cervix occur through gestation. The central linear pattern appears faint at 3 months gestation to become evident from 4 to 9 months gestation and marked with hypoechogenic borders until 10 months, indicating a tonic, firm cervix.[19] It is then loose within a wide band of anechoic tissue indicating cervical relaxation.[19] Cervical defects can be identified with interruption of the linear pattern. Placing the transducer at a 90° angle to the cervical canal will facilitate acquiring a cross-sectional image of the cervix, and the exact location of the defect can be better determined.

4. Ultrasonographic Examination of Fetal Fluids and the Amniotic Membrane

Both allantoic and amniotic fluids should be evaluated for their echogenicity and maximum depth. The transrectal approach is best to assess fetal fluid echogenicity, while the transabdominal approach is more adequate to assess fetal fluid depth.

Transrectal Approach: Fetal Fluid Echogenicity and Appearance of the Amniotic Membrane

The 5.0- to 7.5-MHz linear transducer is placed in the rectum, cranial to the cervix. Allantoic and amniotic fluids should be seen separated with the amniotic membrane. The amniotic fluid generally contains more and smaller free-floating particles than the allantoic fluid from 4 months of gestation to parturition.[1] Echogenicity of the fluids is graded from I to IV: Grade I = white (strongly echogenic or hyperechoic), Grade II = light grey (semi-echogenic or hyperechoic), Grade III = dark gray (hypoechoic: few hyperechoic foci suspended in anechoic medium), Grade IV = black (anechoic).[20] Another grading system (Grade 0–3) established for pregnant mares can also be used.[21] Fluid is graded 0, 1, 2, or 3 when no particles or a small, moderate, or high number of particles are visualized, respectively. Allantoic fluid is always Grade III from 4 months of gestation to parturition, and amniotic fluid is either Grade II or III from 4 to 10 months gestation and Grade II thereafter.[1] Increased echogenicity (Grade I or 3) is abnormal and may be associated with passage of meconium in utero, hemorrhage, or inflammatory debris, which may reflect fetal hypoxia, placental detachment, or placental infection, respectively.[22,23] Increased allantoic and amniotic fluid echogenicity has also been reported with mare reproductive loss syndrome at 60 days gestation[24] and is also seen with fetal death. The amniotic membrane is seen on ultrasound as a hyperechoic floating membrane separating the allantoic and amniotic fluids. Increased thickness can occur in some cases of placentitis[10] and umbilical cord torsion. With hydrops amnion, the amnion is turgid, without the normal undulating appearance.[25]

Transabdominal Approach: Fetal Fluid Volume

The 5.0-MHz linear or 3.5-MHz curvilinear transducer is placed on the caudo-ventral abdomen of the mare and moved until the largest pocket of fluids is found. It is generally located around the fetal thorax in the region of the elbow.[26] Allantoic maximum depth (AllMD) is measured by placing one cursor on the edge of the placenta in contact with the allantoic fluid and the other cursor on the amniotic membrane once it reaches its lowest point on the ultrasound image. Amniotic maximum depth (AmnMD) is measured by placing one cursor on the amniotic membrane (at its highest point on the ultrasound image) and the other cursor on the fetal skin with the connecting line perpendicular to the placental surface. In term mares (>298 days gestation), Reef[26] reported mean AllMD and AmnMD of 13.4 ± 4.4 cm and 7.9 ± 3.5 cm, respectively, and defined abnormal fluid quantities as those greater or less than 2 standard deviations from the normal control means (AllMD < 4.7 cm or AllMD > 22.1 cm; AmnMD < 0.8 cm or AmnMD > 14.9 cm).[27] Pathological increase of allantoic or amniotic fluid, also called hydrops allantois/hydrops amnion, are rare conditions.[28] Hydrops allantois is more common than hydrops amnion and is often associated with growth-retarded fetuses. Hydrops amnion is usually associated with a congenitally abnormal fetus. Given the severity of the complications and the poor fetal outcome associated with hydropic conditions, slow drainage of the excessive fluid(s) with fluid support and a resulting abortion is often recommended to salvage the mare.[28]

5. Ultrasonographic Evaluation of the Fetus

Ultrasonographic evaluation of the fetus is performed using a combination of both transrectal and transabdominal approaches. After finding the fetus, a single versus twin pregnancy needs to be confirmed. Then, fetal presentation is determined, and fetal activity and heart rates at rest and after movement are evaluated. Fetal measurements of body parts by ultrasound, also called "fetal biometry," are performed to assess fetal growth or confirm fetal age. Recently, it has been shown that bone maturation can also be assessed late in gestation.

Finding the Fetus

Using the transrectal approach, part of the fetus should be readily seen when the probe is placed cranial to the cervix. Using the transabdominal approach, the transducer (either the 5.0–7.5 MHz linear or 3.5 curvilinear) is placed on the ventral midline cranial to the mammary glands, parallel to the long axis of the mare. Usually, fetal fluids or part of the fetus (in longitudinal or frontal view) are readily seen. If not, the probe is moved laterally or in the inguinal area when fetuses are located high in the mare's abdomen.

Single Versus Multiple Pregnancy

If there is any doubt about a possible twin pregnancy, a complete examination of the ventral abdomen should be performed. The transrectal ultrasound examination will likely be nondiagnostic. The probe should explore the entire ventral abdomen from the mammary glands to the xyphoid. In cases where twins are present, 2 thoraces/abdomens may be seen in cross-section side by side if the pregnancy is less than 200 days. If the pregnancy is more advanced and the entire fetal thorax or abdomen cannot be entirely seen, each fetus should be scanned from head to abdomen to make sure fetal parts belong to the same fetus. One could also look for the absence of the nonpregnant horn in determining multiple pregnancies in late gestation. With single pregnancies, the nonpregnant horn has significant folding of the placenta and does not contain any fluid nor fetal part. The hindlimbs are

trapped in the pregnant horn, and the fetus occupies all of the placenta except the nonpregnant horn. With multiple pregnancies, both horns contain fetal parts.

Fetal Presentation

Using the transrectal approach, it is usually easy to determine fetal presentation. If a head, eye, neck, or rib cage with the beating heart are seen, then the fetus is in anterior presentation. If a tail or thighs are present, then the fetus is in posterior presentation. In some cases, only legs are imaged, and it is difficult to differentiate between front or hindlimbs. The transabdominal approach needs to be used. Using this approach, one should first identify the image direction (classically the head of the mare is at the right of the image). Fetal landmarks like ribs, scapula, and beating heart should then be found. When the fetus is in anterior presentation, fetal head, neck, ribs, lung, liver, stomach, and hindquarter are successively seen while moving the transducer from the mare's mammary gland to her xyphoid. Before 240 to 260 days of gestation, fetuses are either in anterior, posterior, or transverse presentation.[29] After that time, all fetuses should be in anterior presentation.[8,29] If not, another ultrasound examination any time prior to birth is warranted to make sure the fetus has rotated to anterior presentation. If the fetus is not correctly presented, the mare should be foaled in a veterinary hospital where assisted vaginal delivery and C-section can be performed, due to the increased risk of dystocia.

Fetal Activity

Fetal activity refers to any fetal movements (extension and flexion of the limbs, neck, and head; whole-body rotations around the fetal long axis; spinning and translation).[8,26,27,30] It is graded on a scale of 0 to 3 for the entire examination period (about 20–30 minutes), with Grade 0 and Grade 3 associated with no movement and few or no quiet periods throughout the entire examination period, respectively.[26] Fetal activity declines as gestation advances (Fig 2). After 9 months of gestation, when the hindlimbs are trapped in the pregnant horn, fetal activity is reduced to rotation of the abdomen and thorax and extension and flexion of the head, neck, and limb. Between 100 and 250 days gestation, fetal activity varies from 2 to 3; between 250 and 320 days gestation, from 1 to 3; and after 320 days gestation, from 1 to 2 (rarely Grade 3 except from 5–72 hours before parturition[5]).[26,27,31] Dormant, inactive periods are observed in fetuses of all ages but are more common in late gestation where they can last up to 60 minutes or longer on occasion.[32] Therefore, fetal inactivity late in gestation should be interpreted with caution and should warrant re-evaluation within 24 hours. Fetal activity reflects central nervous system function and development such that a depressed central nervous system function results in decreased activity. Abnormal activity such as prolonged hyperactivity or inactivity is suggestive of poor fetal outcome. Sudden bouts of excessive activity followed by abrupt cessation have also been recorded in fetuses that subsequently died.[33]

Fetal Heart Rate at Rest and After Movement

Fetal heart rate can be obtained either after viewing the cardiac cavity on B-mode by using a stopwatch or utilizing M-mode. In normal pregnancy, the heart rate is regular and decreases as gestation advances. As heart rate accelerations generally occur in response to fetal activity, measurements of the heart rate at rest (HRR) and immediately after fetal movement (HRM) should be obtained. Spontaneous fetal activity results in acceleration of fetal HR of 25 to 40 beats per minute (bpm) in amplitude and 20 to 40 seconds in duration.[8] However, fetal movements without fetal HR accelerations are observed routinely, while accelerations in the absence of detectable stimuli occur only 5% of the time.[8] In the author's experience, accelerations of fetal HR of 15 to 20 bpm are also within normal limits. Mean normal fetal HR values, at rest and after movement have been reported for different gestational ages[8,26,30,31] and are summarized in Fig 2. Normal HRM value is calculated by adding 15 to 40 bpm to the HRR. When mares are sedated, fetal heart rate will be decreased, and normal HR value will have to be lowered. Unusually low heart rates, below 50 bpm, may occasionally be observed in term fetuses and may not be cause for alarm, providing they represent short-lived episodes.[34] Transient elevation of HRR above 120 bpm, during the last weeks of pregnancy, is not threatening either, unless it fails to return to baseline.[34] Maternal anxiety or pain may sometimes be the underlying cause of this transient HRR elevation.[34] Abnormal patterns of fetal heart rate reactivity are reliable indicators of fetal compromise. Fetal tachycardia has been observed preceding abortion[27] and stillbirth.[27,30] Fetal bradycardia is considered the most reliable indicator of impending fetal demise and is often preceded by fetal tachycardia.[35] Bradycardia or lack of HR variation suggests central nervous system depression likely attributable to hypoxia.[36] Fetal asystole ultimately identifies fetal demise.[27,37] When in doubt, color Doppler can be used to confirm the absence of blood flow in the heart cavity or in the umbilical cord when accessible.

Fetal Biometry

Multiple biometric parameters have been described including biparietal diameter (BPD), biparietal surface area, head circumference, eye length, eye width, eye length + width, eye surface area, eye approximated volume (eyV), aortic diameter (aortD), abdominal diameter, abdominal circumference, intercostal distance, femur length (FL), and recently the first phalanx length (P1L).[8,26,30,38,39] In Quarter Horses, among those variables, BPD, eyV, aortD, and FL highly correlate and have a strong linear relationship with days of gestation.[38] To compare with the reference data (Quarter Horses), it is very important to use

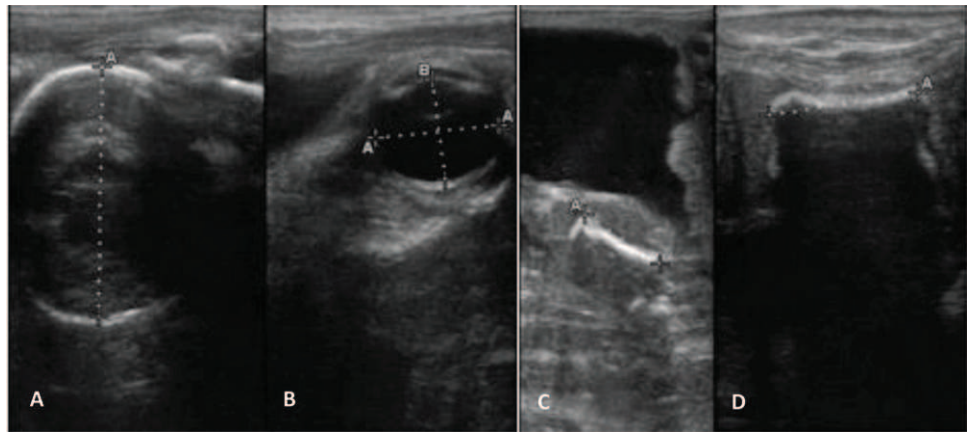


Fig. 5. A, Cross-sectional view of a fetal cranium obtained by transrectal ultrasonography. The biparietal diameter is measured between A+ from the outer margin of the skull nearest to the transducer to the inner margin of the skull furthest away from the transducer. B, Cross-sectional view of a fetal eye obtained by transrectal ultrasonography. The anterior and posterior portion of the capsule of the lens and the optic disc are seen. Eye length (eyL), maximum length of the inner margin of the vitreous body (between A+), eye depth (eyD), and margin of the anterior portion of the capsule of the lens to the inner portion of the optic disc (between B+) are measured. Eye approximated volume (eyV) can be calculated: eyV = eyL × eyL × eyD. C, Longitudinal view of a fetal femur obtained by transrectal ultrasonography. Femur length is obtained by measuring the ossified portion of the femur (between A+). D, Longitudinal view of the first phalanx (P1) obtained by transrectal ultrasonography; P1 length is measured from the proximal extremity of P1 to the distal extremity at the level of the condyle (between A+).

the same anatomical landmarks and standardized scan plans described below.

Measurement of the Biparietal Diameter or Cranium Diameter (Fig. 5A)

The cranium is imaged in cross-section, with the falx cerebri separating the 2 hemispheres symmetrically when internal structures can be seen. The image is frozen when the maximal cross-sectional area of the cranium appears oval. The BPD is measured using caliper cursors positioned from the outer margin of the skull nearest to the transducer to the inner margin of the skull furthest away from the transducer.[38]

Measurement of the Eye Length and Depth (Also Referred to as Width) to Calculate the Eye Approximated Volume (Fig. 5B)

The eye is imaged in cross-section. The anterior and posterior portions of the capsule of the lens as well as the optic disc serve as anatomical landmarks. The image is frozen when the maximal cross-sectional diameter of the vitreous body is obtained. Eye length (eyL) is the maximum length of the inner margins of the vitreous body, and eye depth (eyD), perpendicular to eyL, is measured from the margin of the anterior portion of the capsule of the lens to the inner portion of the optic disc.[38] The eyV is then calculated: eyV = eyL × eyL × eyD.[38] It is important to notice that landmarks used here are different from the ones described by Bucca,[34] where the depth of the eye is measured from the cornea to optic disc.

Measurement of the Aortic Diameter

The aorta is viewed in longitudinal section. The image is frozen when the most anterior portion of the aorta is seen in systole (maximum dilation of the aorta). The aortD is measured by placing the 2 caliper cursors on the vessel margins.[38]

Measurement of Femur Length (Fig. 5C)

The image is frozen when the longest view of the ossified portion of the femur is obtained. FL is then measured with the caliper cursors.[38]

Measurement of the First Phalanx Length (Fig. 5D)

The image is frozen when the longest view of the ossified portion of P1's diaphysis is obtained. P1L is then measured using caliper cursors: One is placed at the proximal extremity of P1 and the other one at its distal extremity at the level of the condyle.[39] The presence and/or absence of the proximal and distal epiphyses should also be noted.[39]

Fetal biometry is used either to assess if the fetus is growing properly based on its known gestational age or to assess fetal age when breeding/ovulation date is unknown. Multiple biometric parameters are usually measured and then compared with the reference data.[31,38,40] In Quarter Horses, fetal age can be predicted within 2 weeks using FL, BPD, or eyV prior to 200 days of gestation, but as pregnancy advances, accuracy decreases.[41] Prediction of fetal age is within 3 weeks from 201 to 300 days (using BPD, eyV) and after 301 days (using eyV).[41] Even though fetal growth will likely vary with breed, the table established using Quarter Horses can be used in Warmbloods, Standardbreds, and Thoroughbreds with similar accuracy as in Quarter Horses up to 200 to 250 days of gestation.[a] Later in gestation (>240 days), P1L and appearance should be used in addition to the BPD and eyV. Interestingly, when P1L is visually the width of the ultrasound image (on most ultrasound machines = 52.5 mm), most pregnant Quarter Horse

mares are above 300 days of gestation and therefore within a month to a month and a half of parturition. The presence or absence of P1 epiphyses, in addition to P1L, is important information to better determine fetal age since P1 epiphyses appear and eventually close at a defined time in gestation. P1 proximal and distal epiphyses are detectable on ultrasound between 277 and 303 days of gestation (mean: 288 days). P1 proximal epiphysis never closes before parturition, while the P1 distal epiphysis closes between 306 and 333 days gestation (mean: 319 days).[39] As a practical guideline in Quarter Horses, pregnant mares are less than 300 days gestation if no P1 epiphysis is present, but if both P1 proximal and distal epiphyses are visible on ultrasound, mares are likely in their 10th month of pregnancy. When P1L is superior to the length of the ultrasound image (52.5 mm), pregnant mares are likely more than 300 days gestation, and if the proximal epiphysis is present and the distal absent, mares are more likely in their 11th month of pregnancy.

Fetal Bone Maturation

In addition to P1, distal metacarpal 3 (MC3), P2, and both proximal and distal sesamoids can be observed via transrectal ultrasound. Distal MC3's, P1's, and P2's epiphyses and sesamoid bones' diaphyses appear in a chronological order, with MC3's distal epiphysis appearing first, P1's second, P2's third, proximal sesamoids fourth, and distal sesamoids last.[b] Based on studies in the Quarter Horse, distal limb ossification can be considered complete when the MC3 distal epiphysis and P1 and P2 proximal epiphyses are present and reached the palmar aspect of their respective diaphysis and all sesamoid bones are present.[b] Clinically, fetal ultrasonography of the distal limb may be used in the decision-making process of not inducing parturition if in utero bone development is not complete. In high-risk late pregnant mares such as the ones who suffer from colic or prepubic tendon or abdominal wall rupture, having this knowledge could be critical to decide if it is worth continuing the pregnancy or not.

6. Conclusion

Ultrasonography is a noninvasive tool used to assess the equine fetus and its environment. After the routine pregnancy checks, all mares should be scanned at least once late in gestation (after 260 days) to ensure that the fetus is in anterior presentation. If the fetus is in posterior or transverse presentation, the mare should foal in a veterinary hospital where assisted vaginal delivery or C-section can be performed. Valuable mares, mares with a history of abortion (especially the ones due to ascending placentitis), and mares with poor perineal conformation may be scanned transrectally once a month starting at 7 months gestation to screen for ascending placentitis. In areas with endemic leptospirosis or nocardioform placentitis, mares should have monthly transabdominal ultrasound examinations starting around 250 to 270 days of gestation to screen for nonascending placentitis. Mares with premature mammary development or secretions with or without vaginal discharge should have a complete ultrasound examination of the fetus and placenta to determine the location of the placentitis, if present and to assess fetal well-being and the presence of twins. Assessment of fetal well-being is an important part of the ultrasound examination, with lack of fetal heartrate reactivity and decreased fetal activity representing acute hypoxia markers. A rapid or steady decrease in fetal HR for gestational age is a sign of poor fetal outcome. Fetal size can be evaluated by measuring biometric parameters. A normal-sized fetus for gestational age is also a sign of fetal well-being as opposed to a gestationally small fetus that may be associated with placental insufficiency/abnormalities or fetal abnormality. When ovulation or breeding date is unknown, fetal age can be determined within 2 weeks in light breed mares and Warmblood mares if mare pregnancies are evaluated by ultrasound before 200 to 250 days gestation. Fetal bone maturation can be evaluated after 240 days of gestation by scanning the distal limb via the transrectal approach. Fetal bone maturation is considered complete in utero when the distal sesamoid "navicular bone" is present.

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.

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Medication Use in the Pregnant Mare: Rationale for Selection

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Evidence-based support for medication use during pregnancy in the mare has undergone a welcome increase in the previous decade. Despite this, limitations persist as practitioners navigate the imperfect world of equine pregnancy. Author's address: Hagyard Equine Medical Institute, 4250 Iron Works Pike, Lexington, KY 40511; e-mail: kvondollen@hagyard.com. © 2023 AAEP.

1. Introduction

Medications selected to treat problems of pregnancy in the mare must be simultaneously safe for the mare, safe for the developing fetus, and able to penetrate the placental barrier. In addition to the importance of medication selection, it is necessary to determine which cases necessitate treatment, when to initiate therapy, and when to cease therapy.

While measurement of biomarkers including serum hormones[1], serum amyloid A,[2] and fetal fluids[3] has been studied in an attempt to develop accurate and early diagnostics for pregnancy health, ultrasound monitoring remains the superior technique for identifying abnormalities before outward signs arise. Early work on ultrasound-guided pregnancy monitoring focused on transrectal and transabdominal measurements of the combined thickness of uterus and placenta[4] (CTUP; Figs. 1–3). Additionally, guidelines for fetal evaluation have been developed.[5,6] More recently, the importance of cervical assessment has been demonstrated in evaluating the equine pregnancy and its association with pregnancy outcome.[7] The presence of cervical mucus serves a critical role as a protective barrier.[8] Accumulations of cervical mucus that are abnormal in their amount and/or distribution and deviations from normal cervical appearance (Figs. 4–9) warrant careful monitoring and possible treatment. Serial examinations, with findings recorded, can help the practitioner keep track of small changes between evaluations and decide when treatment is indicated. Alterations in blood flow through the intricate vasculature of the fetal membranes and uterus may contribute to visible changes in the chorioallantois and/or amnion (Figs. 9–12) despite no evidence of classic placentitis (e.g., increased CTUP or separation). It is through the above monitoring methods that early changes in the health of a mare's pregnancy can be identified and treatment initiated before overt clinical signs are observed. The ability to recognize normal and abnormal characteristics of pregnancy is essential when formulating a treatment plan.

2. Nonantibiotic Medications

Pentoxifylline

In treating mares with abnormalities of pregnancy, maintenance of blood flow to the placenta and

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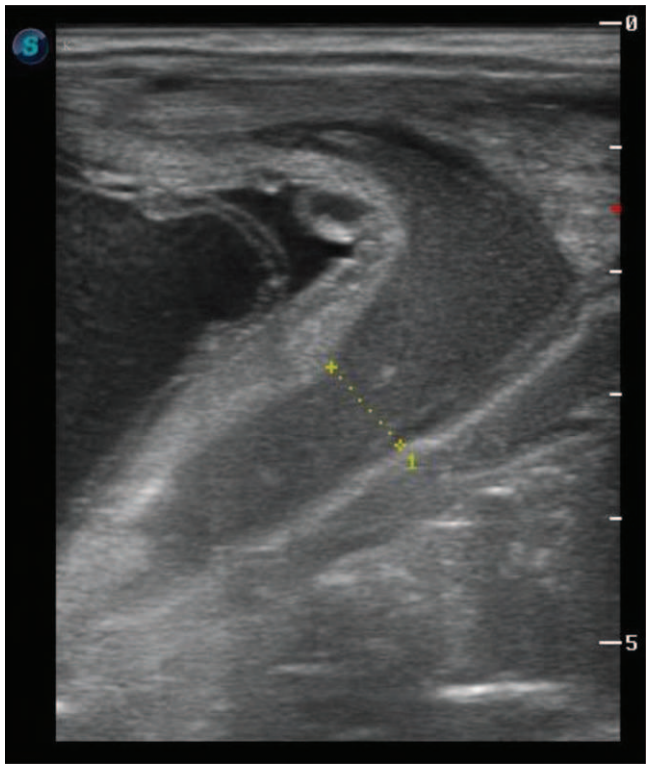


Fig. 1. Transrectal ultrasound of the cervical star region of a mare with ascending placentitis. The distance spanned by the dotted yellow line represents separation of the chorioallantois from the uterus, with accumulation of exudate. Cranial is to the left and caudal is to the right.

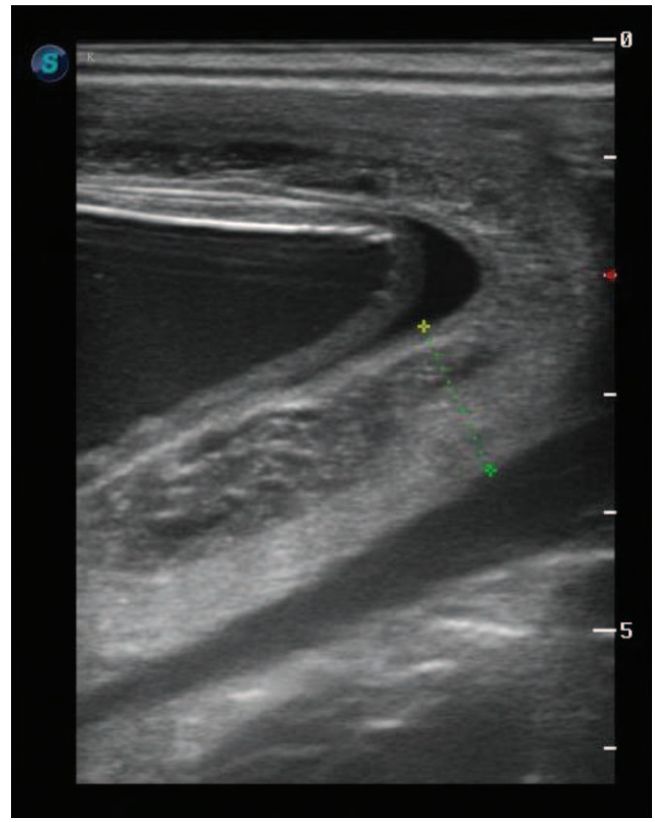


Fig. 2. Transrectal ultrasound of a mare with an enlarged CTUP. The distance between the yellow and green markers measures 13.45 mm. Note lack of separation or exudate. Cranial is to the left and caudal is to the right.

modulating inflammation are paramount. The phosphodiesterase inhibitor pentoxifylline acts to enhance deformability of red blood cells, as well as decrease aggregation of platelets and red blood cells.[9–11] These effects can help improve vascular perfusion. Furthermore, it confers anti-inflammatory properties through inhibition of proinflammatory cytokines.[12,13] Pentoxifylline at a dose of 8.5 mg/kg PO q 12 h has been shown to cross the placenta in pregnant mares[14] and improve pregnancy outcomes in mares with experimentally induced ascending placentitis as part of multimodal therapy.[15]

Aspirin

Acetylsalicyclic acid (aspirin) has been used in human medicine to modulate blood flow in pregnant women for decades[16–18] and is lauded for its analgesic, antipyretic, and antiplatelet properties.[19] Aspirin has been studied in both the nonpregnant[20] and pregnant mare.[21] In nonpregnant mares treated with aspirin (2,500 mg PO q 12 h), increases in ovarian and uterine perfusion, as well as increased plasma progesterone, were seen.[20] In pregnant mares, treatment with aspirin (5,000 mg PO q 12 h) led to an increase in uterine blood flow during late gestation.[21] Aspirin therapy is recommended to be discontinued at least 30 days prior to the mare's expected foaling date due to its effects on

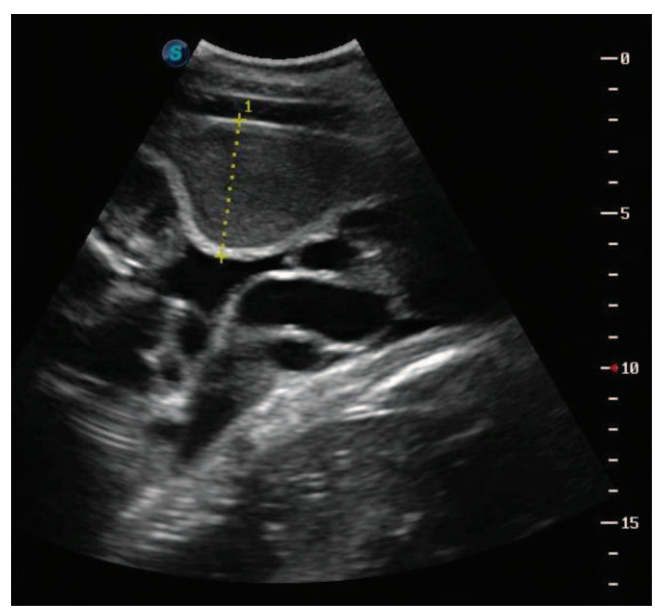


Fig. 3. Transabdominal ultrasound image of focal mucoid placentitis, confirmed postpartum to be caused by *Crossiella equi*. The distance spanned by the dotted yellow line represents accumulation of exudate between the chorioallantois and uterus. Cranial is to the left and caudal is to the right.

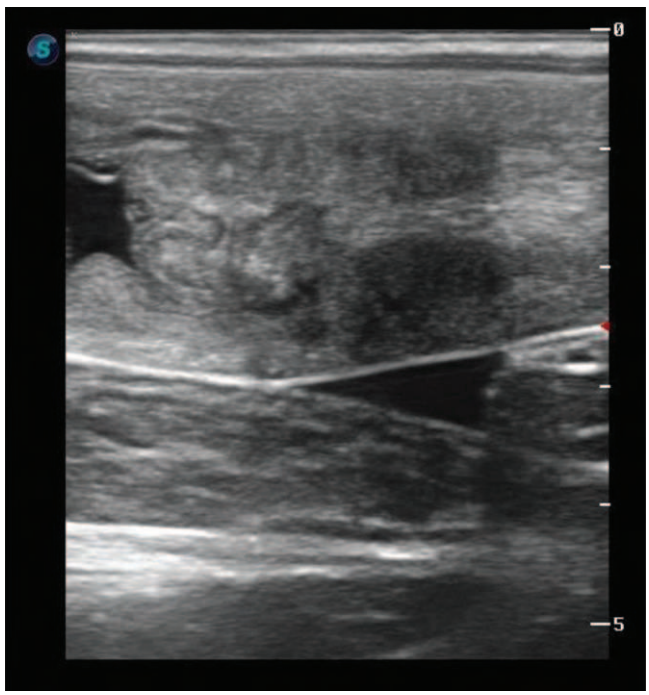


Fig. 4. Transrectal ultrasound image of the cervical star and cranial cervix demonstrating normal appearance of this region. Cranial is to the left and caudal is to the right.

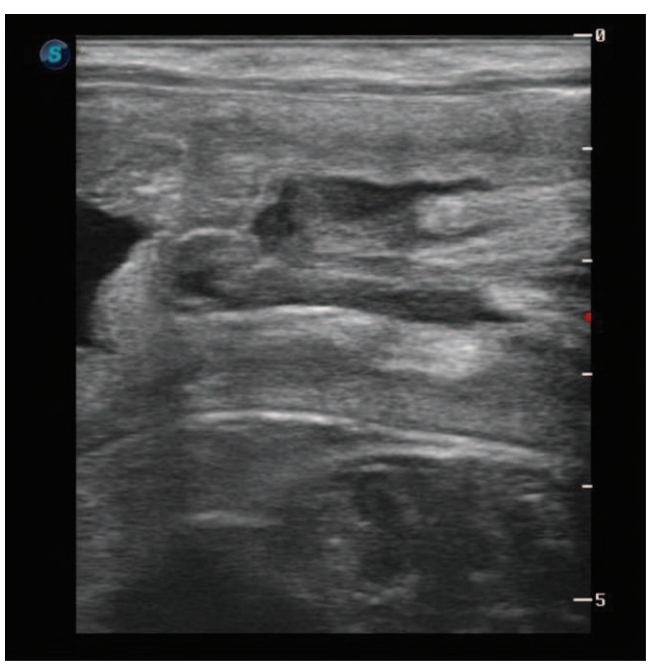


Fig. 5. Transrectal ultrasound image of the cervical star and cranial cervix with mucus accumulation (hypoechoic streaks). Cranial is to the left and caudal is to the right.

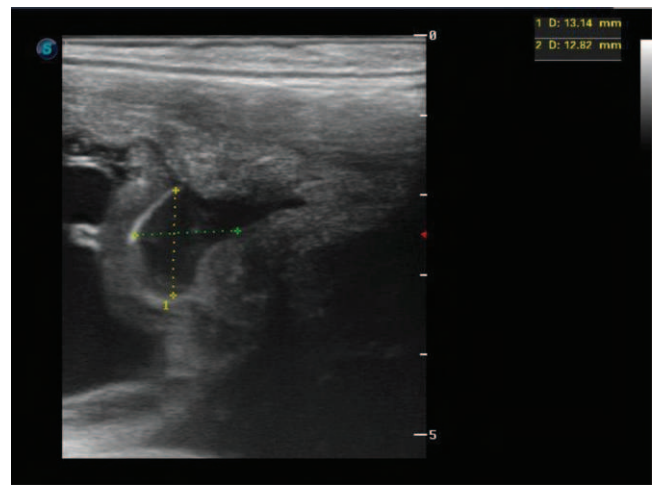


Fig. 6. Transrectal ultrasound image of the cervical star and cranial cervix with mucus accumulation. Measuring this accumulation via serial monitoring can help guide medication recommendations. Cranial is to the left and caudal is to the right.

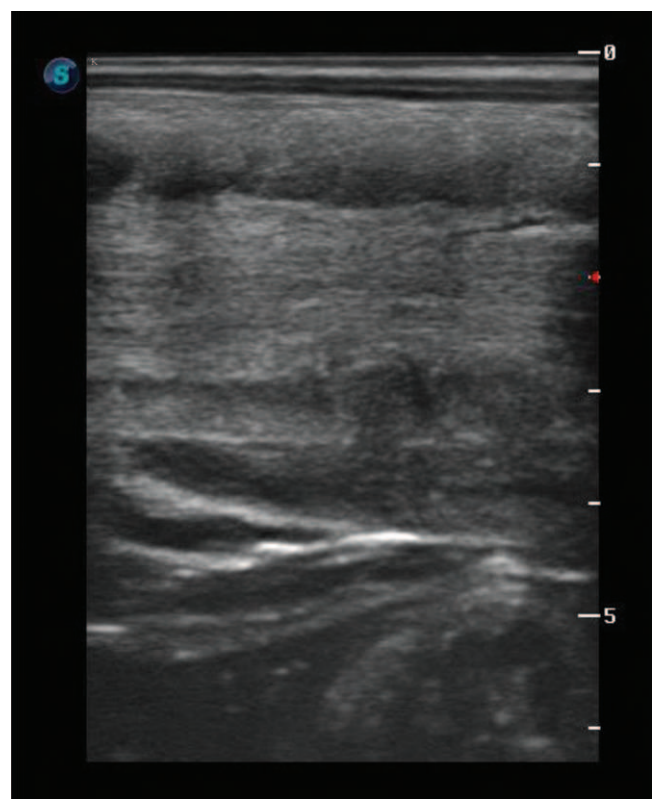


Fig. 7. Transrectal ultrasound image of the midcervical body with normal linear pattern of cervix. Cranial is to the left and caudal is to the right.

platelet aggregation and is contraindicated in mares with a previous history of periparturient hemorrhage.

Nonsteroidal Anti-Inflammatories

Foundational work in the pathogenesis of premature delivery in cases of ascending placentitis documented increases of placental cytokines and fetal fluid prostaglandins.[22] Building on this, treatment regimens suggested for management of mares with placentitis have included flunixin meglumine (1.1 mg/kg PO or IV q 12–24 h).[23] Flunixin meglumine was not identified in allantoic fluid of pregnant pony mares.[24] More recently, firocoxib (0.1 mg/kg PO q 24 h) has been shown to decrease inflammatory cytokines as

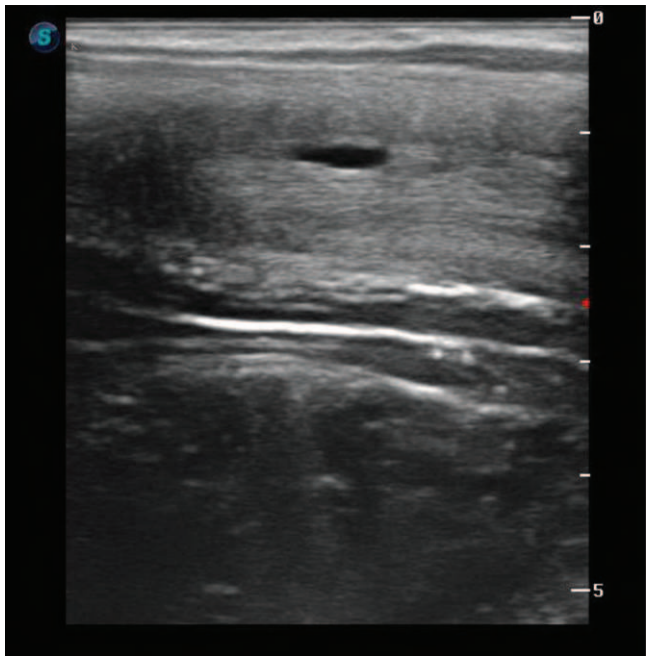


Fig. 8. Transrectal ultrasound image of the midcervical body with focal lucent defect present. As this may serve as a nidus for infection, regular monitoring is recommended. Cranial is to the left and caudal is to the right.

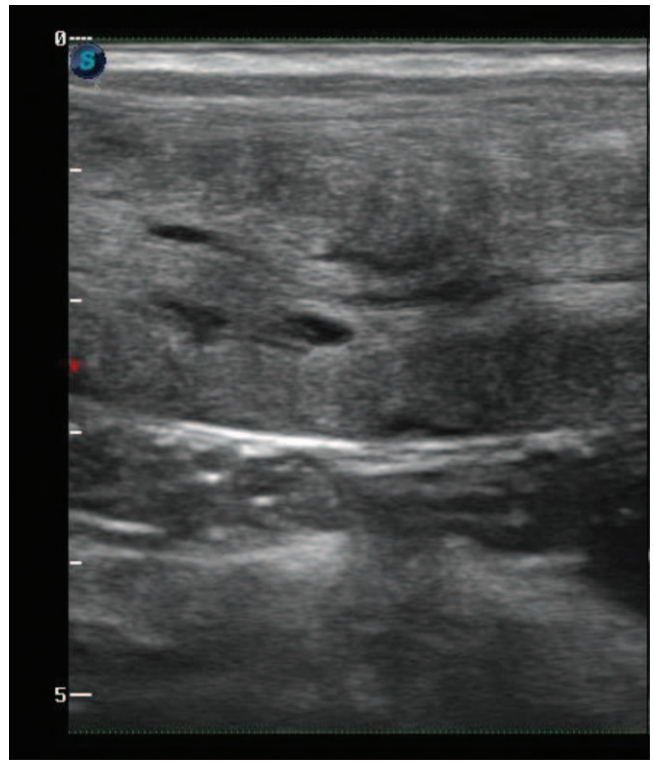


Fig. 9. Transrectal ultrasound image of the midcervical body with irregular fiber pattern (note softening and loss of linearity) and the presence of hypoechoic mucus. Cranial is to the left and caudal is to the right.

well as prostaglandins in mares with experimentally induced placentitis.[25] This work, coupled with the cyclooxygenase-2 selectivity of firocoxib and its potential sparing of unintended side effects of nonsteroidal anti-inflammatory drug administration,[26] make firocoxib an attractive choice for anti-inflammatory management of pregnant mares.

Progestins

The use of oral altrenogest has become commonplace in management of equine pregnancy, even when weak or no indication exists to justify its use. The intended effects of progestin therapy in the pregnant mare are promotion of myometrial quiescence and maintenance of cervical closure.[27] Altrenogest is commonly prescribed at a dose of 0.044 mg/kg to 0.088 mg/kg PO q 24 h. It has been lauded in equine reproduction for its ability to maintain pregnancy in the face of ovariectomy[28] and has been shown in vitro to have greater affinity for progesterone receptors than progesterone.[29] Potential side effects of altrenogest administration include suppression of the mare's immune system,[30] alteration of the neonatal foal's ability to transition to the extrauterine environment,[31] and changes in neonatal blood parameters.[32] The awareness and publication of these unintended consequences have led to a welcome reconsideration of the utility of blanket altrenogest administration to pregnant mares. Pregnancy outcome was improved in mares treated with altrenogest in a canonical study of experimentally induced placentitis.[15] The administration of altrenogest was associated with improved pregnancy outcome in mares presented for colic at a tertiary referral hospital;[33] however, supplementation

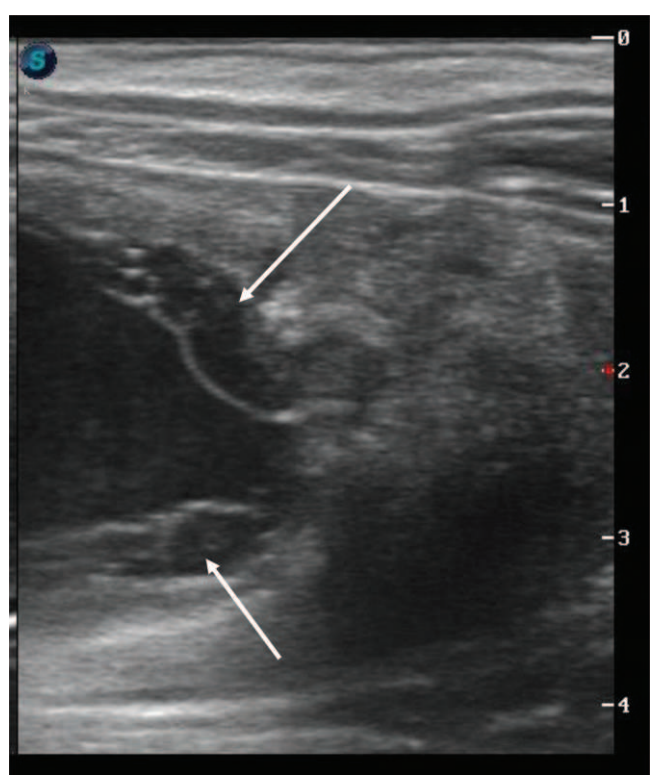


Fig. 10. Transrectal ultrasound of a mare with edema in the chorioallantois (white arrows). Cranial is to the left and caudal is to the right.

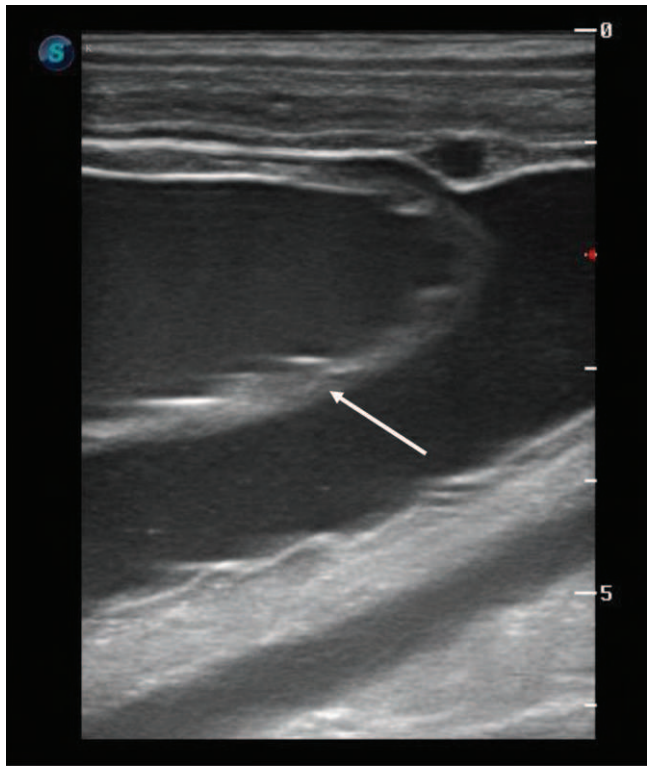


Fig. 11. Transrectal ultrasound with thickened amnion (white arrow) present. Note CTUP within normal limits despite thickened amnion. Cranial is to the left and caudal is to the right.

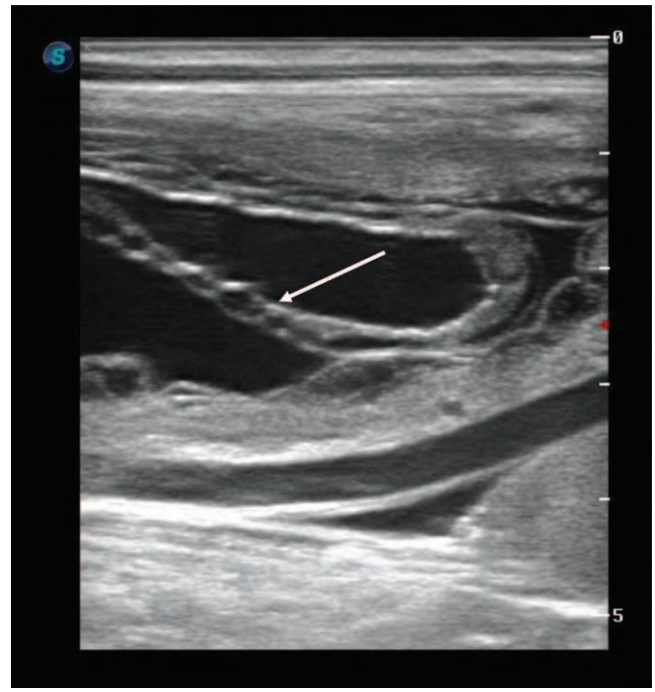


Fig. 12. Transrectal ultrasound with thickened, congested amnion (white arrow) apparent. Note bulges expanded by vasculature. Cranial is to the left and caudal is to the right.

with progestins was not found to affect pregnancy outcome in another study of pregnant mares treated for colic.[34]

Estrogens

Treatment of placentitis with exogenous estrogens is a subject of debate. In a study involving a group of mares with experimentally induced placentitis and treated with trimethoprim-sulfamethoxazole and flunixin meglumine, the addition of estradiol cypionate improved foal outcome, but the addition of altrenogest did not.[35] Mares treated with the aromatase inhibitor letrozole (which prevents placental conversion of androgens to estrogens) produced foals of slightly lower birthweight than untreated controls but otherwise showed no difference in gestation length, placental development, uterine vascular parameters, or neonatal viability compared to untreated controls despite having decreased estrogen levels.[36]

3. Antibiotics

The body of knowledge surrounding the disposition and/or efficacy of systemic antibiotics in the pregnant mare has increased in recent years. To date, relevant work has been published regarding the use of penicillin G, gentamicin, trimethoprim sulfamethoxazole, doxycycline, enrofloxacin, and ceftiofur in the pregnant mare. Antibiotic therapy should be commenced when a pregnant mare is diagnosed with an elevated CTUP or other evidence of placentitis with a suspected bacterial component. Due to the limited ability to sample the fetoplacental unit for culture and sensitivity, antibiotics typically must be selected empirically. The combination of potentiated sulfonamides with an aminoglycoside is a common frontline approach to treating placentitis due to relative ease of administration and broad spectrum of activity. Response to treatment should be monitored through recheck ultrasound at regular intervals (consider q 2–4 weeks), with therapy tailored accordingly.

Penicillin G and Gentamicin

Penicillin G and gentamicin, the broad-spectrum workhorses of equine medicine, have been shown to cross the placenta of pregnant pony mares and reach concentrations above the minimum inhibitory concentration (MIC) of common pathogens associated with ascending placentitis.[24] The largest downsides to these two medications are the administration requirements and limitations (i.e., requirement for intravenous access, volume of intramuscular injection, cost, client compliance), especially when facing long-term treatment. Direct transcervical deposition of procaine penicillin G and gentamicin was recently performed in a group of 9 pregnant pony mares.[37] Following a single transcervical infusion of 2.4 million IU procaine penicillin and 200 mg gentamicin, no change in CTUP, fetal heart rate, or mare clinical signs were observed. All mares foaled a live, viable foal at mean gestational age 323 days, 12 to 58 days following antibiotic infusion. This treatment method is currently experimental and far from achieving widespread clinical use due to persistent concern that trespassing on the

pregnant mare's cervix may lead to further compromise, as well as potential direct irritation secondary to gentamicin. This approach (transcervical deposition of antibiotics) may be considered in more severe cases of ascending placentitis after communication with the client to outline risks and potential benefits.

Trimethoprim Sulfamethoxazole and Trimethoprim Sulfadiazine

Potentiated sulfonamides represent a more attractive antibiotic option due to their oral dosing route. Trimethoprim sulfamethoxazole has been demonstrated to be effective in improving foal outcomes in cases of experimentally induced ascending placentitis[15] and reliably crosses the placenta.[14] While not yet investigated in pregnant mares, trimethoprim sulfadiazine has been shown to reach sufficient concentrations above MIC of common organisms in the endometrium of nonpregnant mares.[38]

Doxycycline

Doxycycline administered at a dose of 10 mg/kg PO q 12 h from 320 days of gestation through parturition was found to cross the placenta into the fetal fluids at a concentration of 0.0735 μg/mL in allantoic fluid and 0.0083 μg/mL in amniotic fluid.[39] As comparison, in isolates from mares with Nocardioform placentitis, the doxycycline MIC_{90} for *Amycolatopsis* spp. has been reported as 8 μg/mL and the MIC_{90} for *Crossiella equi* as 0.25 μg/mL, suggesting that doxycycline would not reach therapeutic concentrations in the fetal fluids.[40] Continued justification for doxycycline's utility in managing Nocardioform placentitis lies in the fact that this disease process classically takes place at the interface of the endometrium and chorioallantois, rather than infiltrating the entirety of the pregnancy and fetus. The currently elusive experimental model of Nocardioform placentitis precludes the ability to perform controlled experiments to scrutinize the efficacy of antibiotics in this disease, compelling the clinician to extrapolate from current knowledge, monitor mares undergoing treatment to assess response, and modify therapeutic approach accordingly. In isolates from mares with metritis, the doxycycline MIC_{90} for *Escherichia coli* and *Streptococcus zooepidemicus* have been reported as 4 μg/mL.[41] Further work is necessary to determine the impacts (if any) of gestational stage of administration, dose, and duration of treatment on potentially increasing the transplacental transfer of doxycycline.

Enrofloxacin

Due to fears about potential negative impacts on cartilage health stoked by research in juvenile canids showing vesicles that burst and lead to erosion of cartilage,[42] enrofloxacin has traditionally been avoided in pregnant mares. A portfolio of work in the late 2010s by Ellerbrock et al. examined the use of enrofloxacin in pregnant mares.[43–46] The pharmacokinetics of ciprofloxacin and enrofloxacin were found to be altered in pregnancy, with higher plasma concentrations seen in pregnant versus postpartum mares as a result of a smaller volume of distribution and less systemic clearance.[43] Therapeutic concentrations above MIC for common organisms were achieved in the allantoic and amniotic fluid of pregnant mares administered 5 mg/kg enrofloxacin intravenously daily or 10 mg/kg intravenously daily (supratherapeutic) starting at 260 days gestation for 11 days.[44] Oral treatment with enrofloxacin for 2 weeks starting at 280 days gestation with either 7.5 mg/kg daily or 15 mg/kg daily (supratherapeutic) did not result in any discernible cartilaginous lesions or observable lameness in foals assessed at 5 months of age.[45] Similarly, oral treatment with enrofloxacin from 46 to 60 days gestation at a dose of 7.5 mg/kg daily did not result in any detectable fetal abnormalities.[46] These findings may be explained by the conclusion that weight bearing was a necessary component of the pathogenesis of enrofloxacin-induced articular cartilage damage in dogs.[47] Given the understandable sensitivity of horse owners to joint health, enrofloxacin use in the pregnant mare is recommended to be reserved for cases for which there exists no other reasonable antibiotic option and should not be considered a first line antibiotic. The thorough work of Ellerbrock et al. to confer some sense of peace of mind is valued for its ability to expand the practitioner's antibiotic toolbox in cases where enrofloxacin is the best or only choice for treatment of a pregnant mare. Risks of its use should be discussed with clients, as the above literature, while multifaceted, has inherent and fully disclosed limitations regarding duration of treatment, stage of gestation when treatment was initiated, and foal age when cartilage assessments were carried out.

Ceftiofur

Ceftiofur, in both ceftiofur crystalline free acid and ceftiofur sodium formulations, failed to cross the placenta at therapeutically relevant concentrations, and its utility for treatment of bacterial infections of equine pregnancy is highly questionable.[48,49]

4. Conclusion

Regardless of the pregnancy abnormality encountered, the practitioner must employ diagnostic acuity with knowledge of medication behavior in the pregnant mare to select treatment promoting a positive outcome for mare, foal, and client.

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.

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Assessing Placental Progestogenic Support of Equine Pregnancy: Assay for Progesterone and the Placental Progestin, 5α-dihydroprogesterone

Alan J. Conley, BVSc (Melb), MS, PhD, FRCVS, Hon DACT

The progestogenic support of pregnancy is especially complex in mares, not only because it shifts from the ovaries (luteal) to the chorioallantois (placenta) but because it also shifts from progesterone to the 5α-reduced metabolite but equally bioactive progestin, 5α-dihydroprogesterone (DHP). This progression of progestogenic support, commonly referred to as the luteo-placental shift, can be monitored in maternal blood by liquid chromatograph tandem mass spectrometry (LC-MS/MS) but not by immunoassays, which cannot distinguish progesterone from DHP. It is generally agreed that embryonic loss in early gestation is a significant problem, but the principal causes remain controversial. Potential luteal insufficiency is particularly contentious but is a uniquely treatable cause, no matter how uncommon it might be. Fear of the loss of valuable pregnancies has led to the widespread use of progestogenic therapies, most commonly the synthetic progestin, altrenogest. Altrenogest is a potent and effective progestin but also an androgen that can induce clitoromegaly in filly foals. Androgen exposure in utero has been shown to induce symptoms of polycystic ovarian disease and metabolic syndrome in animal models and to potentially reduce ovarian follicular reserve, thereby impacting reproductive longevity. Though not documented in fillies exposed as fetuses, limiting altrenogest exposure would seem to constitute a best clinical practice. The luteo-placental shift can be documented by inversion of the DHP: progesterone ratio in the blood of pregnant mares around 110–120 days of gestation and can be accomplished using commercially available LC-MS/MS if definitive, objective evidence is valuable. Author's address: Department of Population Health & Reproduction, School of Veterinary Medicine, University of California – Davis, Davis CA 95616; email: ajconley@ucdavis.edu. © 2023 AAEP.

1. A Historic Problem

Pregnancy loss in mares has been a concern of the breeding industry for a very, very long time. In the classic monograph on the equine chorioallantois published 125 years ago,[1] Ewart noted that 40% of mares selected for breeding each season fail to produce a foal and indicated that the impetus for the anatomical study of placental development was an attempt to "account for so many mares breaking service from the sixth to the ninth week." The description of the equine chorioallantois as it develops during this interval of time was one of the first in the English literature, but

NOTES

it gave no insight into possible causes of pregnancy failure. Rather, the recommendations offered in conclusion were general in nature, pertaining to management practices only. Several decades passed before progesterone was isolated and characterized, and the role of this particular steroid in pregnancy was defined.[2] It was several more again before the contributions of the ovaries[3] and the chorioallantois[4] to the maintenance of pregnancy in mares were clarified.[5] Yet, the potential involvement of progesterone (luteal) insufficiency in early embryonic loss in horses remains a concern as well as an issue of continued debate.[6] The prospect of potential deficiency fuels the treatment of a great many mares that is probably unnecessary in most cases.[7] Discussion of the presumed benefits and potential long-term costs of these treatments that are seldom considered will be addressed in this review.

2. Progesterone, 5α-dihydroprogesterone (DHP), and the Luteo-Placental Shift

The reproductive endocrinology of equine pregnancy is unique among livestock species and especially complex in the way in which the ovaries and the chorioallantoic placenta are involved in providing progestogenic support.[8] Understanding these events is crucial in determining if, when, and how a lack of progesterone can result in pregnancy loss. Like all mammals, progesterone in mares is secreted initially by the primary corpus luteum following ovulation, but secretion wanes between weeks 3 through 6[9,10] until endometrial cup formation and secretion of equine chorionic gonadotropin (eCG) revives it.[11] The variable formation of accessory luteal structures[12] stimulated by equally variable eCG secretion[13] is associated with a further increase in progesterone after day 40 that peaks around 70 days,[10,14] though the physiological relevance of these events in pregnancy maintenance has been questioned.[15] In any case, luteal progesterone secretion begins to decline between gestation day 70 and 100,[12] and the placenta takes over the support of pregnancy from the ovaries, and progesterone disappears in the second half of gestation.[10,16–18] This clinically significant event, referred to as the luteoplacenta shift,[8] can be monitored by measuring the 5α-reduced metabolite of progesterone, 5α-dihydroprogesterone (DHP), which is synthesized by the equine chorioallantois in pregnant mares.[9,19,20] DHP is as potent a progestin as progesterone itself in the horse and capable of maintaining pregnancy alone.[14] Although DHP is also present in the circulation of cyclic[21] and early pregnant mares,[14,18] it is at much lower concentrations (DHP:progesterone $\ll 1$) until the luteo-placental shift takes place, and concentrations of DHP and progesterone invert (DHP:progesterone > 1) around 110-120 days of gestation (Fig. 1).[8,9,22] The shift (from ovarian to placental support) is not easily detected because immunoassays cannot distinguish

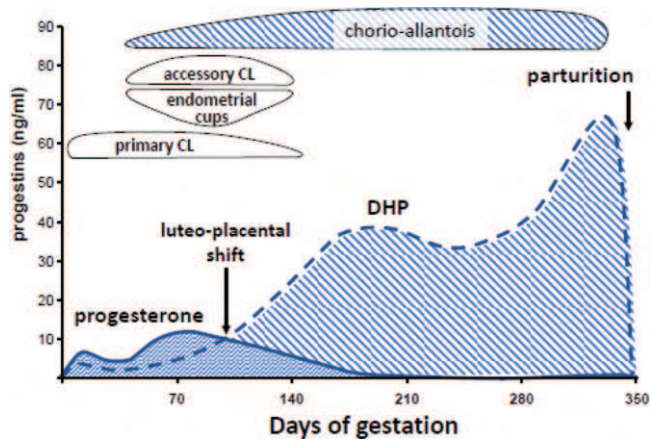


Fig. 1. Concentrations of progesterone and 5α-dihydroprogesterone (DHP) in maternal plasma during equine gestation. Note, the revival of progesterone secretion by the primary corpus luteum (CL), with a parallel increase in DHP, supplemented subsequently by secretion from induced accessory luteal structures is associated with chorionic gonadotropin secretion from the endometrial cups. The increasing contribution of the chorioallantoic placenta to the progestogenic support of pregnancy is marked by increasing DHP as the contribution from luteal tissue wanes, resulting in a decline in progesterone concentrations from around day 70. The point at which DHP concentrations exceed those of progesterone (≈day 110-120 of pregnancy) marks the luteo-placental shift when the DHP:progesterone ratio inverts.

progesterone from DHP and other metabolites,[23] some present at 100 to 1000-fold higher concentrations than progesterone in late gestation (Fig. 2).[9,10] Measuring DHP and progesterone requires chromatography,[17,18] more recently combined with mass spectrometry.[9,10,14] Liquid chromatography tandem mass spectrometry (LC-MS/MS) is more suited to high throughput clinical applications[24] and is more commercially accessible. The analytical, physiological, and clinical significance of the shift in the support of pregnancy from ovary to placenta, and progesterone to DHP, which is detectable in the blood of pregnant mares, constitutes the primary focus of this discussion.

3. Embryonic Loss: Luteal Insufficiency in Perspective

At least in the initial stages, the success of pregnancy relies on three primary intrinsic factors: a healthy and receptive reproductive tract, a genetically competent and viable embryo, and a functional corpus luteum.[25] Pregnancy failure is common among all species but involves multiple causes that include, to varying degrees, contributions from any and all of the above three components, influenced by a variety of extrinsic factors. Rates of loss tend to be higher in older mares and in early gestation before endometrial cups become fully functional, during which estimates of loss vary from 3-24%.[26–37] No specific etiology is ascribed in the majority of cases of pregnancy failures and abortions investigated.[38–40] Considering each of these factors (endometrial infection excepted), a loss of oviductal or endometrial integrity probably accounts for the increased rates of failure as mares age and

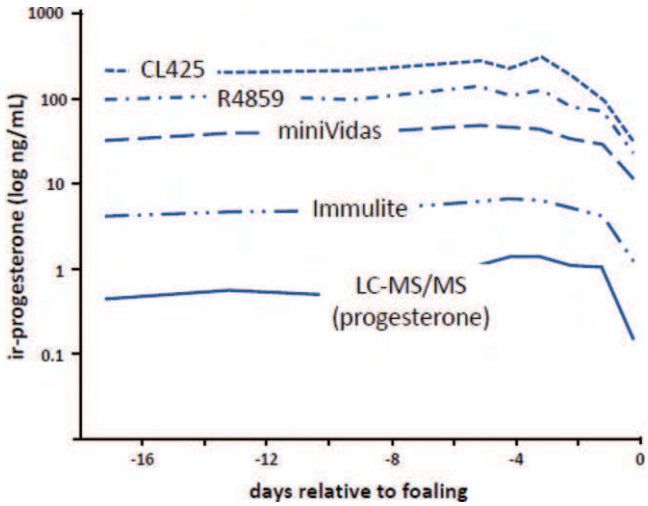


Fig. 2. Concentrations (ng/mL) of immuno-reactive (ir; apparent) progesterone concentrations measured in serum from mares in days prior to foaling as measured using different immunoassay platforms designated as CL425, R4859, miniVIDAS, Immulite 1000, and actual progesterone concentrations measured by liquid chromatography tandem mass spectrometry (LC-MS/MS). Note the y-axis was transformed to a log scale to accommodate the range of values. Adapted from Wynn et al.[23]

endometrial health declines.[26,29,41,42] Clearly, genetic defects such as aneuploidy also result in at least a small percentage of early pregnancy failures.[43] None of these can be mitigated. On the other hand, many agree that luteal insufficiency is unlikely to be involved to any significant degree,[35,36,44] and it is often not even mentioned as a cause in some reviews.[39,40] Studies conducted on research herds have been contradictory. One[35] found little evidence of luteal insufficiency in mares experiencing early embryonic loss after day 17 of pregnancy (1/15). A more recent study that began monitoring progesterone when pregnancy was first detected (day 11.5 to 12.5) found 50% of losses were associated with luteal failure.[45] Under clinical circumstances, perhaps only two cases have ever been documented.[46,47] Consequently, the adequacy of luteal function and progestogenic support remains the most controversial of all possible factors.[7,30,38,48] But, because (presumptive) luteal insufficiency can be mitigated by treatment with synthetic progestins, these therapies are commonly employed. How necessary or effective progestin therapy is in rescuing supposedly doomed pregnancies remains unknown and will not likely ever be known. Clinical realities aside, supplemental progestin therapy, often administered for fear of luteal (progesterone) insufficiency,[7,25,28,48–50] certainly becomes unnecessary after the luteo-placental shift (Fig. 1).

4. What Constitutes Enough Progesterone: Ovariectomy and Replacement Studies

The diagnosis of luteal insufficiency in mares is based on somewhat arbitrarily defined progesterone concentrations determined by various authors using different assay platforms under various experimental circumstances. In truth, what is considered necessary to maintain or support pregnancy is not easy to determine nor is it easily justified.[51] Ovarian progesterone secretion is necessary to maintain pregnancy for the first 2-3 months of equine gestation only. Pregnancies continue in at least some mares after ovariectomies performed from 50-70 days, and continued gestation is increasingly independent of ovarian support as it progresses.[5] Supplementation with exogenous progesterone until d 100 sustains pregnancies in ovariectomized mares and pregnancies survive thereafter without it because the placenta is sufficiently developed to re-establish adequate endogenous progestin synthesis. For instance, Shideler et al.[52] treated several groups of mares on d 29 or 30 of gestation with various doses and regimens of exogenous progesterone (250 mg every other day [5/8 maintained]; 500 or 1000 mg every 4 days [1/8 and 8/8 maintained, respectively]) then performed ovariectomy on d 34 or 35. Pregnancies and progesterone were monitored until d 100, and the authors concluded that mares needed at least 4ng/mL of progesterone to sustain their pregnancy. However, progesterone fluctuated from day to day, and it was suggested that an average of 2 to 3 consecutive daily samples should be assayed to diagnose progesterone deficiency. Moreover, several mares with progesterone <2 ng/mL maintained pregnancy, even if most of those with concentrations that low lost their pregnancies. What constitutes adequate or insufficient concentrations of progesterone to sustain pregnancy likely differs among mares and probably among pregnancies under different circumstances even if in the same mare. Importantly, even if less generally appreciated, different assay platforms do not necessarily agree and can vary significantly in the concentrations they estimate on the same sample (Fig. 2).[23] Yet 4 ng/mL remains a virtual industry standard regardless of where or how determinations are made and how different estimates might vary from assay to assay (Fig. 2) and hence laboratory to laboratory.

5. What Constitutes Enough Progesterone: Embryo Transfer Studies

Inadequate progesterone concentrations in mares in early pregnancy remains a significant concern in the embryo transfer industry, and it is possible that luteal function is compromised by manipulation of the reproductive tract. It has been suggested that even nonsurgical embryo transfer itself on d 7 may impair luteal function and decrease progesterone concentrations in recipient mares on d 14, lowering pregnancy rates,[53] by increasing early embryonic loss presumably if that were indeed true. Success of pregnancy was less when embryos were transferred at the morula stage, perhaps due to delayed development with subsequent inadequate maternal recognition signaling allowing prostaglandin release and partial luteal regression.[53] Three times as many recipient mares with progesterone concentrations >2.5 ng/mL at d 12 were pregnant as those that were not, and the authors arbitrarily designated <2.5 ng/mL of progesterone as

defining luteal dysfunction.[54] Ovariectomized mares supplemented with exogenous progesterone have also been used as recipients. McKinnon et al.[55] reported that all ovariectomized recipient mares supplemented with progesterone that achieved >2.6 ng/mL (at 24 hrs after dosing) maintained pregnancy. Using a similar number of ovariectomized recipient mares on a low dose of progesterone that achieved only 1.3-3.0 ng/mL serum concentrations, Knowles et al. reported maintaining pregnancies to d 35 with similar success to that seen in intact mares.[56] In a general review of embryonic loss, Ginther[57] concluded that concentrations of progesterone exceeding 4 ng/mL was consistent with embryonic survival. The proposed 4 ng/mL critical concentration for pregnancy maintenance in mares was also highlighted by a study of just 3 ovariectomized recipient mares that maintained pregnancies on supplemental progesterone.[58] That standard seems to have been adopted broadly ever since, though some still report that progesterone supplementation does not improve pregnancy rate in recipient mares after surgical transfer.[59]

6. Embryo Autonomy and Luteal Insufficiency

Equine embryonic development appears to be remarkably resilient and tolerant of low progesterone concentrations. For instance, it can be many days before embryos are actually lost after prostaglandin administration or even ovariectomy.[60] Kastelic et al.[61] reported that after prostaglandin treatment or ovariectomy performed on d 12, some embryos were still viable at d 19 and d 26, respectively. The survival of embryos during an extended period after luteolysis was verified by the observation that pregnancies could be rescued and survive with progesterone replacement begun on d 16, 4 days after induced luteal regression on d 12.[61] Similarly, Betteridge et al.[62] induced luteolysis on d 12-16 of pregnancy and observed that some embryos continued development out to d 22. Embryos in mares given prostaglandin on d 12 took 6.8 days on average to be lost, prompting the authors to describe "the relative autonomy (from progesterone) of embryogenesis during this period."[62] Perhaps this is relevant to the unusual degree of tolerance of equine embryos to asynchronous transfer,[63] which is increased even further in mares given prostaglandin synthesis inhibitors.[64] Moreover, the prolonged survival of equine embryos after loss of luteal support in early pregnancy makes it possible for mares to re-ovulate and the pregnancy to survive.[65] Clearly, pregnancies that would otherwise be lost from luteal regression,[66] and perhaps uterine expulsion induced by endotoxins for instance, can be saved with progestogenic support.[67] But a positive correlation between intra-uterine fluid accumulation and progesterone concentrations and a negative correlation with pregnancy rate,[68] led to the conclusion that early pregnancies are more dependent on uterine health than luteal function. Therefore, it is not clear how significant pregnancy losses from luteal insufficiency in practice are and hence whether the broad use of supplemental progestins is justified.

7. Supplemental Progestogenic Support: Altrenogest

Supplemental progestogenic therapy became a routine, if controversial, practice in managing equine pregnancies,[7,25,28,48,51] despite evidence indicating that the chances of pregnancy loss due to luteal or progesterone deficiency are small. Nonetheless, it may still be reasonable to propose that, however small the odds, rescuing even a single, valuable pregnancy justifies the financial cost and managerial effort. Exogenous progesterone can maintain physiological concentrations in ovariectomized mares,[69] and several commercially obtainable progestins have been investigated for their ability to maintain pregnancy after induced luteolysis in mares on d18, but not all are physiologically active or clinically effective.[70] Altrenogest certainly is sufficiently progestogenic to maintain pregnancies at recommended doses,[55,70] binding and activating the progesterone receptor, and it can be administered orally. However, altrenogest is unusual among the synthetic progestins because it also binds and activates the androgen receptor as well, which is why the drug poses risks for those administering or exposed to it, pregnant women and children in particular. Altrenogest is a potent and effective progestin, but it is also a potent androgen in humans and is five times as potent as testosterone in human androgen receptor bioassays,[71] presumably binding the human androgen receptor more avidly. Hence the product is labeled with a caution for untoward exposures during daily oral administration to mares. Altrenogest is a 17α-alkylated synthetic androgen. Alkylation at the C-17 position allows the steroid to avoid first-pass hepatic metabolism, making it bioavailable after oral administration, but this substitution also increases potential hepatotoxicity.[72] Early studies in cyclic mares administered altrenogest exhibited elevated aspartate aminotransferase concentrations at the two highest doses used toward the end of the three-month treatment period, but no histologic evidence of hepatic damage was found at necropsy.[73]

8. Androgenic and Other Possible Effects of Altrenogest in Filly Foals from Treated Mares

The progestogenic effects of altrenogest are well known,[50] but how potently does altrenogest also activate the equine androgen receptor, and what untoward side-effects or costs might that incur? Altrenogest is measurable in fetal fluids and in foals born to mares treated with 0.088 mg/kg from 20 to 325 days.[74] Filly foals from mares receiving the same daily dose throughout gestation were born with clitoromegaly,[75] clitoral size was twice that of filly foals from mares not treated during pregnancy. Significant clitoral hypertrophy was reported in filly foals in another study of mares administered 0.1 mg/kg from 20 to 320 days of gestation,[76] though the actual difference in

size was not stated. No other adverse events were observed in either dams or their foals in the study by Shoemaker et al.,[76] but 2 of 13 fillies died within 18 months of birth of unreported causes in the study by Naden et al.[75] The remaining 11 fillies had higher gonadotropin concentrations than fillies from untreated pregnancies until the age of puberty but all cycled normally and established pregnancies.[75] In a more recent study, mares were treated with 0.088 mg/kg of altrenogest from 280 days of gestation until foaling which, interestingly enough, was not delayed and may even have been advanced by a few days.[77] Foals from altrenogest-treated mares experienced a prolonged delivery. They also exhibited a lower respiratory rate, elevated blood pH, and a base excess after birth. All foals from control mares were delivered and developed normally, but half (3/6) of the foals delivered by altrenogest-treated mares suffered some degree of maladjustment or died soon after birth.[77] The causes of the apparent loss of neonatal viability were not reported.

9. Potential Long-Term Costs of Altrenogest on Exposed Filly Foals

Despite being so potently androgenic in humans,[71] altrenogest remains a popular drug and it has been estimated that thousands of pregnant mares are administered altrenogest each year.[7] This is especially true if they have a history of recurrent pregnancy loss or evidence suggestive of low progesterone concentrations, although no data exists to support actual clinical efficacy.[50] And, as noted above, all fillies exposed to altrenogest in utero established normal cyclicity and pregnancies in their first season.[75] However, might there be other associated "costs" that are not as obvious as clitoromegaly? It is well known that in utero exposure of female fetuses to androgen (testosterone treatment of their pregnant dams) induces symptoms of polycystic ovarian syndrome in nonhuman primates, sheep and rodents.[78] This includes elevated concentrations of luteinizing hormone (LH) and an exaggerated LH response to gonadotropin-releasing hormone (GnRH) in rhesus monkeys[79] and sheep.[80] Fillies exposed to altrenogest in utero also exhibited elevated basal concentrations of LH and an exaggerated LH response to GnRH.[75] Additionally, in utero exposure of fetuses to androgens is associated with the development of insulin resistance, metabolic syndrome, and obesity in both rhesus monkeys[81] and sheep,[82,83] just as with polycystic ovarian syndrome in women at all ages.[84] More importantly, the syndromes associated with in utero androgenization in both rhesus monkeys[85] and sheep[86] are accompanied by a reduction in follicular reserve post-natally, that can impact reproductive longevity in livestock.[87] It has been proposed that more primordial follicles in the equine fetal ovaries arose from oogenesis that is completed after day 150 of gestation than before.[88,89] Therefore, the potential for androgenic exposure from altrenogest to reduce primordial follicle populations and follicular reserve would likely increase if therapies were extended beyond this point. Fertility decreases as mares age, displaying many of the same features seen in women reaching menopause as follicular reserves are exhausted.[90] Whether or not there is any decrease in the long-term fertility among fillies exposed to altrenogest in utero will likely never be known, but the value of foals born later in a mare's fertile life becomes clearer from the performance of their earlier born siblings. Premature ovarian senescence leading to the loss of potential foals late in the reproductive life of older, proven valuable, mares are probably costlier than any lost before, begging the question, is it worth the risk? Therefore, limiting the exposure of filly fetuses to altrenogest in utero would seem to constitute best practices to ensure that their reproductive longevity and potential is maximized.

10. Objective Evidence to Facilitate Limiting Exposure of Fetal Fillies to Altrenogest

It is clear from the studies cited above that luteal insufficiency is, at the very least, a relatively rare event[46,47] and, to the author's knowledge, there are no cases of pregnancy loss due to inadequate placental progestin synthesis that have ever been documented. Thus, if equine pregnancies do benefit to some degree from supplemental progestins, it is only necessary when the ovary is the primary source of progestogenic support prior to the luteo-placental shift. As a supplemental therapy, altrenogest does not appear to affect progesterone secretion.[91] It is worth noting that there might also be other effects of progestins that could affect pregnancies, and perhaps even the susceptibility to placentitis. Altrenogest (and progesterone) has been shown to suppress interferon-γ pro-inflammatory cytokine secretion and thereby might influence immunological responsiveness in mares, though this requires further investigation.[92] To reiterate, however, and despite very small numbers studied, just over half (8/14) of mares ovariectomized at d 70 of gestation subsequently maintained their pregnancies without any exogenous progestogenic support. In contrast, all mares ovariectomized at 140 days of gestation or later foaled successfully,[5] presumably due to sufficient development and progestogenic support in the form of DHP from the chorio-allantoic placenta.[19,20] Similarly, 8/8 pregnancies in ovariectomized mares that were maintained on a high level of progesterone replacement (1000 mg every 4 days) administered until d 100 of gestation only continued to term, while only 7/8 ovariectomized mares on altrenogest maintained theirs.[52] The interval of approximately 2 months between 70 and 140 days of gestation (Fig. 1) is when the support of pregnancy transitions from the ovary (luteal progesterone) to dependence on the placenta (DHP), the so-called luteo-placental shift,[8] at which point supplemental support of pregnancy can stop. Providing objective evidence that the luteo-placental shift is complete might be of value in supporting the decision to stop altrenogest treatment.

11. Conclusion

The luteo-placental shift is uniquely detectable and can be monitored and definitively documented in mares unlike any other livestock species because DHP is the major progestin secreted by the equine chorioallantois.[19,20] As noted above, DHP concentrations are consistently lower (by half) than those of progesterone in cyclic[21] and early pregnant mares[14] but increase as pregnancy proceeds and the chorio-allantoic placenta develops. This becomes evident as DHP concentrations increase from about d 70, eventually exceeding those of progesterone at around d 110-120 as it declines and eventually disappears.[9,14] It has been proposed that the concentration inversion, when DHP exceeds progesterone, provides objective evidence of the luteo-placental shift.[8] If objective evidence confirming that the shift is complete is valuable, determining progesterone and DHP by mass spectrometry can provide it. The lower the concentrations of progesterone are before the shift, the sooner DHP concentrations will exceed it, and the luteo-placental shift will become obvious.[a] Altrenogest is androgenic as well as progestogenic, and filly fetuses can be inadvertently androgenized in utero in treated mares. This has the potential to affect their long-term reproductive lifespan and metabolic health based on fetal androgenization studies conducted in other species, though this is unlikely to ever be known in horses with certainty if it does. If altrenogest is a worthwhile insurance policy against early embryonic loss, however unlikely or unnecessary that might be, confirming the luteo-placental shift and terminating treatment as soon as possible would seem to be an equally valuable investment in the reproductive longevity and long-term health of filly foals.

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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 the current Director of the Clinical Endocrinology Laboratory, Department of Population Health & Reproduction, School of Veterinary Medicine, University of California, Davis CA 95616, a self-funded, non-profit diagnostic unit within the School of Veterinary Medicine offering a fee-based assay service for reproductive hormones to the veterinary community.

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Is This a Good Neck Radiograph?

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1. Introduction

Imaging of the cervical spine is becoming more common and can occur following a clinical evaluation for lameness, poor performance, neurologic signs, pain, and stiffness or as part of a purchase examination.[1,2] Radiographic examination of the cervical spine can be performed in the field. These examinations should be undertaken with a thorough knowledge of the cervical spine anatomy and imaging techniques.

2. Radiographic Evaluation

Anatomic Landmarks and Projections of a Complete Study

A complete radiographic examination of the cervical spine should include lateral projections of the caudal aspect of the skull to the cranial aspect of the first thoracic vertebra (Figs. 1 and 2). Oblique views can provide additional information about the complex cervical spine anatomy.[3] Ventrodorsal radiographs can be performed for evaluation of the cervical spine in foals,[4] and ventrodorsal radiographs of the cranial cervical spine can sometimes be acquired in a standing adult horse.[5] Obtaining diagnostic quality images of the caudal cervical spine (C6-C7, C7-T1) with a portable x-ray generator can be difficult in larger horses, and additional information will be included below on improving the image quality in this region. However, in the case of a purchase examination, referral to a facility with a higher power generator may be indicated if diagnostic quality images of the caudal cervical spine cannot be obtained in the field.[1]

Horse Preparation and Management

In most cases, sedation is beneficial for manipulation of the horse and aids in obtaining diagnostic quality images. Once the horse is sedated, the temperament of the horse should be considered when planning the order of the images. If the horse is particularly head shy, it may be best to obtain images of the cranial cervical spine when the horse is most sedate. In general, the horse should be standing squarely on the fore and hind limbs with a straight head and neck position. However, asymmetric limb positioning may be helpful in the caudal cervical spine, which will be addressed in more detail later. Depending on the sensitivity of each patient to noise, as well as sensitivity to the plate and/or x-ray machine near the patient's head, earplugs can be considered. The ears can create mixed opacity over the cranial aspect of the cervical spine, and if this is a primary area of interest, the ears can be taped forward (Fig. 1). The position of the head and neck should be closely evaluated following sedation. Ideally, the head and neck should be in a neutral position with support of the head as needed. It is important to explain to the person holding the horse that they have a great influence over the quality of the images based on the position of the head and neck.[3,6,7] Radiation safety recommendations to keep exposure as low as reasonably achievable should be followed.[1]

Evaluation of the Image Quality

Evaluation of the image quality should include an assessment of the radiographic technique and positioning as well as identification of any artifacts, especially

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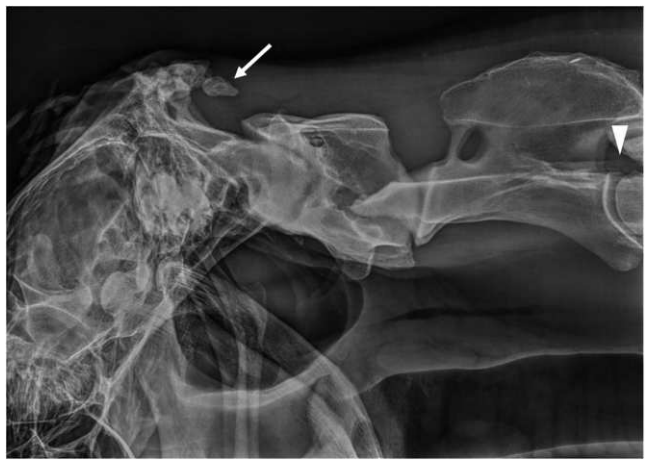


Fig. 1. Lateral radiograph (caudal skull to C2-C3) with mineralization (arrow) caudal to the external occipital crest and protuberance, which may be associated with the nuchal ligament or the semispinalis capitus tendon. The ears are taped forward to allow visualization of this region. The C2 transverse processes are superimposed over the C2-C3 intervertebral foramen (arrowhead).

motion. A proper radiographic technique should allow evaluation of all the anatomic features of the vertebrae including distinction of dense (subchondral, compact, and cortical) bone and trabecular bone. In many cases, the caudal cervical spine is underexposed due to the thickness of the musculature in this region. In these cases, caudal placement of the limb closest to the cassette can remove musculature from overlying the cervical spine, improving image quality.[5] If this is unsuccessful, an assistant can pick up the limb, flex the carpus, and pull the limb caudally, which should remove the musculature from overlying C6-C7, improving the diagnostic quality of the image at this level (Fig. 3). When this technique is employed, care should be taken as much as possible to keep the chest, head, and neck straight. The study quality should be assessed at the time the images are obtained. On the lateral cervical spine radiographs, ideally the articular processes are superimposed over each other (Fig. 4).

Comparing the dorsal and ventral margins of the articular processes is helpful in determining if the images are straight. It is important to note that beam divergence and magnification can cause the articular processes that are properly superimposed over each other with a straight image to appear mildly oblique.

In addition, the transverse processes on the ventral vertebral margins can be obliqued on that same projection due to beam divergence. Asymmetric enlargement of the articular processes can cause the appearance of obliquity. Therefore, evaluation of the dorsal and ventral margins of multiple articular processes in a row should be used to determine how straight the laterolateral image is and if it should be retaken. Alignment of the vertebral/spinal canal should be evaluated at the time the study is obtained (Fig. 4). If vertebral canal malalignment and/or neck flexion with the appearance of kyphosis and/or subluxation is identified, which may

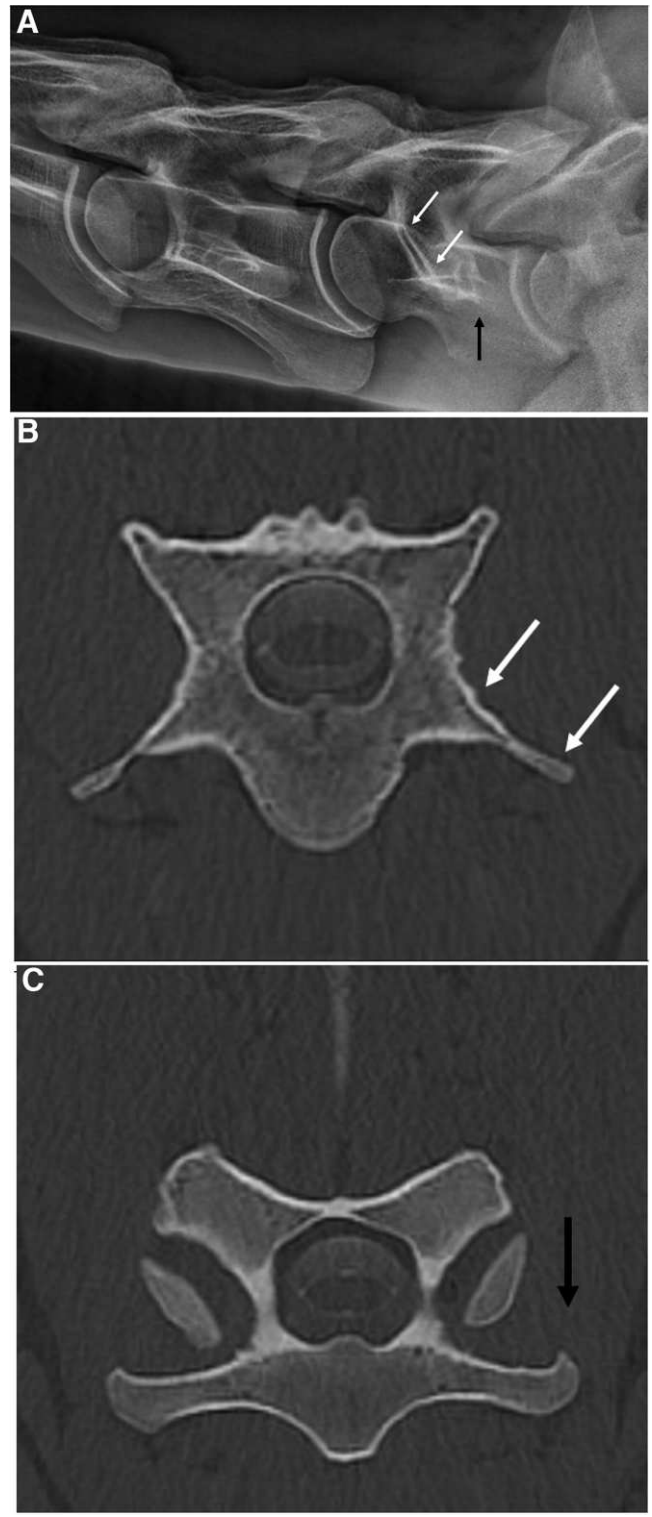


Fig. 2. Lateral radiograph of caudal cervical spine (A) and corresponding C7 computed tomography images (B, C). The anatomic characteristics of the C7 transverse processes cause the linear radiopaque lines to be superimposed over the vertebral body on a lateral radiograph with comparison cranial to mid (white arrows) and mid to caudal (black arrow) computed tomography images. These anatomic characteristics can be used to distinguish C7 from the adjacent vertebral bodies.

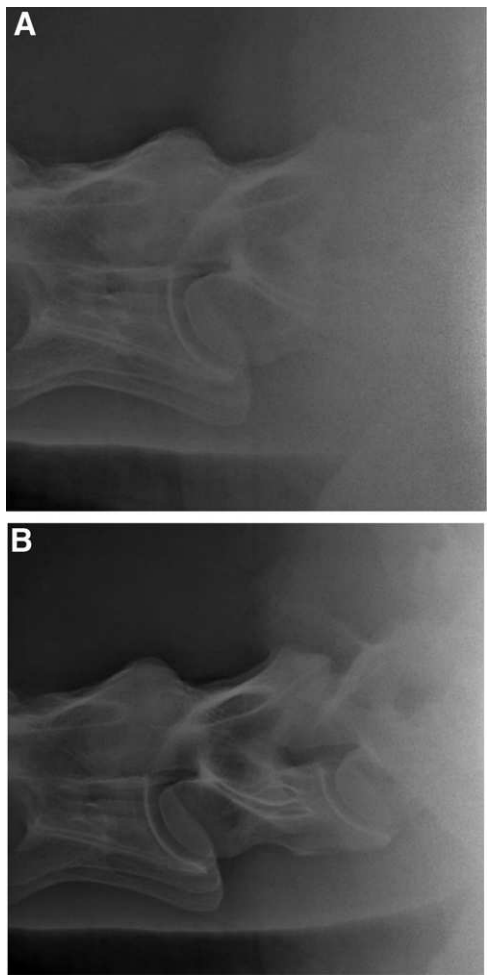


Fig. 3. A, Lateral radiograph taken in the field with the horse standing squarely on both forelimbs. B, Lateral radiograph with the forelimb that is on the side of plate flexed at carpus and caudally positioned to displace musculature overlying caudal cervical spine while maintaining position of head, neck, and chest. This allows evaluation of C7-T1, which was not visible on the initial radiograph and improves the image quality at C6-C7.

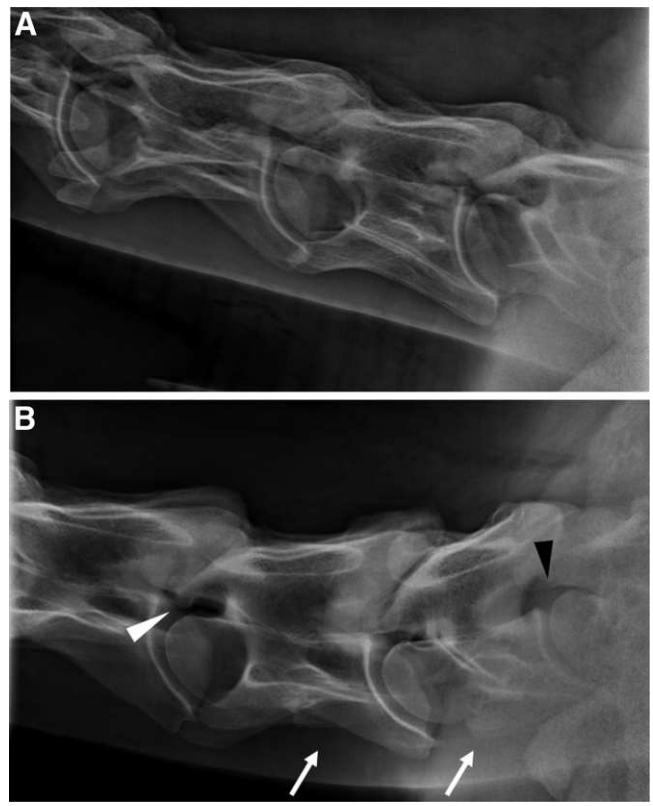


Fig. 4. A, Lateral radiograph that is not well positioned based on the obliquity of the articular processes and the superimposition of the ventral articular process margins over the intervertebral foramina. B, Well-positioned lateral radiograph with multiple findings. There is transposition of the C6 caudal ventral tubercles onto the ventral aspect of C7 (white arrows), which can be compared to C6 on image A. On image B, the C6-C7 articular processes are enlarged with heterogenous opacity and periarticular remodeling. Focal C5-C6 ventral articular process remodeling is present that is superimposed over the dorsal aspect of the intervertebral foramen (white arrowhead). There is subluxation of the cranial aspect of T1 with malalignment of the vertebralspinal canal at C7-T1 (black arrowhead).

be the result of the head position on how the handler was holding the horse, then the views should be repeated with the head and neck in a neutral position (Fig. 5).[1,5]

Oblique views of the cervical spine can provide additional information and are recommended as part of a radiographic study, especially in regions of suspected abnormality (Fig. 6). They allow evaluation of different regions of the articular processes as well as the remaining osseous structures of the vertebrae and can be helpful with fracture detection. Orthogonal oblique views should be oriented through the articular process joint spaces on both sides of the neck, which can be accomplished with the beam oriented from dorsal to ventral (beam oriented to the articular process joint space on same side of the horse as x-ray generator) or ventral to dorsal (beam oriented to articular process on the opposite side of the horse as x-ray generator). The best way to determine if an oblique view has been taken at the correct angle for evaluation of the articular process margins and joints is to evaluate the position of the ventral articular process joint relative to the intervertebral disc space. On a properly positioned oblique view, the midpoint of the ventral articular process joint will transect the midpoint of the intervertebral disc space. The optimal range of angles for obtaining oblique radiographs is 50° to 55° for C4-5, 45° to 55° for C5-6, and 45° to 55° for C6-7.[3] However, the angle required to obtain this orientation will change from cranial to caudal and is influenced by the head and neck position.[3,5]

Identification of Specific Cervical Vertebra Anatomic Features

The first, second, sixth, and seventh cervical vertebrae have specific anatomic features that make them easily identifiable in a normal cervical spine. The first and second cervical vertebrae have synovial joints, and the first cervical vertebra articulates with the caudal occipital condyles. The second cervical vertebra can



Fig. 5. Lateral radiographs of the cranial cervical spine. A, Flexion of the neck at C3-C4 that is likely positional with normal alignment of the vertebral/spinal canal. Additional views with the head and neck in different positions could be obtained to confirm this appearance is positional. B, Subluxation at C3-C4 with flexion and dorsal displacement of cranial C4 and malalignment of the vertebral canal. This assessment is made by comparing the ventral margin of the vertebral/spinal canal across multiple vertebral bodies.

have variable sized transverse processes that can be superimposed over the intervertebral foramen at C2-C3 (Fig. 1). The remaining vertebral bodies articulate with intervertebral discs and then have synovial joints at the level of the articular processes. The third, fourth, and fifth cervical vertebrae are anatomically similar and cannot be distinguished radiographically in the absence of the second or sixth vertebra. Skin markers can be helpful in this case when a small plate is used and only 1 to 2 vertebrae are present on an image. The normal sixth cervical vertebra has a continuous ventral margin with the caudal ventral tubercles distinguishing it from the fifth cervical vertebra. When there is caudal ventral tubercles transposition onto C7 or the tubercles are absent, C6 has an angled ventral margin at the mid aspect of the vertebral body as the transverse processes extend dorsally. The distinctive shape of C6 should be used to ensure that C6-C7 can be identified when oblique views are taken. The seventh cervical vertebra is reduced in the cranial to caudal dimension when compared to the sixth cervical vertebra, can have a variable sized and shaped spinous process, and typically has 2 radiopaque lines that extend caudoventrally from the ventral vertebral canal margin beginning at the level of the physeal scar. These lines represent the transverse processes that increase in size and become more horizontally oriented radio-opaque lines that end at the mid to caudal aspect of the vertebral body (Fig. 2). The spinous process of the seventh cervical vertebra can vary in size with variable opacity and irregular margins and can also be absent.[5,8]

Image Interpretation

The vertebral bodies and their position relative to each other, the alignment of the vertebral/spinal canal, the articular processes, the intervertebral foramina, and the intervertebral disc spaces should be evaluated for abnormalities. Malalignment of the vertebral bodies is identified by comparing the position of the ventral vertebral/spinal canal margin across multiple vertebral bodies in consideration with the head and neck position at the time the image was obtained. Flexion of the spine with a normal vertebral canal alignment should be distinguished from subluxation, where a vertebra is malpositioned relative to a cranially or caudally located vertebra, resulting in malalignment of the vertebral canal (Fig. 4).[7,9]

The caudal dorsal margin of the caudal endplates is specifically evaluated for any evidence of prominence (flaring), fragmentation, or physeal remodeling.[5] The size, shape, margins, opacity, and position of the articular processes should be evaluated. The ventral articular process margins should not appear flat or have squared edges. The size and shape of the intervertebral foramen should be evaluated. It is important to note that although the articular processes may appear to obliterate the intervertebral foramen, they may be superimposed over the foramen with no impact on the foramen or the nerve root in this region. Obliteration of the intervertebral canal cannot be definitively diagnosed on lateral radiographs in the absence of remodeling of the caudal endplate of the cranially located vertebra and/or vertebral body remodeling. Marked ventral abaxial enlargement of the articular processes can be present, causing the articular processes to be superimposed over the intervertebral foramen. However, the enlarged portion of the articular process may be completely removed from the intervertebral foramen. Definitive diagnosis requires advanced imaging, typically computed tomography, and has been demonstrated by recent publications,[10,11] due to the limitations of imaging the cervical spine with magnetic resonance imaging. The size and position of the intervertebral disc spaces should be evaluated, although this can also be influenced by the head and neck position.[12] Intra- and intervertebral minimum sagittal diameter ratios can be used as part of the radiographic evaluation to assess for vertebral/spinal canal stenosis as an indication of cervical vertebral malformation.[13]

Intra and Intervertebral Sagittal Diameter Ratios

Sagittal diameter ratios allow objective evaluation of the cervical spine (Fig. 7). Cervical vertebral stenotic/compressive myelopathy is a concern when the measurement is abnormal, based on published numbers.

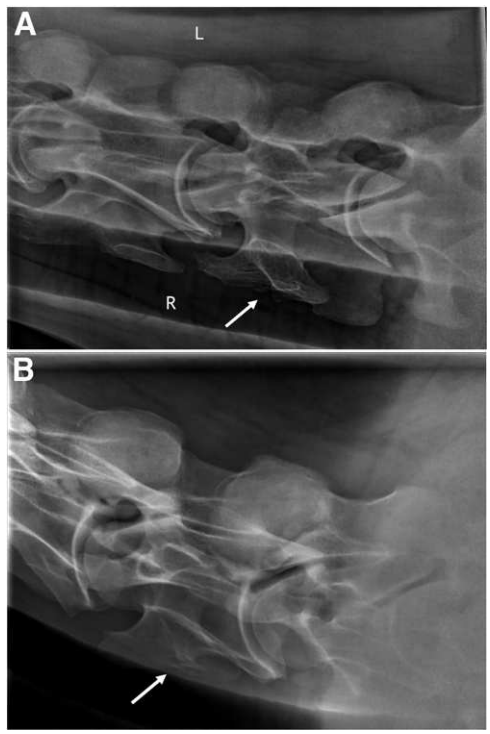


Fig. 6. Oblique radiographs of the caudal cervical spine (A, B). The C6 vertebra can be identified by the shape of the transverse process (white arrows). Radiograph A is well positioned at C6-C7, allowing evaluation of the articular process joints and periarticular margins with mild osteophytosis and mildly undulating subchondral bone margins. However, this image is cranially to caudally obliqued at C4-C5 and C5-C6. This can be identified because the mid aspect of the ventral articular process joint does not transect the midpoint of the intervertebral disc space and the dorsally located articular processes are separated in a cranial to caudal direction. Radiograph B demonstrates a common problem that occurs. Oblique views are often not angled enough in the dorsal to ventral direction, similar to this radiograph where the ventral articular process joint is superimposed over the dorsal aspect of the intervertebral disc space and the intervertebral foramen, preventing evaluation of the joint space and periarticular margins. However, the dorsal articular processes can still be evaluated, and abnormalities are identified at C6-C7 and C5-C6. The C6-C7 articular processes are enlarged and misshapen with periarticular remodeling and heterogenous opacity. The C5-C6 articular processes have focal ventral osseous proliferation superimposed over the intervertebral disc space.

To identify the proper landmarks for measurements, the radiographs must be of good quality and properly positioned. The sagittal ratio is calculated as the ratio of the minimum sagittal diameter of the vertebral foramen to the maximum sagittal diameter of the vertebral body. For the intra and intervertebral sagittal diameter, the cranial aspect of the vertebral body is measured at its largest dimension, perpendicular to the vertebral canal. For the intravertebral sagittal ratio, the smallest dimension of the vertebral foramen is used, and the measurement is taken at the cranial laminar margin extending to the ventral margin of the vertebral canal, perpendicular to the canal. In contrast, the vertebral foramen measurement for the intervertebral ratio is taken from the caudal laminar margin of the cranial vertebral body to the craniodorsal margin of the caudal vertebral body. An intravertebral sagittal ratio of less than 50% for C3, C4, and C5; less than 52% for C6; and less than 56% for C7 is indicative of vertebral canal narrowing.[14] An intervertebral sagittal ratio of less than 48% at any site in the vertebral canal is considered to be diagnostic for cervical vertebral malformation.[13] However, this does not necessarily indicate the site of compression accurately; this must be determined with myelography.[13]



Fig. 7. Technique for performing inter and intravertebral measurements. Vertebral body measurement (solid line overlying vertebral body) is performed at largest cranial dimension of the body, perpendicular to the vertebral canal. For the intravertebral sagittal ratio, the smallest dimension of the vertebral foramen (solid line overlying vertebral canal) is used, and the measurement is taken at the cranial laminar margin extending to the ventral margin of the vertebral canal, perpendicular to the canal. The vertebral foramen measurement for the intervertebral ratio is taken from the caudal laminar margin of the cranial vertebral body to the craniodorsal margin of the caudal vertebral body (dashed line overlying vertebral canal).

3. Summary

Many clinically relevant abnormalities of the cervical spine can be well evaluated with radiographs. This is best achieved with a thorough examination, keeping in mind the anatomic features of the cervical spine, and with a clear understanding of the limitations of these modalities as well as when advanced imaging should be employed.

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.

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Ten Radiographic Abnormalities Identified on Prepurchase Radiographs of Sport Horses

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This presentation will introduce and discuss 10 radiographic findings in sport horses that can lead to uncertainty in a prepurchase examination. Authors' addresses: Puchalski and Associates Equine Diagnostic Imaging, 975 Henry Road, Gibsons, BC, V0N 1V2, Canada (Puchalski, Graham); Cummings School of Veterinary Medicine at Tufts University, 200 Westboro Road, North Grafton, MA 01536 (Graham); e-mail: smpuchalski@gmail.com. *Corresponding and presenting author. © 2023 AAEP.

1. Introduction

Diagnostic imaging, in particular radiography, is an integral part of the prepurchase or purchase examination. Prepurchase radiography is a multilayered process, beginning with the decision to take radiographs, choosing the anatomic areas of interest, obtaining the radiographs, and interpretation. Accurate interpretation is dependent on both the identification of lesions and the appropriate assignment of relevance, or conversely the assignment of risk, based on the horse's history and intended use. Although radiographs have long been standard practice in the prepurchase examination of sport horses (i.e., horses not used for racing), there is a dearth of longitudinal studies assessing the implications of specific radiographic findings on career longevity or performance over time. Ultimately, purchase decisions are made based on clinician experience and opinion, which can vary widely.

Unusual or unexpected radiographic findings are identified with reasonable frequency, particularly with large numbers of radiographs or radiographs of unfamiliar regions. Often, these "unfamiliar" lesions are without scientific investigation, and even less information is available with respect to the lesions' relevance for a given sport or discipline. When an unfamiliar or unusual lesion is found, it is prudent to follow a step-wise approach rather than outright rejection of the horse based on a lack of industry knowledge. These steps include radiographic description of the lesion, ruling out artifactual causes, consideration of complementary radiographic projections or alternative imaging modalities to more fully characterize the abnormality, and finally, risk assessment. In regard to risk assessment, it is important to be as specific as possible in order to generate a thorough understanding of the problem, which includes examining the horse for known negative sequelae associated with the lesion. For example, although articular fragments can occasionally be innocuous, osteoarthritis is a known sequela, and consequently the radiographs should be evaluated for evidence of osteoarthritis. The question must be asked,

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Fig. 1. Dorsal 15° to 20° proximal to plantar distal radiograph of a hind fetlock. A short vertical lucent line is present in the subchondral compact bone of the sagittal groove of the proximal phalanx.

is this sequela manageable, or is there a risk of a negative effect on the horse's performance? Moreover, even though the risk of having a negative sequela is low, management of that sequela may be difficult to impossible. Risk tolerance undoubtedly varies among both clinicians and buyers and may change based on other parameters of the sale (e.g., suitability of that horse for a specific type of rider/person), supporting the need for judicious analysis of prepurchase radiographs.

There are several radiographic findings that often prompt additional investigation or a second opinion during prepurchase examinations. This presentation will review 10 such radiographic findings. Notably, many of these radiographic abnormalities are undescribed in the veterinary literature as incidental findings. If the radiographic abnormalities have been investigated, it is often as a study of lame horses rather than a longitudinal study assessing prevalence and outcome. Thus, this is a compilation of experiential learning supplemented with literature when available, with an emphasis on why the lesions are controversial.

2. Radiographic Abnormalities

Proximal Phalanx Sagittal Groove Fissure

Radiographic description: There is a vertical lucent line in the compact bone of the sagittal groove of the proximal phalanx (Fig. 1), visible on the dorsoplantar radiographs of the fetlock. These are often best seen on down-angled dorsoplantar views (dorsal 15–30° proximal to plantar), as they are frequently located within the central to dorsal portion of the proximal phalanx.

Current understanding and potential negative sequelae: First, the etiology of these radiographic abnormalities is uncertain. Although an incomplete, sagittal fracture can be considered when there is a known history of trauma,[1] these fissures can be present in asymptomatic horses from a very early age, making a developmental etiology plausible. This lesion may be present from their first set of radiographs as a juvenile; however, as many breed screening radiographic sets do not include dorsoplantar radiographs of the fetlocks, this may be an unrecognized lesion in a greater number of asymptomatic horses. Sagittal groove subchondral lesions have many manifestations that are clinically relevant and a cause of lameness.[2–4] The lesions can range from a solitary vertical lucent line to regions of compact bone demineralization, varying in severity from mild to very lucent and housing synovial fluid. Furthermore, these are implicated in the initiation of not only subchondral stress remodeling but also complete and potentially catastrophic fractures of the proximal phalanx.



Fig. 2. A, Dorsal 15° to 20° proximal to palmar distal radiograph of a fore fetlock region. A shallow contour abnormality is present at the peripheral aspect of the distal articular surface of the proximal phalanx (solid arrow). There is alteration in the opacity of the underlying trabecular bone (dashed arrow), with a focal lucency surrounded by trabecular bone sclerosis. B, Dorsal-palmar (horizontal beam) radiograph of the same limb as in A. The lesion is no longer visible as the radiographic beam is not tangential to the articular surface contour defect.

Proximal Phalanx Distal Articular Surface Contour Abnormalities in the Medial or Lateral Aspect of the Condyle (i.e., Not Sagittal)

Radiographic description: There is alteration of the distal articular surface contour of the proximal phalanx. These alterations range from flat to concave (Fig. 2A), with or without adjacent trabecular bone abnormalities, and may include osseous cyst-like lesions.

Current understanding and potential negative sequelae: These contour abnormalities have been described in young Thoroughbreds,[5–7] and although most did not see a correlation with performance, one study showed that the horses with subchondral cysts were less likely to start as 2- and 3-year-olds. Articular surface contour abnormalities, as a general rule, are associated with the initiation and propagation of joint disease. In this location, they may also be associated with the initiation of further subchondral injury such as subchondral intraosseous fluid accumulation/trabecular bone remodeling.

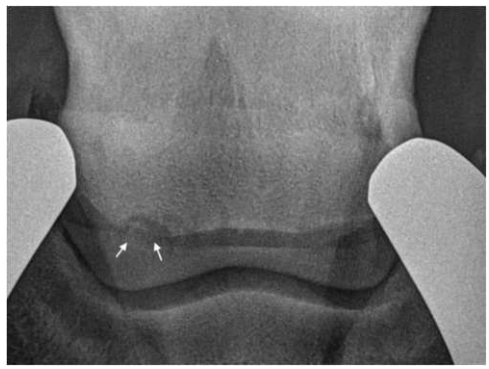


Fig. 3. Dorsal 65° proximal to palmar distal radiograph of a front foot. An irregular navicular bone distal margin fragment is present (arrows).

Subchondral osseous cyst-like lesions, even when developmental in origin rather than acquired, are invariably important in the prepurchase scenario. These contour abnormalities can be small, shallow, and smooth and present in horses with neither clinical signs nor radiographic evidence of joint disease.

Navicular Bone Distal Margin Fragmentation

Radiographic description: There is distal margin fragmentation (medial or lateral) that may or may not communicate with a distal synovial invagination (Fig. 3).

Current understanding and potential negative sequelae: In North America, navicular bone, distal margin fragments are considered part of the broad group of findings associated with "navicular disease" or "navicular degeneration." Their specific etiology is unknown, with trauma, degeneration, and impar ligament avulsion or impar ligament mineralization as possibilities. Although these fragments have been found more frequently in horses with other navicular bone pathology and were more common in lame horses in one radiographic study,[8] a magnetic resonance imaging study found no association between the presence of navicular bone fragments and lameness.[9] In continental Europe, these are considered to be "acceptable" findings on purchase examinations, particularly when present in isolation.

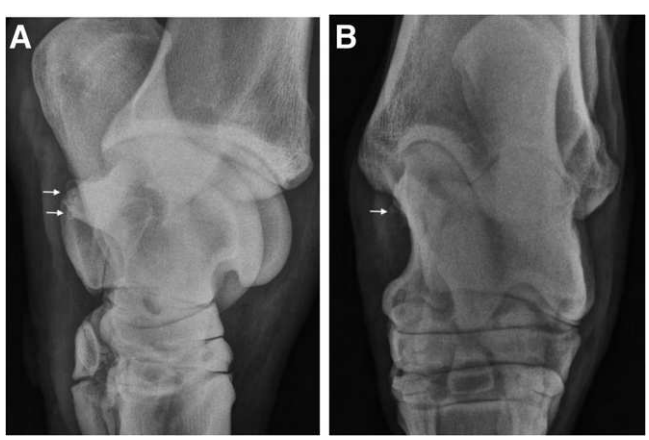


Fig. 4. A, Dorsomedial to plantarolateral oblique radiograph of a tarsus. The medial proximal tubercle of the talus is enlarged and irregular (arrow), projecting caudally to superimpose with the sustentaculum tali. B, Dorsoplantar radiograph of the same tarsus featured in A. The medial proximal tubercle of the talus is irregular and potentially partially fragmented (arrow).

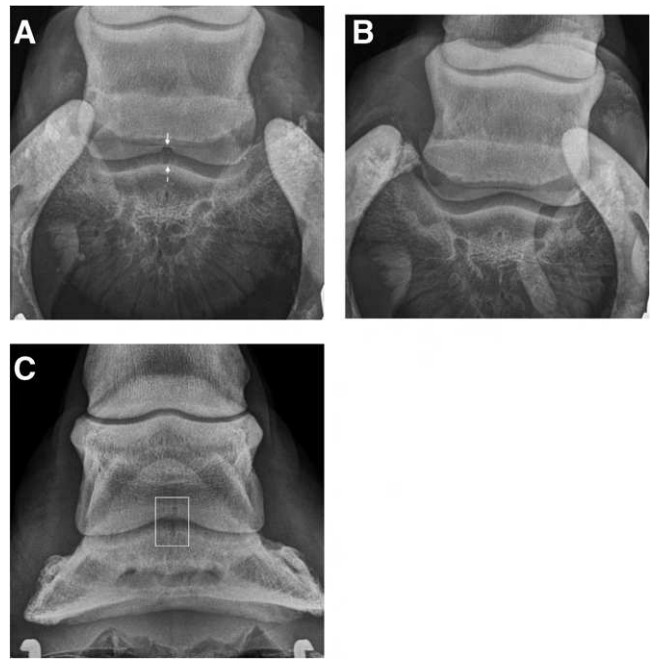


Fig. 5. A, Dorsal 65° proximal to palmar distal radiograph of a right front foot. There is a sharply demarcated contour defect of the sagittal aspect of the distal margin of the middle phalanx (arrow). In this foot, there is a region of abnormal (decreased) opacity in the opposing surface of the distal phalanx superimposing with the distal interphalangeal joint space (dashed arrow). B, Dorsal 65° proximal to palmar distal radiograph of the left front foot of the horse shown in A, showing a normal contour of the distal margin of the middle phalanx and opposing distal phalanx. C, Dorsopalmar (horizontal beam) radiograph of the right front of the horse shown in A and B. The opposing surface defects of the middle and distal phalanges are seen in the sagittal aspect of the distal interphalangeal joint (outlined).

Talus Medial Proximal Tubercle Fragmentation/Irregularity/Enlargement

Radiographic description: There is abnormal size, shape, margination, and/or fragmentation of the medial proximal tubercle of the talus. Infrequently, the medial distal tubercle of the talus may also be abnormal (Fig. 4).

Current understanding and potential negative sequelae: This radiographic abnormality tends to look alarming; however, it is generally incidental in the absence of a traumatic event, is seen more frequently in Warmbloods, and is often not associated with lameness.[10–12] The identification of this lesion may warrant closer clinical scrutiny or ultrasound of the region including the collateral ligaments of the tarsus.

Sagittal Divot in the Distal Articular Surface of the Middle Phalanx

Radiographic description: There is a contour defect of the distal, sagittal articular surface of the middle phalanx, with varying width and depth (Fig. 5A).

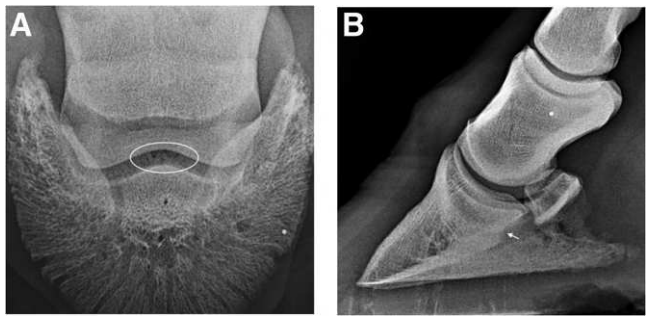


Fig. 6. A, Dorsal 65° proximal to palmar distal radiograph of a front foot. Several lucent foci superimpose with the distal interphalangeal joint space (circle). B, Lateromedial radiograph of the horse shown in A. There is an abrupt contour change on the palmar surface of the distal phalanx at the impar ligament attachment (arrow). This is supportive evidence that the radiographic lucencies are the result of bone resorption on the palmar aspect of the distal phalanx.

Current understanding and potential negative sequelae: As stated previously, articular surface contour abnormalities are associated with the initiation and propagation of joint disease. In the case of distal, sagittal P2, many (arguably most) of these defects are clinically silent and will remain so. However, some are associated with broader articular cartilage defects, can extend proximally into the subchondral trabecular bone as osseous cyst-like lesions,[13] and can be associated with opposing surface lesions in the sagittal aspect of the distal phalanx (Fig. 5C).

Distal Phalanx (P3) Lucent Foci Superimposing with the Articular Surface

Radiographic description: There is lucent foci superimposing with the distal interphalangeal joint space, typically on the upright pedal (oxspring) or dorsal 65° proximal-palmar radiographic projection (Fig. 6).

Current understanding and potential negative sequelae: The lucent foci are frequently located on the palmar surface of the distal phalanx, near or dorsal to the impar ligament attachment. They are actually periarticular/associated with the distal interphalangeal synovial fluid in the palmar, distal recess of the joint. The etiology is unclear, potentially representing impar enthesopathy, but may also be associated with synovitis of the distal interphalangeal joint. They must be differentiated from small osseous cyst-like lesions extending distally from the articular surface of the distal phalanx into the body of the distal phalanx.[13] The lateromedial view can be useful to evaluate the palmar surface of the distal phalanx for further evidence of osseous resorption (Fig. 6B).

Proximal Tibia Lucency at the Cranial Medial Meniscotibial Ligament Attachment

Radiographic description: There is lucent focus at the base of and slightly medial to the intercondylar eminence of the tibia. This is best seen on the caudocranial view (Fig. 7A) but can be further characterized on the lateromedial (Fig. 7B) and caudolateral to craniomedial oblique view and the flexed views of the stifle (flexed lateromedial, flexed lateral oblique).

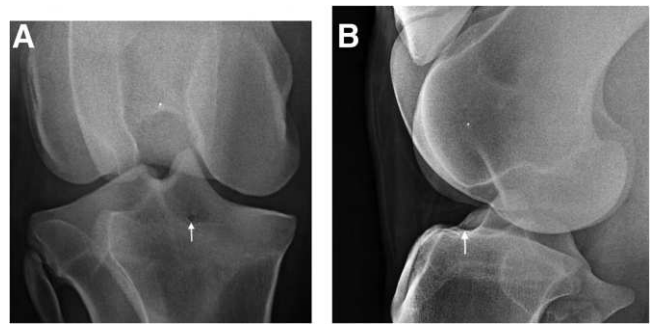


Fig. 7. A, Caudocranial view of a stifle. Round lucency of the proximal tibia distal to the base of the medial intercondylar eminence (arrow) at the attachment site of the cranial medial meniscotibial ligament. B, Lateromedial view of the stifle featured in A. The round lucency is at the base of the cranial margin of the medial intercondylar eminence (arrow).

Current understanding and potential negative sequelae: This lucency corresponds to either previous or ongoing bone resorption at the enthesis of the cranial medial meniscotibial ligament. This should be differentiated from lesions of the caudal tibial plateau, including the entheses of the caudal meniscal ligaments and caudal cruciate ligament.[14] This finding can be an unsettling radiographic abnormality that varies in imaging characteristics from faint to very lucent, smoothly margined to irregular, and small to large. Although this is occasionally an incidental finding, it is recommended to carefully examine the joint for other evidence of joint disease that could be secondary to intracapsular soft tissue injury. This should be related to the clinical examination of the region and, if indicated, ultrasound of the stifle.

Ulnar Carpal Bone Axial Lesions

Radiographic description: There are abnormalities of the axial margin of the ulnar carpal bone that may include osseous cyst-like lesion or fragmentation with a fragment bed (Fig. 8).

Current understanding and potential negative sequelae: This is an uncommon radiographic finding in an uncommonly radiographed region (in sport horses). The abnormality is near to or associated with the attachment of the lateral palmar intercarpal ligament on the ulnar carpal bone and could be due to avulsion fracture,[15] osseous cyst-like lesions, or normal anatomic variation[16] but is typically clinically insignificant. This lesion was the most common carpal lesion in pre- and postsale radiographs of Thoroughbred yearlings in one study, affecting approximately 20% of horses.[17] Similar to the described proximal tibial lucency, given its juxta-articular/articular location, this type of radiographic finding should prompt further

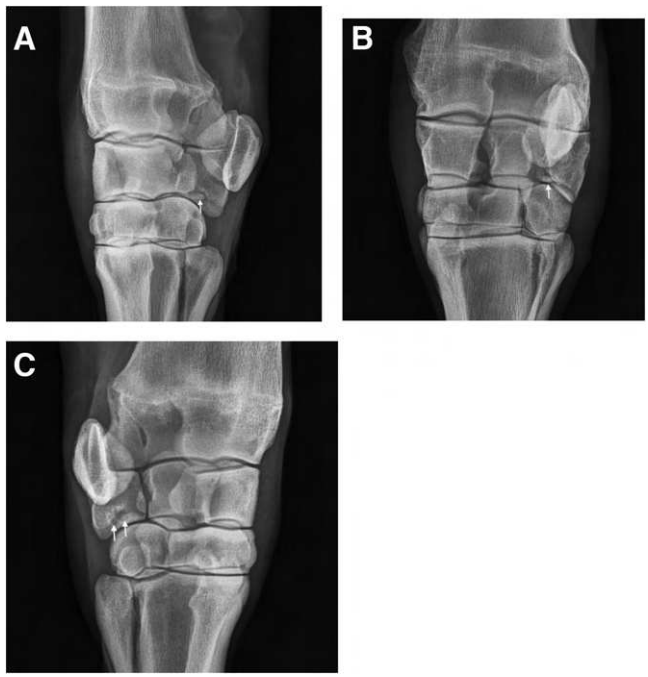


Fig. 8. A, Dorsolateral to palmaromedial oblique view of a carpus. A smoothly margined ovoid fragment is present in association with the distal, axial, and palmar aspect of the ulnar carpal bone (arrow). B, Dorsopalmar view of the same carpus in A. The fragment is identified at the distal, axial margin of the ulnar carpal bone (arrow). C, Dorsolateral to palmaromedial oblique view of a carpus. Irregularly margined lucent regions with sclerotic rims are present in the distal, axial, and palmar aspect of the ulnar carpal bone (arrow). In this horse, a fragment is not identified.

evaluation of the radiographs for evidence of joint disease.

Third Metatarsal Bone, Plantar, Lateral Surface Prominence

Radiographic description: There is an oblong osseous plateau on the plantar, lateral, proximal aspect of the third metatarsal bone, often abutting the tarsometatarsal joint (Fig. 9). This is best identified on the dorsoplantar view.

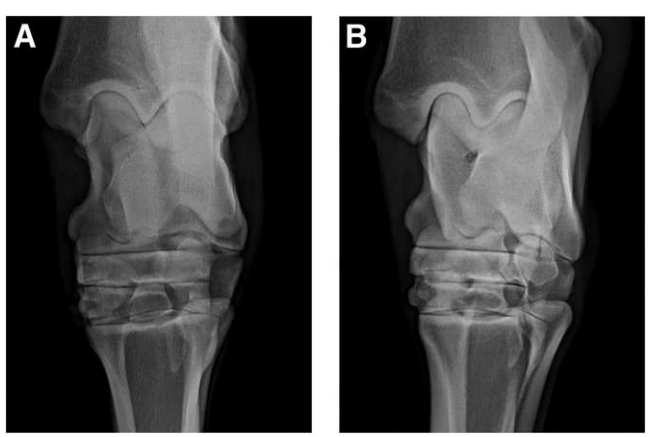


Fig. 9. A, Dorsoplantar radiograph of a tarsus. A well-demarcated, oblong region of increased opacity is present in association with the plantar, lateral, proximal aspect of the third metatarsal bone. B, Dorsolateral to plantaromedial oblique radiograph of the same tarsus featured in A. The region of increased opacity is seen as a prominence on the plantar surface of the third metatarsal bone.

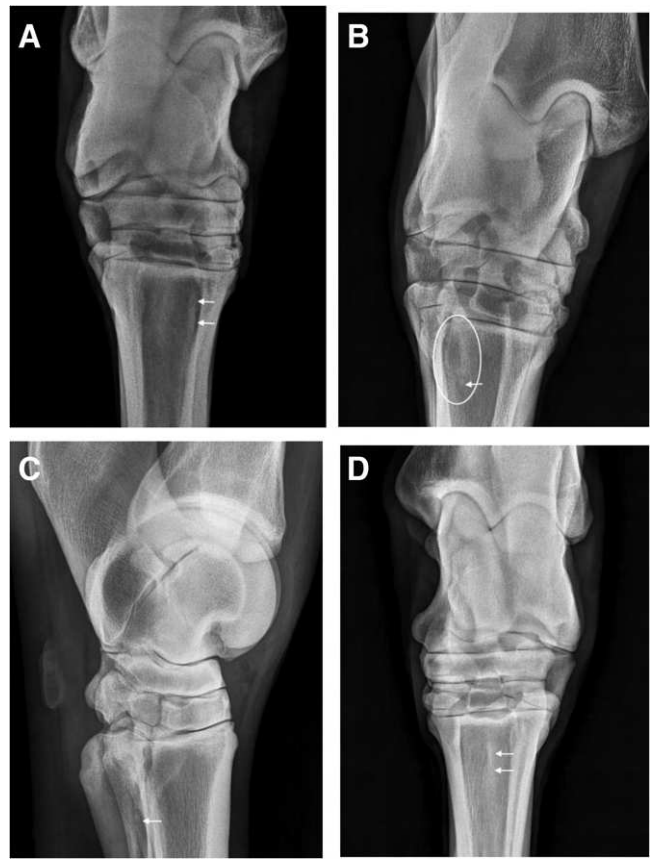


Fig. 10. A, Dorsoplantar radiograph of a tarsus. There is variable opacity in the proximal aspect of the third metatarsal bone. A linear region of increased opacity (arrow) is present along the proximal, axial margin of the second metatarsal bone. This is most often associated with new bone formation along the margin of the suspensory ligament (third interosseous muscle) origin. B, Dorsal 10° lateral to plantaromedial oblique of a tarsus. There is variable opacity of the proximal, lateral aspect of the third metatarsal bone with a separate focus of increased opacity (arrow). C, Lateromedial radiograph of the horse featured in B. The separate focus is displaced from the plantar surface of the third metatarsal bone and likely represents dystrophic soft tissue mineralization or an avulsion fragment (arrow). D, Dorsoplantar radiograph of a tarsus. A linear region of increased opacity is present between the medial and lateral aspects of the origin of the suspensory ligament (third interosseous muscle). This can be associated with bone proliferation in a plantar dimension or appear relatively opaque due to adjacent resorption.

Current understanding and potential negative sequelae: This is a not yet described or poorly described anatomic feature of the third metatarsal bone. It is near, but usually proximal to, the origin of the proximal suspensory ligament. It can be misinterpreted as trabecular bone sclerosis associated with the origin of the suspensory ligament and lead the reviewer to believe there is suspensory enthesopathy, when in fact it is most likely an incidental finding. This finding must be differentiated from suspensory origin disease.

Third Metatarsal Bone, Proximal Suspensory Enthesopathy (Third Interosseous Muscle Origin)

Radiographic description: There is alteration in bone quality at the origin of the suspensory ligament on the proximal, palmar/plantar metacarpal/metatarsal bone. The alteration may manifest as lucency, sclerosis, and/or a ridge of bone proliferation along the abaxial margin of the suspensory ligament or between the medial and lateral aspects of the origin of the suspensory ligament (Fig. 10A–C).

Current understanding and potential negative sequelae: Osseous remodeling and modeling is seen with proximal suspensory enthesopathy/desmopathy,[18] and it indicates either prior or ongoing enthesis abnormalities. Occasionally, sound horses can also have these radiographic changes.[19] The identification of abnormalities at this location is important and should prompt further investigation of the suspensory ligament either clinically or with ultrasound. Moreover, in the case of a sound horse, it should pique awareness of the potential for prior surgery in the region. The pattern of osseous changes may be helpful in interpretation, with one study finding that multifocal rather than diffuse sclerosis was only seen in horses with proximal suspensory desmitis.[20]

3. Conclusion

While experience has found some of these findings to be of limited clinical significance, others require careful consideration based on the horse's history and intended use. The paucity of scientific literature including these radiographic findings presents an opportunity for future longitudinal studies, most importantly related to any impact on long-term performance.

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.

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Is the Fetlock the New Foot?

Laura Faulkner, VMD

A diagnosis of bony pathology of the fetlock joint, subchondral or otherwise, can often be made using field radiography. Frequent acquisition of both standard and nonstandard radiographic projections will increase the practitioner's familiarity with obtaining optimal images and with interpretation of these images. Author's address: Watermark Equine, 103-107-109, 79 Danbury Road, Ridgefield, CT 06877; e-mail: laura@watermarkequine.com. © 2023 AAEP.

1. Introduction

Radiography has long been recognized as a mainstay diagnostic technique for evaluating the metacarpophalangeal and metatarsophalangeal (fetlock) joints for field practitioners. Standard and nonstandard radiographic projections of the fetlock joint provide a safe, readily available diagnostic test for the identification of bone injury involving these joints. However, there is increasing recognition of the importance of repetitive stress-induced injury to the subchondral bone of the fetlock region.[1–4] The majority of the literature has focused on advanced imaging techniques, including nuclear scintigraphy, computed tomography, magnetic resonance imaging, and more recently positron emission tomography to substantiate a subchondral bone injury diagnosis.[1,4–9] While advanced imaging may provide valuable information about subchondral bone injuries to the fetlock joint, it is not always readily available or affordable.

Radiographic characterization of fetlock subchondral bone injury is possible, however, given the acquisition of an adequate number of appropriately positioned radiographic projections. A "standard" set of radiographs is not established but by convention typically includes 4 views plus or minus a flexed lateromedial view. Taking additional nonstandard views beyond the 4 views typically described (dorsal 30° proximal-palmarodistal oblique view, weight-bearing lateromedial view, dorsal 20° proximal 45° lateral to palmaromedial oblique view, and dorsal 20° proximal 45° medial to palmarolateral oblique view) can greatly aid such a diagnosis.[10] Nonstandard projections of the fetlock include additional variable angle dorsal proximal to palmaro- (plantaro-) distal views, and a dorsoproximal to dorsodistal skyline view, and the use of contrast arthrography.[10] This type of radiographic study can also easily be augmented in the field with the use of ultrasound, which can be useful for examination of the dorsal cartilage surface of distal metacarpal (MC) and metatarsal (MT) III, as well as for information about soft tissues and their attachments in the region.

Sport horse practitioners are increasingly recognizing the importance of the fetlock region as a source of lameness, regarding it as a rival for the foot in causing performance issues. This paper will describe how to make a diagnosis of bony pathology of the fetlock using field radiography, including both the standard radiographic projections and nonstandard radiographic

NOTES

projections that have been developed to better evaluate common areas of subchondral bone injury in the sport horse.

2. Technique

Preparation

While no special preparation is necessary to acquire radiographic views of the fetlock region, routine preparation of the horse for radiography includes removing any dirt or gross debris from the skin surface of the fetlock region. Depending on patient compliance and pain level, sedation may be required to acquire optimal radiographs. For all radiographs of the distal limb, particularly when the evaluation of joint space is anticipated, the horse should be standing squarely, with equal weight on the medial and lateral aspects of the limb. Generator settings and film focal distance are equipment dependent, and manufacturer or user protocols should be used. External radiographic markers are strongly recommended to annotate the lateral (or dorsal) aspect of the limb. Many digital radiographic markers are not accurate, particularly when acquiring nonstandard projections.

Anatomy

Prior to beginning the radiographic examination, it is important to consider the anatomy of the fetlock joint and the common sites of fetlock joint-related pathology. The fetlock area may appear simple in comparison with other regions, involving only 4 bones (the third metacarpal or metatarsal bone, the proximal phalanx, and the medial and lateral proximal sesamoid bones); however, as in any situation where one is translating 3-dimensional objects into a 2-dimensional rendering, subtle variations in positioning can make a significant difference in the ability to detect lesions on radiographs. For example, dorsopalmar, dorsoplantar, and oblique projections taken with a flat beam angle will superimpose the proximal sesamoid bones over not only the MC III or MT III condyle but also over the articular surface. Additionally, because of the curving nature of the distal MC III or MT III condyle, a steeper dorsopalmar or dorsoplantar projection will highlight a more dorsal portion of the distal condyle or articular margin than will a flatter beam angle (Fig. 1). Therefore, it is important to be aware of common locations of pathology in the type of horse being imaged.

In racehorses, the primary area of interest for subchondral injury of distal MC III or MT III is the palmar or plantar aspect of the condyle, and special radiographic projections were developed for evaluation of this region.[5,11,12] In sport horses, distal MC III lesions are often located dorsally and are thus better identified on nonstandard projections such as a steeper dorsopalmar (plantar) view or a dorsoproximal to dorsodistal skyline view.[1,10] Injuries of the sagittal groove of the proximal phalanx in the forelimbs of sport horses are also typically located centrally or dorsally.[13] Lesions of the medial condyle of distal MC III are more prevalent than lesions of the lateral condyle in both sport horses and racehorses.[5,6] In all cases of fetlock joint-related lameness in sport horses, it is recommended to obtain both the standard and nonstandard radiographic views described below. However, differential diagnoses in a particular case may warrant tailoring additional views to highlight a specific location.

Standard Radiographic Views of the Fetlock Joint

While the number of views and radiographic beam angle projections included in a standard fetlock study may vary depending on region and practice, in general, 5 views are taken as standard radiographic projections of the fetlock joint in sport horse practice. These include the following:

- Dorsal 30° proximal-palmarodistal oblique (D30° Pr-PaDiO) view
- Weight-bearing lateromedial view
- Flexed lateromedial view
- Dorsal 20° proximal 45° lateral to palmaromedial oblique (DLPMO) view
- Dorsal 20° proximal 45° medial to palmarolateral oblique (DMPLO) view

Dorsal 30° Proximal-Palmarodistal Oblique and Dorsal 30° Proximal-Plantarodistal Oblique Views

Dorsopalmar and dorsoplantar views are obtained parallel to the sagittal plane of the limb and can be obtained with varying degrees of proximal to distal beam angle (Fig. 1). The standard dorsopalmar or dorsoplantar (D30° Pr-PaDiO or D30° proximal-plantarodistal oblique) view uses 30° of down-angle in order to project the proximal sesamoid bones above the articular margin, allowing a less impeded evaluation of the distal MC III or MT III condyles and articular margin.

Weight-Bearing Lateromedial and Flexed Lateromedial Views

Standing and flexed lateromedial views are obtained perpendicular to the sagittal plane of the limb. In some horses, the coffin and fetlock joints have differing sagittal planes due to variation in conformation, and so positioning for lateromedial views of one may not be appropriate for the other. In addition, the person holding the limb in flexed position for the flexed lateromedial view must take care to hold the limb perpendicular to the radiographic detector and generator. A correctly obtained lateromedial view should completely align the medial and lateral condyle of MC III or MT III (Fig. 2). Because of superimposition, lesions in the subchondral bone of the condyle may be difficult to identify, but lesions of the sagittal ridge are readily evident.

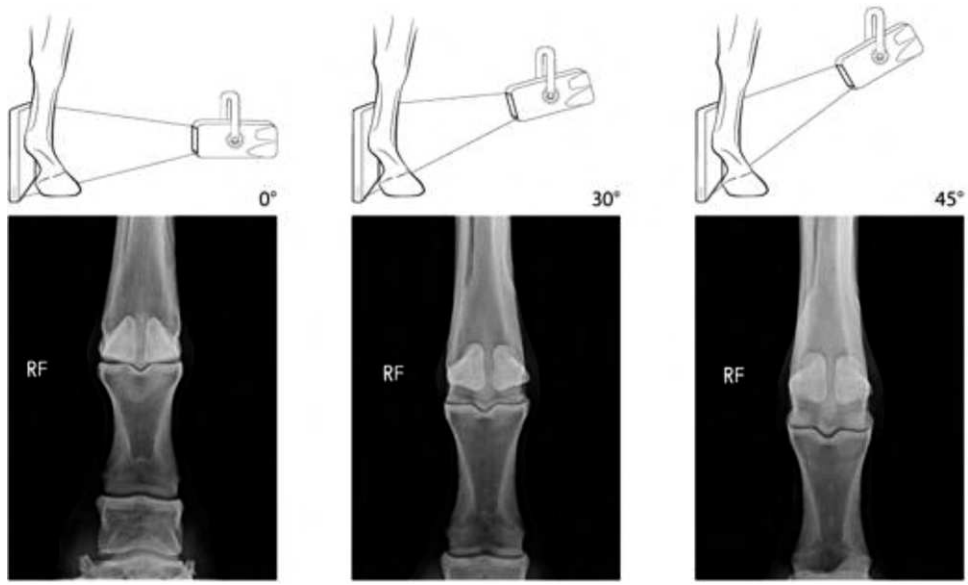


Fig. 1. Left, Illustration of positioning to obtain a dorsopalmar radiograph (0° of down-angle) and a corresponding normal radiograph. Center, A dorsal 30° proximal-palmarodistal oblique with a corresponding normal radiograph. Right, A dorsal 45° proximal-palmarodistal oblique with a corresponding normal radiograph. *Reprinted from AAEP Proceedings, 2016.*

Dorsal 20° Proximal 45° Lateral to Palmaromedial Oblique and Dorsal 20° Proximal 45° Medial to Palmarolateral Oblique Views

The oblique views, DLPMO and DMPLO, are typically obtained as dorsal 15° to 20° proximal 45° lateral (or medial) to palmar/plantar distal medial/lateral. This view is slightly less steep (15° to 20°) than the dorsopalmar D30° Pr-PaDiO view (30°) from proximal to distal. The view is positioned halfway (45°) between a dorsopalmar and a lateromedial view. Proximal to distal beam angulation at 15° to 20° projects the proximal sesamoid bones sufficiently away from the joint margin. The 45° angulation from dorsal to lateral (or medial) separates the proximal sesamoid bones and MC III or MT III condyles. Therefore, in a DLPMO view, for example, this separation means the lateral sesamoid and lateral metacarpal condyle can be viewed with minimal superimposition (Fig. 3). However, these views may obscure dorsal, proximal P1 fragments when such fragments occur in an axial location.



Fig. 2. Normal lateromedial radiograph, showing proper alignment of the lateral and medial distal MC III condyles.

Nonstandard Radiographic Views of the Fetlock Joint

The following views and techniques are not routinely obtained in radiographic studies of the fetlock joint in sport horse practice. When made consistently, these nonstandard views allow for evaluation of specific regions of the curving subchondral bone surface that are often implicated in fetlock joint-related lameness in the sport horse. A retrospective study of radiography of subchondral bone lesions in sport horses showed that in 25% of cases, the subchondral lesion was only evident on nonstandard views, and in an additional 40% of cases, the lesion was best seen on nonstandard views.[10] Finally, contrast arthrography augments the routine projections and allows for evaluation of the cartilage surface.

Additional Dorsal Proximal to Palmaro- (Plantaro-) Distal Views

Due to the curving nature of the MC III or MT III condyle, varying the proximal to distal beam angle changes the region of the joint through which the beam is tangential (Fig. 1). A steep (45° to 60° proximal to distal) beam angle is tangential to the dorsal portions of the fetlock joint. A flat beam angle is tangential to the most distal portion of the condyle near the transverse ridge. As the exact lesion location



Fig. 3. Normal dorsal 20° proximal 45° lateral to plantaromedial oblique radiograph. Note the separation of the medial and lateral proximal sesamoid bones and the projection of the proximal sesamoid bones about the joint margin and distal metatarsal condyles.

(subchondral bone lesion or other) is usually not known in advance of obtaining radiographs, multiple dorsopalmar or dorsoplantar views should be obtained with varying proximal to distal angulation—for example, a D20° Pr-PaDiO view, a D30° Pr-PaDiO view, and a D45° Pr-PaDiO view. The sport horse practitioner should keep in mind the more dorsal location of many distal MC III and proximal P1 lesions, however, and be aware that the lesions are likely to be best appreciated on steeper views.[1,10,13]

Dorsoproximal to Dorsodistal Skyline View

The dorsoproximal to dorsodistal view, or skyline view, aids in the diagnosis of subchondral lesions of distal MC III. This view is obtained by holding the limb in a forward and flexed position, with the plate underneath the flexed fetlock and the radiographic beam oriented in a nearly vertical direction (Fig. 4). The view is difficult to perform in the hindlimb because the abdomen of the horse can be in the way and the horse often resents having the hindlimb brought forward and flexed at the fetlock. The value of this view is to present the dorsal portion of the articular surface of MC III with minimal superimposition of additional structures. As detailed above, the more dorsal and medial locations of many injuries to distal MC III should be kept in mind when taking these projections.

Contrast Arthrography

Positive contrast arthrography aids in the indirect evaluation of the cartilage within the fetlock joint.[14] While contrast arthrography is not essential to the diagnosis of subchondral bone lesions of the fetlock joint, it can provide additional valuable information about communication between the subchondral bone

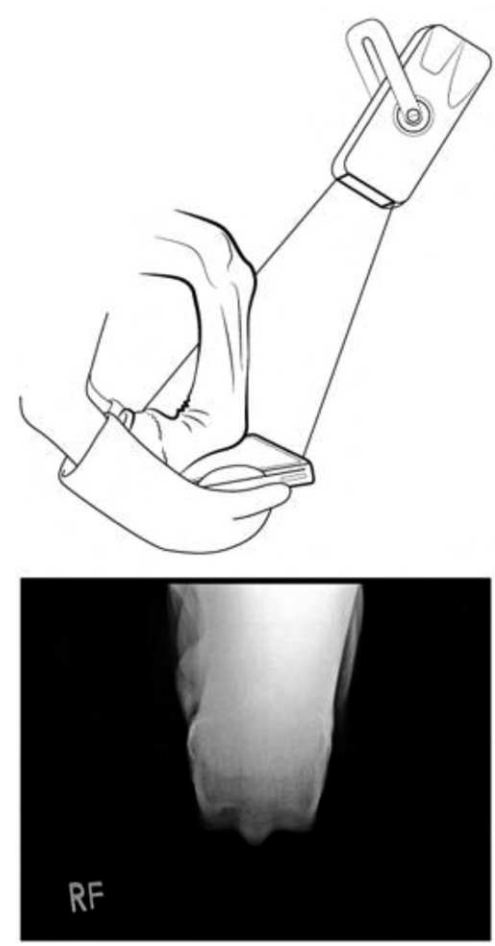


Fig. 4. Illustration of positioning to obtain a dorsoproximal to dorsodistal skyline view with a corresponding normal radiograph. *Reprinted from AAEP Proceedings, 2016.*

lesion and the fetlock joint, which in turn can direct the treatment plan and prognosis. In order to perform arthrography, non-ionic, sterile, iodinated positive contrast media[a] diluted 1:1 with sterile saline is injected into the joint in an aseptic manner.[14] A total volume of 12 to 15 mL should be injected. After injection, flexion and extension of the joint should be performed in order to allow for even distribution of the contrast media. Radiographic projections should be obtained immediately and then again after 1 to 2 minutes. The dorsopalmar or dorsoplantar projection at varying proximal to distal beam angles and the skyline projection are useful for further characterization of subchondral bone lesions of the fetlock joint (Fig. 5).

3. Summary

A diagnosis of bony pathology of the fetlock joint, subchondral or otherwise, can often be made using field radiography. Frequent acquisition of both standard and nonstandard radiographic projections will increase the practitioner's familiarity with obtaining optimal images and with interpretation of these

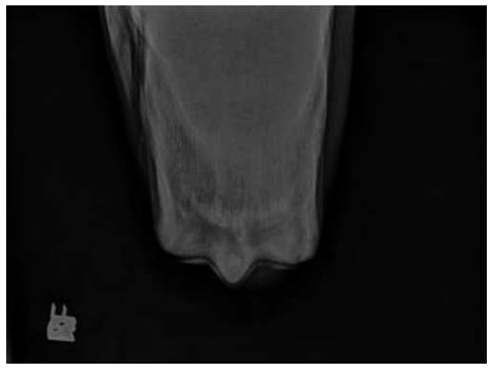


Fig. 5. Dorsodistal skyline contrast arthrography view of a case with a subchondral lesion of medial MC III. A radiolucent line representing soft tissue is present overlying the subchondral lesion. This line indicates either cartilage or other reparative soft tissue is overlying the defect.

images. Careful attention to positioning and angle makes a substantial difference in the ability to make a good radiographic evaluation of the fetlock joint. In the instance of a negative result from radiographic screening, repeat radiographs obtained at a later time may yield new information.

Acknowledgments

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Declaration of Ethics

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

Conflict of Interest

The author has no conflicts of interest.

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[a]Omnipaque, MWI, Boise, ID 83705.

Radiographs and Risks in Equine Practice

Nina Mouledous, DVM

Equine veterinarians practice in a difficult environment with a public that has increasingly unrealistic expectations of perfection in services provided. Accordingly, the equine veterinarian has a higher risk of facing either an administrative licensing complaint or civil litigation, regardless of whether there is any merit to the complaint. Therefore, it is more important than ever for veterinarians to develop and follow reasonable imaging protocols and techniques. After years of reviewing claims of veterinary malpractice related to deficient imaging studies, the author has identified key components of radiograph procedures and components that would constitute best practices. These include practicing good medicine by using state-of-the-art, standardized imaging techniques and protocols; preserving images as part of the medical record when appropriate; and investing in radiographic consulting services as part of a diagnostic assessment protocol if warranted in certain situations. Employing these suggestions as well as other practice standards in the veterinary community decreases the potential for malpractice claims and lawsuits that could result in liability exposure and damages. The goal of this presentation is to raise awareness on imaging protocols and to provide suggestions for equine practitioners to help prevent image-related complaints that may lead to allegation of questionable veterinary care, whether in the form of a malpractice claim or a licensure board complaint. The paper will focus on radiologic imaging; however, the same information provided can be used for any patient imaging diagnostic tests such as ultrasound, computed tomography, and magnetic resonance imaging studies. Author's address: 8510 Main Street, Downers Grove, IL 60515; e-mail: nina.mouledous@avmaplit.com. © 2023 AAEP.

1. Introduction

The American Veterinary Medical Association's Professional Liability Insurance Trust (AVMA PLIT) program receives thousands of potential or actual claims every year. Although only a small percentage of these claims are equine-specific incidents, due to the relative value of the animals involved, equine claims can result in higher exposure than companion animal claims. More importantly, equine malpractice complaints end in litigation more often than claims involving companion animals for several reasons, including the potential higher value of the patients.[1]

To help illustrate this, a closed equine claim related to imaging will be provided and reviewed. In addition, a recent paper on recordkeeping highlighted the AVMA PLIT's four key principles to help veterinarians minimize the likelihood of malpractice claims and board complaints. The principles are practicing good medicine, keeping good medical records, keeping people and patients safe, and practicing good communication.[2] The first principle, practicing good medicine, can be effectively accomplished by using state-of-the-art, standardized imaging techniques and protocols, which can help prevent complaints that lead to liability allegations.

NOTES

It is important to note that recommendations are presented to help reduce the number of complaints and potential legal claims. When discussing claims, it is important to recognize that clients' "complaints" do not equate to legal or administrative liability. That said, even in cases where there is no liability, taking steps to avoid claims helps avoid the professional inconvenience and stress that can accompany a legal proceeding.

2. Causes

Allegations of improper or incomplete prepurchase exams (PPEs) are one of the most common claims against equine practitioners.[3] Litigation is more common in claims related to a PPE when compared to the other equine claim causes and species disciplines.[4] While PPE claims involve varying issues, many of these claims are related to the veterinarian's interpretation of the radiographic images regarding whether the veterinarian identified all abnormal radiographic findings. There are certain aspects of this type of claim that are "black and white," meaning if radiographic findings are noted by the veterinarian or not. For example, if a straightforward lesion on a radiograph was not identified or not disclosed as an abnormality, regardless of the significance, this could be difficult to defend. For simplification, this type of allegation will be referred to as "missed radiographic lesions" (MRLs). Equally as important is the need to note the radiographic findings in the medical records, as this would prevent a client from later disputing that they were advised of the lesion.

Analysis of past equine malpractice claims shows most of these PPE claims involved horses that demonstrated some degree of lameness after the sale. The allegations related to lameness issues can further be broken down into specific accusations related to the exam incident. These postsale lameness issues often involve a radiographic component, specifically an allegation of undisclosed radiographic abnormalities.[3] In other words, the client had not been informed of the abnormality, also known as nondisclosure. Clients who become aware of MRLs may then allege that the purchase would not have proceeded had they received knowledge of the lesion(s) through the PPE report.

Another subset of these types of claims are radiographic findings the veterinarian recognized but believed in their professional judgment were not "significant" and therefore did not advise the client of the findings. This can be problematic because, in many jurisdictions, the determination of what is "significant" is often subjective to the owner of the horse. Accordingly, there have been claims where a veterinarian's professional judgment as to the significance of a radiographic finding was not a complete defense due to the claimant's individualized subjective risk tolerance. This again emphasizes the importance of identifying radiographic findings in medical records and then discussing the findings with the client.

A recent internal review of claims was performed to assess the frequency and severity of PPE claims over a recent 5-year period. The data found MRLs as the most common allegation in PPE claims. The data also demonstrated an increase in the number of these claims filed on an annual basis. Finally, the data confirmed MRLs were the costliest type of PPE claim to resolve, accounting for a majority of the total PPE payouts.[5]

While MRLs are the most common cause of PPE complaints, there are varying underlying causes for lesions not being reported. First, it is important to note there is no indication that veterinarians intentionally withhold findings for an improper purpose such as to conceal a lesion. Rather, the cause is often related to circumstances of the review process such as seller or buyer pressures demanding stall-side immediate opinions, resulting in an inadvertent omission of a finding. In addition, the physical environment can impact the accuracy of a review. Images that are read stall-side in daylight during the PPE may not always undergo a re-review in a methodical manner indoors in a dark setting later. Veterinarians involved in these cases often acknowledge the hurried review and agree that the lesions were missed and later become apparent once re-reviewed under improved environmental conditions. Having a built-in re-review protocol in place when reviewing images out in the field may aid in identifying abnormalities.

Additionally, some incidents are related to veterinarians' opinions that the abnormalities are within normal limits and therefore are deemed "not significant," eliminating the need to disclose or record the findings. Due to the vast difference in opinions within equine radiographic findings, best practices are to acknowledge any abnormality verbally and in the medical record or PPE report even if the reviewer perceives it as not significant. Taking this step of documenting all findings, regardless of the veterinarian's opinion on their significance, can help support that the reviewer did not miss the abnormalities.

Finally, failing to identify any "insignificant" lesions on PPE films that developed into significant pathology later could be cause for image-related malpractice claims. Examples include a bone lucency developing into a fracture, a bone spur developing into a bone chip, or a cyst developing into an osteochondritis dessicans lesion. Often, these previously considered nonclinical lesions develop into significant pathology that can result in lameness and have an impact on serviceability and resale value. These in turn can prompt client complaints. Often the development of these lesions cannot be predicted. However, noting findings and discussing them with the client is the best method of avoiding a future potential claim.

Other causes of nondisclosure and MRLs include errors in reviewing the radiographs, a lack of experience and expertise by the veterinarian, and unfamiliarity with normal anatomy and radiographic lesions. As noted in the *Atlas of Diagnostic Radiology of the Horse Part 1*, "Interpretation of radiographs is based

on systematic film reading, clinical knowledge and experience."[6] Also, Dr. D. M. Dutton's recent abstract reports that "knowledge of normal radiographic anatomy is imperative in making a proper radiographic diagnosis and thus in being able to identify abnormal findings."[7]

3. Roles

It is critical for veterinarians to define the scope of their involvement when reviewing radiographs taken by other veterinarians. Equine practitioners can potentially expose themselves to liability when providing radiographic services for a PPE on behalf of the buyer's primary veterinarian (PDVM). This situation usually arises when the buyer requests the veterinarian performing the PPE take the radiographs and then send the images to the PDVM for review. Often, it is unclear what the veterinarian's role is in these situations. Does the buyer also expect the veterinarian taking the images to provide an opinion in addition to the PDVM's opinion? Equally as important is whether the PDVM is aware of any opinions the veterinarian taking the images may have provided. It is important in these situations to clarify the roles of each veterinarian involved, particularly when it comes to the matter of who will be providing the review. Best practices would be that the veterinarian taking the radiographs secures a copy of the PDVM radiographic report for their medical files along with the PPE report and ensures the buyer receives the PDVM report in the event of miscommunication between the buyer, the PPE veterinarian (taking the images), and the PDVM. Everyone involved in the PPE should be clear on everyone's expectations and understand the scope of services being provided. A written consent form outlining the roles and expectations could prove beneficial if a situation arises later.

4. Miscommunication Closed Claim

A closed PPE malpractice claim involved a communication breakdown between the PPE DVM and the buyer who requested the PPE DVM send the PPE report, radiographs, and radiographic interpretation to their PDVM. The PPE DVM examined a 10-year-old Quarter Horse gelding for the buyer and found positive hock and stifle flexion tests. Radiographs found mild degenerative joint disease in the lower hock joints and degenerative changes in the front navicular bones. Nothing further was requested of the PPE DVM by the buyer, and the results were not discussed. The PPE DVM sent the PPE report to the PDVM. Ten days later, the horse was lame. After the PDVM examined the horse and reviewed the PPE films for the first time, abnormalities related to the lameness were noted. The PDVM was not asked by the buyer to review the PPE report prior to the sale. The buyer filed a small claims lawsuit against the PPE DVM for the purchase price, shipping, and medical expenses, totaling $22,285. The buyer alleged they were not informed of the abnormalities. The PPE DVM was under the impression that the buyer's PDVM was responsible for determining the serviceability of the horse based on their communication with the buyer before the exam. The court ruled in favor of the PPE DVM based on the PPE DVM's deposition and communication log.

5. Other Causes

Many situations involving radiography and client complaints are related to PPEs. However, other image-related causes for claims have been identified. Another image-related cause for equine malpractice claims includes mislabeling of images. Correct labeling of images is important for patient identification not only for medical purposes but also for legal purposes.[4] When images lack complete information including the name of the patient, client, date, veterinarian, clinic, limb, and location, errors can occur. Mislabeling of images has resulted in surgeries on the wrong limb or body part. Additionally, image mislabeling has been the cause of inadmissible evidence in court cases and licensing board citations due to medical recordkeeping violations, which are discussed in detail in the next section.

A delay in diagnosis and treatment due to failing to perform radiography in a timely manner is another image-related situation that could instigate a client complaint. A common example of this cause would be extended treatment of a foot abscess and radiographs later diagnosing laminitis or a third phalanx bone fracture, resulting in a delay in diagnosis and appropriate treatment.

Other situations regarding radiography and complaints have occurred due to incomplete radiographic studies (only taking one view of a joint), poor image quality, and improper labeling resulting in the inadequate studies for expert reviews.[4] Software malfunctions resulting in lost images have been problematic issues involving client complaints. In these situations, the veterinarian may report the views were taken and reviewed stall-side but then were unavailable later from the software system when requested by the claimant or their attorney.

6. Medical Records

Another of the AVMA PLIT's four principles revolves around medical records and the need to maintain good documentation in practice. Dr. C. G. MacKenzie reported that "medical records are a necessary part of equine clinical practice and practitioners should be aware of all the medical, legal, regulatory, and ethical reasons for producing and maintaining good medical records in practice."[8]

It is important to understand the duties of equine practitioners as set out in state practice acts for licensure. State practice acts outline that complete medical records are to be maintained on patients. In some instances, there is a misconception that images are not part of the medical record or do not need to be included in the medical record. For example, below is

the veterinarian patient recordkeeping section of the Texas Veterinary Practice Act stating that images are part of the medical record:

The Texas Veterinary Practice Act

Current through Reg. 47, No. 6; February 11, 2022

Section 573.52 *– Veterinarian Patient Record Keeping* ***(a)*** *Individual records shall be maintained at the veterinarian's place of business, shall be complete, contemporaneous, and legible and shall include, but are not limited to:* ***(9)*** *any diagnostic images or written summary of results if unable to save image.*[a]

An online FAQ on medical record requirements for California licensed veterinarians informs that "radiographs are part of your medical records and therefore must be maintained for a minimum of three years after the animal's last visit."[9]

A last example, shown below, can be found in the Indiana Practice Act, which includes radiographs and sonographic images as part of the patient's medical record:

Sec. 5.5. (a) Each person who provides veterinary medical services shall maintain medical records, as defined by rules adopted by the board.

(b) Veterinary medical records include the following:

(1) Written records and notes, radiographs, sonographic images, video recordings, photographs or other images, and laboratory reports.[b]

In conclusion, the failure to include images in the medical record exposes a veterinarian to potential administrative liability from a state licensing board. Failing to archive and save images may also affect the defensibility of a malpractice claim involving imaging as clients may deny proper diagnostic images were obtained. Therefore, equine practitioners should assure images are preserved as part of the medical record where applicable and provide an assessment of the image review. Some state boards require veterinarians to maintain radiographs and interpreting reports whether stored in the cloud or in medical records. In addition, should a lawsuit arise, medical records including any imaging records could be part of the defense.

7. Opinions and Reliance

Providing opinions as to the content or significance of any radiographic findings can expose the veterinarian to potential liability depending on the completeness and the quality of the images reviewed. These situations can be formal or informal. Dr. Carolyn Arnold cautioned equine practitioners about the potential liabilities that can exist when attempting to render opinions on compressed images or incomplete sets of images. In her article, "Telemedicine and the Equine Veterinarian," Dr. Arnold noted that there are liability risks for interpretation of digital medical information sent informally to equine practitioners. She provided a specific example of several equine sports medicine specialists raising concerns about reading images that had previously been modified (compressed) or altered such that they could not magnify the image or change the contrast. Studies that did not include a complete set of views and proper labelling as to patient identity, date, and view made interpretation more difficult, thereby potentially increasing the risk of offering any opinion as to the condition of the subject horse. It is important to note that even providing a verbal opinion that a person might rely upon can create potential liability. This risk is only increased if the opinion is based on poor-quality images or less than complete images. If the veterinarian has any reservation as to the quality of the films, no opinion should be offered. Dr. Arnold advised veterinarians to review "Recommendations About Teleradiology" on the American College of Veterinary Radiology's website at acvr.org/page/teleradiologyguidelines for more information.[10]

Another cited article regarding opinions and quality of radiographs when reviewing other veterinarians' images indicates the concern for liability in the industry when providing recommendations under these situations. "Part of the problem of reading the radiographs is the quality of the radiographs," said Jim Becht, DVM, Dipl. ACVIM of Colorado State University. "If you don't know what you're doing (taking radiographs), you should leave your equipment in the car."[11]

8. Consultation

Radiology is an important diagnostic tool frequently used in equine practice. Equine practitioners who use radiography may consider investing in the implementation of a radiographic interpreting service as part of their radiographic diagnostic assessment protocols in certain situations such as PPEs and complicated cases. Radiology consultation can provide detailed, written interpretations of radiographs in conjunction with patient medical history. Interpretation of PPE images is also offered by some services.

Providing clients with prompt and visual expert radiology reporting can be a positive practice builder and an added value for veterinarians' clientele. It can give the practice timely, transparent, professional, and legitimate radiology test results and assure accurate assessments.

This value-added tool can also be used in a positive manner from a marketing perspective. By advertising expert radiographic review services on the practice website, in addition to the practitioner's assessment, veterinarians can assure clients their horses' radiographic interpretations are thoroughly reviewed and "stamped" with a specialist's opinion.

An overarching goal in equine practice is client complaint prevention, specifically with the intention of securing client satisfaction and decreasing the risks of malpractice claims, lawsuits, and board complaints. Providing an expert review with the radiographic studies can decrease client complaints, malpractice claims, and lawsuits when there are allegations of

missed radiographic diagnoses. Consider the fundamental principle "prevention is better than cure": "It is better to stop something bad from happening than it is to deal with it after it has happened."[12] A strategy used in legal arenas to support veterinarians' radiographic interpretations under scrutiny is to obtain an expert review. If an expert review is already in place, this can positively affect the defensibility of a veterinarian's case and can deter complaints and lawsuits. The plaintiff's attorney would then be tasked with finding another expert review to contradict the expert opinion already provided at the time of the veterinary incident in question. It has been shown that having more "sets of eyes" looking at each film significantly improve interpretation accuracy to the 95% percentile range.[13]

It is also worth noting that having a second set of eyes on radiographs can also improve patient care. For solo practitioners who may not have the benefit of readily available colleague opinions in the same practice, having a convenient second set of eyes can provide confident assessments and added value for their radiology services.

Additionally, consider the value added for PPE reports. Having an expert radiology report attached to a horse's PPE can only increase the value of that report for the impending sale and for future sales (added value for buyer) and help protect the veterinarian in the event of a complaint after the sale.

Finally, it is important to note that expert radiology reviews are not considered standard in equine practice for radiology services. However, offering the service to clients could be a consideration and allows the client to choose an additional review if desired.

9. Conclusion

Equine veterinarians, especially those performing PPEs can minimize client complaints related to radiology issues. After years of collecting data from reviewing PPE claims, the AVMA Trust has identified common trends and created tips on avoiding complaints and allegations of malpractice to help educate equine practitioners. The tips related to imaging include providing good-quality imaging with complete radiographic studies, obtaining additional documented opinions of image interpretations when possible, and providing the buyers with a final copy of the PPE report in a timely manner including videos, radiographs, and additional imagery. Consider sending a hard copy via certified mail to officially document receipt.[4]

Client complaints in equine practice are preventable, especially when it comes to radiology-related issues. Liability exposure can be minimized by practicing good medicine. Best practices include using state-of-the-art, standardized imaging techniques and protocols and preserving images as part of the medical record when appropriate. Equine practitioners may also consider investing in radiographic consulting services as part of their radiographic diagnostic assessment protocol for certain situations.

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.

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[a]Texas Veterinary Practice Act. Section 573.52.
[b]Indiana Veterinary Practice Act. Section 5.5.

How to Transfer Medical Images

Erik Berger, BA*; Alan Jacobson, RVT, CDIP; and Laura Ellison, RVN

Equine veterinary medicine relies heavily on diagnostic imaging to accurately diagnose a wide range of conditions in horses. Authors' address: 7405 Trans Canada Route #100, Saint-Laurent, QC, H4T 1Z2, Canada; e-mail: erik@asteris.com. *Corresponding and presenting author. © 2023 AAEP.

1. Utilizing PACS Solutions for Equine Veterinary DICOM Imaging

Seeking diagnostic opinions from specialized radiologists facilitates accurate and confirmed diagnoses. This is where the introduction of veterinary Picture Archiving and Communication Systems (PACS) plays an integral role by allowing different medical facilities to share images and information easily and accurately.

2. What Is a PACS Solution and DICOM?

A PACS is a digital system that manages the storage, retrieval, distribution, and presentation of DICOM images. DICOM, or Digital Imaging and Communications in Medicine, is a standard used for storing and transmitting medical images. It provides a common format for medical imaging equipment to communicate with each other and with PACS systems that store and manage the images. DICOM standards include protocols for image transmission, data structure, and data elements, as well as guidelines for how images should be displayed.

3. Why Is a PACS Solution Important for Managing and Transferring Images?

A PACS solution provides improved efficiency and productivity for equine practitioners. This technology allows for the quick and easy retrieval of images, reducing the time and effort required to access them. This ultimately leads to improved efficiency and productivity for veterinary staff needing to send studies/images as well as the veterinarians, specialists, and radiologists needing to receive them. Additionally, PACS solutions prevent people from "losing" images digitally by creating redundancy in the storage of images in the event of catastrophic hardware failure. Equine veterinarians mainly are concerned about losing images acquired by their various imaging modalities (e.g., radiographic, ultrasound [US], magnetic resonances imaging [MRI], computed tomography [CT], etc.). While the risk of losing data is a commonly reported concern by veterinarians, modern advancements in data transfer and management through a PACS solution with cloud-based architecture ensure that veterinarians no longer need to carry the technical burden of backing up and safeguarding their data for short and long-term storage.

A proper PACS solution also fosters better collaboration and sharing of medical images. With properly managed study/image data via a PACS solution, images can be easily shared between veterinary

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providers, allowing for better collaboration and improved/expedited patient care. Improved image quality is another leading factor in utilizing a PACS solution to transfer and send medical images. PACS solutions allow for the storage and retrieval of high-resolution images, leading to improved image quality and better diagnostic accuracy when received by a specialist and/or radiologist.

4. Transferring Images with DICOM

The process of transferring images from clinics to the cloud using DICOM compression and encryption is a crucial step in implementing a PACS solution. Compression algorithms are employed to reduce image size, facilitating internet transfer, while encryption ensures secure transmission of sensitive medical images. Additionally, PACS vendors offer integrated solutions through an Application Programming Interface (API), including Practice Management Software integrations and direct integrations with teleradiology service providers, which can further streamline radiology workflows and allow easy access to patient studies within different software solutions. These integrations offered by different PACS providers enable equine practitioners to select the best solutions for their specific needs, whether it's a local PACS, cloud based PACS, or a PACS solution that integrates with the clinic's existing software stack and teleradiology provider(s).

5. Financial Impact and Compliance

Another aspect to consider when utilizing a PACS system is the financial impact on the practice and potential cost savings associated with the type of PACS system being utilized. A PACS solution can help to reduce the costs associated with the storage and management of physical images, such as storage space (physical local server or if the data is hosted in the cloud). Lastly, a PACS solution will assist in compliance with regulations. PACS solutions are designed to meet regulatory requirements for the storage and handling of medical images, helping veterinary providers to comply with relevant regulations and long-term storage requirements. Additionally, PACS systems prevent people "losing" images digitally by creating redundancy in the storage of images.

In summary, utilizing a PACS solution for managing and sharing of DICOM images in equine veterinary practice can bring significant benefits to the practice. It improves efficiency, fosters better collaboration and sharing of medical images, improves image quality, and allows for cost savings. Furthermore, utilizing a PACS solution helps to ensure compliance with regulations and prevents the risk of digital loss of images. Equine practitioners should consider the different integrated solutions offered by various PACS vendors. These solutions can substantially enhance collaboration and allow clinics to integrate with different vendors. To fully benefit from the capabilities of a PACS system, it is important to understand the semi-technical process of transferring the images from clinics to the cloud using compression and encryption with DICOM. With the help of a PACS solution, equine practitioners can improve diagnostic accuracy and ultimately provide better care for their patients.

Acknowledgments

Declaration of Ethics

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

Conflict of Interest

Erik Berger serves as the General Manager of Asteris, a Veterinary PACS provider; Alan Jacobson serves as the Product Manager at Asteris, a Veterinary PACS provider; and Laura Ellison serves as a Technical Sales Representative at Asteris, a Veterinary PACS provider.

Diagnostic Imaging in the Prepurchase Examination: European Perspective

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There is no standardized set of radiographs for purchase examinations among the various countries discussed. These differences in the standard radiographic set are often historical and/or based on experience or breeding selections. Communication, including defining the expectations of the radiographic set to be taken at a purchase examination, is essential to ensure a smooth and successful transaction. Authors' address: Sporthorse Medical Diagnostic Centre. Hooge Wijststraat 7, 5384 RC Heesch, The Netherlands; e-mail: vanveggel@sporthorsemdc.com. *Corresponding and presenting author. © 2023 AAEP.

1. Introduction

Purchase examinations are an important component of the equine veterinary practice and, with the import and export of horses from all around the world, an international business. There are many differences between different countries and continents regarding the methods of performing purchase examinations. Open communication, including defining the expectations of the purchase examinations between the buying and the selling parties within the different countries, is essential to ensure a smooth and successful transaction.

In this talk, various countries within Europe and their ways of performing purchase examinations will be discussed with the focus on the radiographic component of the purchase examination. The "standard" purchase set of radiographs of the different countries will be discussed as well as the most common labelling and positioning.

Performing purchase examinations for the potential sale of horses is a common undertaking in equine practice. These purchase examinations are commonly used to identify pre-existing or potential problems/injuries that may affect the current or future performance and/or the intended use of the horse.[1] Purchase examinations allow the potential buyer to make an informed purchase decision,[2] and they are performed widely among various breeds and disciplines around the world.

Purchase examinations involve an anamnesis and a complete physical examination, as well as a thorough clinical examination (in hand, on the lunge, and, in some instances, under saddle). Often, a radiographic examination follows the clinical component of the purchase examination. This radiographic examination most commonly involves a radiographic set of the distal limbs and, more and more commonly, the vertebral column. Additional ultrasonographic examination, upper respiratory tract endoscopy, and/or bloodwork

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Table 1. Commonly Acquired Standard Set of Radiographs of the Limbs as Part of a Purchase Examination in Various Countries within Europe and the United States

	The Netherlands	Germany	Denmark	Belgium	Sweden	United States
FL foot	LM, DP60	LM, DP 45–60	LM, DP	LM, DP60	LM, DP60	LM, DP0, DP60 and skyline
FL fetlock	LM, DLPMO, DMPLO	LM	LM, DP	LM	LM	LM, DP, DLPMO, DMPLO
HL fetlock	LM (DP)	LM including the foot	LM	LM	LM including the foot	LM, DP
HL hock	LM, DP, DMPLO	LM, DMPLO, DLPMO	LM, DMPLO, DLPMO	LM, DP, DMPLO, DLPMO	DLPMO, DMPLO	LM, DP, DMPLO, DLPMO
HL Stifle	LM, CdLat oblique	LM, CdCr	CdLat Obl	LM	LM	LM, CdCr

Abbreviations: FL, frontlimb; HL, hindlimb.

may be requested and/or recommended. It must be noted that requirements and protocols for performing purchase examinations at auction sales and for breeding stallions and mares differ significantly from those associated with pleasure and performance horse disciplines.[3] There are also large differences among the protocols for performing purchase examinations between different countries specifically with regard to the standard projections of radiographs, labelling, and grading systems.

Open communication and clearly defined expectations and requirements for the purchase examination are vital for achieving a satisfactory outcome for both the seller and buyer.

Sharing material from the purchase examinations is now easy and quick. Clinical examination videos and all diagnostic imaging can be shared electronically. Preferably the diagnostic imaging is shared using DICOM (Digital Imaging and Communications in Medicine) format for both radiographs and ultrasonography as well as any advanced imaging, magnetic resonance imaging, computed tomography, or scintigraphy.

2. Method

Colleagues in the Netherlands, Belgium, Germany, Denmark, Spain, and Sweden as well as the United States were contacted to collect the "standard" set of radiographs which are commonly acquired in their countries. It must be noted that there is huge variability in the radiographs taken by different colleagues. Generally, more elaborate sets of images, often including ultrasound, are taken when evaluating high-level performance horses or sport horses. For the purpose of this article, colleagues were asked what was included in a standard set of radiographs, which are most commonly taken.

3. Results

The common set of radiographs taken are listed in Table 1 for the different countries where a standard set was defined.

The "standard" radiographic set in the Netherlands is focused on assessing juvenile osteochondral conditions and signs of degenerative joint disease in the joints that are radiographed. The standard radiographic set is often used as a screening tool for young horses as well as part of breeding program requirements. No marker is added to the radiographs, and this is not required as the viewing of the images is standardized and is projected on the radiographs as taken. On a right front (RF) or right hind (RH) radiograph, the medial aspect is on the right side of the image. On left front (LF) or left hind (LH) radiographs, the medial aspect is on the left side of the image. An example is shown in Fig 1 of the left and right front fetlocks. From the veterinary association, there is a grading scheme for the synovial fossa of the navicular bone, the degenerative changes of the fetlocks and hocks, as well as the appearance of the frontlimb proximal sesamoid bones. These are graded from 1-4, with 1 being the best grade and 4 being the worst grade. Within Table 1 in the list of radiographs from the Netherlands, DP is in brackets in the hindlimb fetlocks radiographs because originally it was not part of the standard set of the radiographs taken in the Netherlands but is now very commonly used.

For both Belgium and the Netherlands, the LM and DP60 or "oxspring," projection of the feet is done in the oxspring block and is therefore non-weight bearing as shown in Fig 2. In Belgium, a marker is placed lateral or dorsal. For Belgium, there is no official list of radiographs that are recommended by the association, but the above listed radiographs are commonly taken and are also taken for the stallion selection done at the university clinics. With respect to labelling, left front is LiV, right front is ReV, right hind is ReA, and left hind is LiA.

In Spain, as indicated by the Asociación de Veterinarios Equions de España, the number of radiographs is chosen by the buyer. The basic set involves 12–18 radiographs, intermediate 20–36, and extended 36–60. However, the veterinarian decides the number of radiographs chosen. With regard to labelling, the marker is lateral and dorsal/cranial.

The standardized German protocol of the radiological examination includes lateromedial views of the four distal limbs, upright pedal view (dorso proximal-

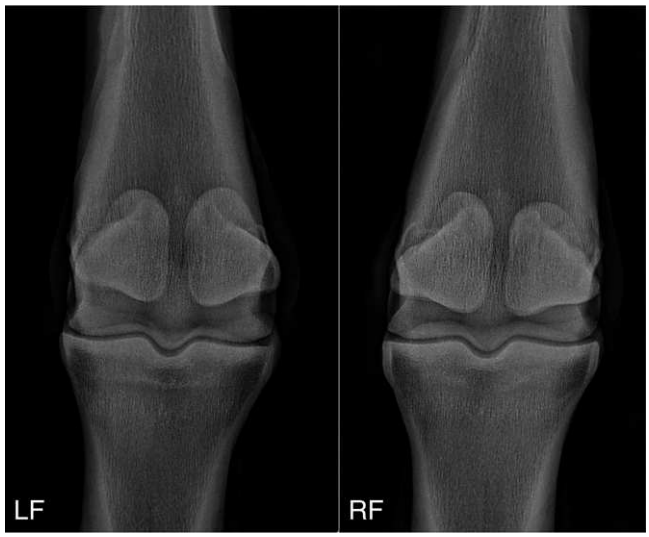


Fig. 1. As is commonly seen in the Netherlands, no laterality labeling is added to the radiographs. For the LF, the lateral is on the right and for the RF, lateral is on the left side of the image. The LF fetlock is on the left and the RF fetlock is on the right.

palmarodistal oblique) of each front foot, three views of each hock (0, 45 and 135 degrees), and 2 views of each stifle (0 and 90). As with every other country, additional radiographs can be added. For the LM of the distal limb, the fetlock is included as well as a separate view of the fetlock alone. Radiographic ratings were eliminated as of 2018. These ratings were previously noted to be categories I, II, III, and IV with in-between classifications, with a total of seven gradings. According to German radiographic guidelines, Röntgen-Leitfaden 2018, radiographs are evaluated as follows: radiographs with normal or anatomic variations are graded as "o.b.B." which translates to no findings. All findings that deviate from this are to be noted in the report. These are either findings where the risk cannot be assessed or findings that carry a lameness risk.

In Denmark, the marker (L) is placed lateral or dorsal. The extended set would include the neck and back lateral projections as well as the oxspring and skyline of the navicular bone. The common set of radiographs taken are listed in Table 1.

In Sweden, there is no official purchase examination radiograph list from the veterinary association or other groups. The most commonly performed set of radiographs by two large equine hospitals in Sweden is listed in Table 1. Labels are not required, but when placed are lateral or dorsal.

The labelling for the different countries is summarized within Table 2.

4. Discussion

As can be seen above, there is quite a variability in the radiographs that are taken within the different countries. The standard recommended sets within for example the Netherlands, Belgium, and Germany are commonly used for breeding selection and the detection of developmental lesions. Different gradings and criteria are present for these breeding selections. For the Netherlands, a grading system is used for which the grading is outlined by the KNMVD, the Dutch veterinary association. It must be noted that other remarks, for example, a cyst or subchondral bone lesion should be noted, but are not graded or scored during this examination. Many mares and stallions within the Netherlands also go through a PROK selection, which translated stands for Project Radiographical research. The predicate PROK is awarded to KWPN-horses that comply with the radiographical conditions of the studbook. As noted above, the radiographs are examined for the score of the navicular bone, proximal sesamoid bone, fetlock, and hock arthritis score as well as osteochondrosis of the hock, stifle, and fetlocks.

The grading scheme previously used within Germany was eliminated in 2018, as well as the recommendation for radiographing the back. The X-ray guide is based on 18 radiographs as listed above and was compiled by the X-ray Commission of the Society for Equine Medicine.[4]

As can be seen above, skyline projections, also known as PaPr-PaDi-Obl projection, of the navicular bone are not part of the standard radiographs assessment in any of the above European countries. Neither are oblique projections of the front feet (D60Pr45L/M), which are more commonly acquired in the United States.

The decision of what to radiograph can be the subject of much debate. Knowledge of the future discipline, breed, and history (ex-racing career) of the horse is essential to make appropriate decisions related to imaging. Furthermore, previous radiographs of the horse that show the existence of a particular lesion for many years may be important for interpretation and potential significance.[5]

It is recommended that radiographs be viewed by the buyer's veterinarian prior to the purchase of the horse. Communication prior to the purchase examination is important to ensure that all the required or recommended radiographs are taken. Often, the

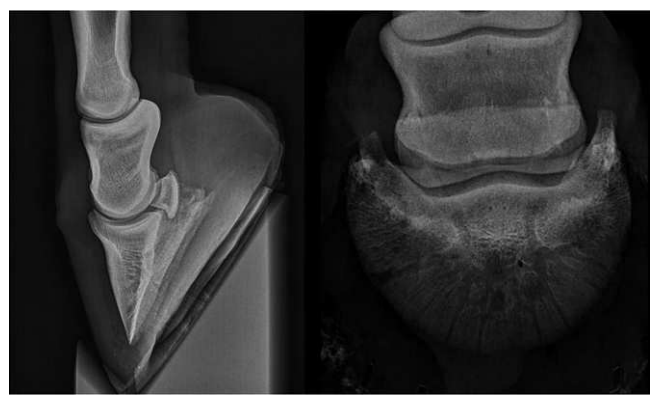


Fig. 2. Example of the oxspring block used to take the LM as well as the DP60 radiograph of the foot in the Netherlands as well as Belgium.

Table 2. Common Labeling of Radiographs within Different Countries

	The Netherlands	Germany	Denmark	Belgium	Sweden	Spain	United States
Left front	LiV	VL	VF	LiV	VF	AI or MAI	LF
Right front	ReV	VR	HF	ReV	HF	AD or MAD	RF
Left hind	LiA	HL	VB	LiA	VB	PD or MPD	LH
Right hind	ReA	HR	HB	ReA	HB	PI or MPI	RH

radiology/imaging specialist or veterinarian reviewing the radiographs has their own standard set that they recommend for each anatomic region or a set of radiographs based upon previously viewed (old) radiographs of the horse. This prior communication also saves time when the horse does not have to return to the clinic for further examination. Use of radiographic reports composed solely by the sellers' veterinarian for proposed buyers has the potential to jeopardize all parties involved. The buyer may not be represented adequately, the seller incurs greater risk by potentially misrepresenting the horse, and the veterinarian does not have the opportunity to explain their findings and opinions with regards to the relevance for resale or training.[6] Furthermore, all radiographic findings should be reported when interpreting radiographs for either the seller or buyer at public auctions and private sales.[6] It remains that radiographic evaluation in the purchase environment has many limitations, and these should be discussed with the buyer. Routine or limited radiographic views may not detect all lesions, and apparently normal radiographs do not always exclude pathological processes. Furthermore apparently abnormal findings may not have current or future clinical relevance.[6] Potentially, in the future, a more global standardized radiographic set for purchase examination could be established to reduce confusion and frustration.

In conclusion, the set of radiographs taken within a sample of countries within Europe are different from each other and different from the standard within the United States. These differences are based on historical traditions and experiences and within some countries are guided by national recommendations and breeding selections. Communication including defining the expectations of the radiographs to be taken at a purchase examination is essential to ensure a smooth and successful transaction.

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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Efficacy and Safety of Multiple Intra-Articular Corticosteroid Injection for the Treatment of Osteoarthritis: Systematic Review

Paula Keiko Anadão Tokawa, DVM*; Raquel Yvonne Arantes Baccarin, DVM, PhD; and Gustavo Zanotto, DVM, PhD, DACVSMR

Current evidence regarding the use of multiple intra-articular injections of corticosteroids for osteoarthritis treatment is unexpectedly scarce and mostly of unclear/high risk of bias. Results point to differences regarding corticosteroids type, usually with no consistent improvement in symptoms and possible negative effects on disease progress. Authors' addresses: School of Veterinary Medicine and Animal Science, University of São Paulo, Brazil (Tokawa, Baccarin); Texas A&M University, College of Veterinary Medicine and Biomedical Sciences, Large Animal Clinical Sciences Department, College Station, TX 77843 (Zanotto); e-mail: p.tokawa@gmail.com. Corresponding and presenting author. © 2023 AAEP.

1. Introduction

Corticosteroids are commonly used for intra-articular treatment of osteoarthritis among equine veterinarians. However, controversy regarding its use as a multiple-injection treatment exists. This systematic review gathers and critically appraises evidence regarding the effects of multiple-injection corticosteroid treatment for osteoarthritis and aims to answer if the frequency of injections lower than 3 months can be detrimental for the clinical and structural progression of osteoarthritis.

2. Materials and Methods

Titles of published articles up to June 2022 generated by searches in PubMed, CAB, and Web of Science were screened for inclusion criteria. In vivo equine or human studies were included if effects of more than one corticosteroid injection were evaluated. Study design varied according to species. Risk of bias was assessed according to study design.

3. Results

From 6,417 titles generated by the systematic search, only 9 papers fit inclusion criteria. Most studies showed unclear/high risk of bias. Triamcinolone acetonide was mostly represented. Symptom-modifying changes were better at first injections for triamcinolone acetonide with a decrease in its improvements over time. No changes in symptoms were found for methylprednisolone acetate (MPA) and betamethasone (BTM). Disease-modifying changes appeared to improve in shorter follow-ups, but degenerative changes were evidenced on longer term for

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triamcinolone acetonide. MPA showed a mostly negative impact, while BTM treatment showed no significant positive or negative changes.

4. Discussion

Inconsistencies in clinical improvements among corticosteroids exist, but neither showed enough positive effects long term to justify its frequent use. Degenerative changes might negatively affect joints at longer follow-ups. These findings are a summary of a few studies at unclear/high risk of bias regarding the topic.

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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.

Review of Intra-Articular 2.5% Polyacrylamide Hydrogel, a New Concept in the Medication of Osteoarthritis

Aziz Tnibar, DVM, PhD, DECVS, DACVSMR, DECVSMR

Clinical and experimental trials have demonstrated that intra-articular 2.5% polyacrylamide hydrogel is highly effective, lasting, and safe for the treatment of equine osteoarthritis. Observations on the mechanisms of action support a mechanical effect through integration into the synovial membrane, an increase in joint elasticity, and provision of lasting viscosupplementation. Author's address: The Equine Hospital – Riyadh, Jockey Club of Saudia Arabia, PO Box 26323, Riyadh, SA 11486; e-mail: aztnibar@gmail.com. © 2023 AAEP.

1. Introduction

Osteoarthritis (OA) is the most common joint disease resulting in chronic pain and physical impairments in horses.[1]

The medical treatment of OA in the horse is one of the most utilized therapeutic regimens in equine practice. Various nonsteroidal anti-inflammatory drugs can be used. The use of intra-articular medication is common practice, such as corticosteroids, hyaluronic acid, and polysulfated glycosaminoglycan. A recent development in the treatment of OA is the use of autologous, regenerative, and innovative preparations to achieve restoration of articular cartilage.[2] The main medications used are autologous conditioned serum, platelet-rich plasma, mesenchymal stem cells, and gene therapy.

Until recently, there was a lack of available effective long-term medication for OA, with a long-lasting efficacy needed, as most of the available therapeutic options only provide short-term mild-to-moderate effects.[3–5] There are several classical medication options for OA,[3–5] but the majority of these options do not provide long-lasting management of OA. However, over the last decade, 2.5% polyacrylamide hydrogel (iPAAG) was introduced and received considerable interest in equine OA therapy. The objectives of this paper are to review the recent studies that provide evidence-based information concerning the use of 2.5% iPAAG in the treatment of OA in horses and to highlight its safety and mechanisms of action.

2. 2.5% Polyacrylamide Hydrogel

The 2.5% iPAAG[a] is a nontoxic and nonimmunogenic biocompatible polymer injectable hydrogel consisting of 97.5% sterile water and 2.5% cross-linked polyacrylamide.[6,7] Biocompatibility within soft tissues (urology, reconstructive surgery, ophthalmology) has been demonstrated in humans and pigs.[8–10] Also, 2.5% iPAAG is a nonparticulate, stable, homogenous gel similar to

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sodium hyaluronate gel in overall structure and tissue compatibility,[11] but with a longer-lasting viscous effect, and it is also nonbiodegradable and nonmigratory in human breast tissue.[6] The 2.5% iPAAG has also proven to have an excellent safety profile in humans validated through over more than 20 years of use for the augmentation of connective tissues in both urology and reconstructive surgery.[10,11]

Based on its highly positive results for equine OA, the effects of 2.5% iPAAG[b] on knee osteoarthritis were recently studied in humans, and the results of the reported clinical studies are very encouraging.[12–18]

Four-percent PAAG hydrogel[c] is different from 2.5% iPAAG and will not be discussed in this review.

3. Clinical and Experimental Studies of 2.5% Polyacrylamide Hydrogel

Over the last decade, 2.5% iPAAG has gained considerable interest in equine OA therapy.[19–27] Clinical trials have investigated the effect of 2.5% iPAAG on improving clinical signs of OA in horses,[19–26] and an experimental trial has investigated its effects on induced OA in goats.[28,29]

In the first clinical trial using intra-articular 2.5% iPAAG in 43 horses (Warmbloods: 70%, racing breeds: 19%, other breeds: 11%), older than 2 years and with OA located within only one joint (metacarpo[metatarso]phalangeal: 93%, one of the carpal: 7%), horses were followed up at 1, 3, 6, 12, and 24 months. The confirmation of OA was based on clinical evaluation, lameness abolished after intra-articular anaesthesia, and imaging (radiography). Lame horses with severe radiographic abnormalities were also included in the study. The study was designed as a prospective multicenter clinical study. Efficacy of the treatment was evaluated by lameness examination of the affected joint, including response to flexion tests. Lameness grading[30] was performed at baseline and at 1, 3, 6, 12, and 24 months. All horses were clinically assessed under similar circumstances by clinicians (one per centre) different from the one who had originally examined and treated the horse, and they were unaware of the identity of the horse and whether joints were treated or not at 1, 3, 6, 12, and 24 months posttreatment. Safety of the joint treatment was evaluated through recording of any adverse reaction following joint injection. All horses received only one injection of 2.5% iPAAG during the study. The first published report of this trial was about the 6-month follow-up results.[19] Before treatment, the proportion of horses with lameness score 1, 2, 3, and 4 was 27.3%, 33.3%, 33.3%, and 6.1%, respectively. The estimated lameness improvement at 1, 3, and 6 months was 81%, 88%, and 87%, respectively. At 6 months, approximately 79% of horses were free of lameness.[19] At the 24-month follow-up, 82.5% of horses were free of lameness, and no side effects were observed related to the treated joints during the study period.[22] In this study, there was a significant decrease in lameness score from baseline to 1, 3, 6, 12, and 24 months ($p < 0.0001$) and a significant positive association with joint effusion ($p < 0.0001$). Estimates for odds ratio revealed that the effect of treatment increased over time (odds ratio for lower lameness scores from month 1 to 24, relative to baseline, increased from 20 to 58). There were some study limitations including a low number of horses, the fact that it was a prospective noncontrolled clinical study, and the subjective assessment of joint distension. This was a multicenter study, which represented another study limitation due to several clinicians involved in the study and the potential for inconsistency in application of the lameness grading scale among the clinicians and within clinicians at different examinations.

Tnibar et al.[21] performed a controlled prospective nonrandomized clinical trial for the efficacy of 2.5% iPAAG in horses older than 2 years with OA located within only one fetlock joint. Fetlock pain was confirmed using intra-articular anaesthesia. OA signs were detected using radiography and/or magnetic resonance imaging (MRI). Forty lame horses were enrolled, 20 (Warmbloods: 80%, other breeds: 20%) in each group. An intra-articular injection was performed with either 2 mL 2.5% iPAAG or 10 mg triamcinolone acetonide (TA) + 20 mg sodium hyaluronate (HA). A clinician, different from the one who had originally examined and treated the horse and blinded to the treatment, assessed lameness at 1, 3, and 6 months postinjection. Efficacy of the treatment was evaluated by lameness examination of the affected joint,[30] including response to flexion tests. Safety of the joint treatment was evaluated through recording of any adverse reaction following joint injection. At 1 month postinjection, 55% of the horses in the 2.5% iPAAG were free of lameness versus 15% in the TA-HA group. At 3 months postinjection, 65% of the horses in the 2.5% iPAAG were free of lameness versus 40% in the TA-HA group. At 6 months postinjection, 75% of the horses in the 2.5% iPAAG were free of lameness versus 35% in the TA-HA group. This study demonstrated that 2.5% iPAAG significantly improved OA clinical signs when compared to horses treated with TA-HA ($p = 0.001$). The main study limitations included the fact that it was a controlled but nonrandomized clinical study with a low number of horses.

Janssen et al.[20] investigated the effects of intra-articular use of 2.5% iPAAG as a treatment for OA of the distal interphalangeal joint in 12 horses (11 Warmbloods, 1 pony). The diagnosis was based on clinical signs associated with distal interphalangeal joint OA, presence of lameness with a positive response to intra-articular anaesthesia, and the presence of distal interphalangeal joint osteoarthritic signs on radiography and/or MRI. All horses had been lame for at least 3 months prior to injection. All horses had previously been treated with TA and HA and/or autologous conditioned serum. An intra-articular injection of 2 mL of 2.5% PAAG was performed. The clinical investigation, treatment, and follow-up were carried out by an experienced orthopaedic surgeon. None of the horses developed side effects. At 6 months

postinjection, 8/12 (67%) horses were free of lameness, 2 were improved, and 2 were nonresponsive. The main limitations of the study included the fact that it was a prospective noncontrolled study with a low number of horses.

Bathe et al.[23] performed a prospective study on 20 sport horses nonresponsive to treatment for proximal/distal interphalangeal joint OA. Lameness was associated with OA, diagnosed by diagnostic analgesia and radiography/MRI. All horses were persistently lame after previous corticosteroid treatment. The average length of lameness was >15 months, and grade was 3/10 at day 0. All horses were injected with 1 mL of 2.5% iPAAG intra-articularly. In total, 18 horses were available for follow-up at a median of 12 months later. This revealed 12/18 returned to full function, 3/18 returned to a lower level, and 3/18 failed to improve. One horse was treated twice, and 1 horse had a transient adverse reaction. The study limitations include the lack of a control group—however, each case could act as its own control, as conventional treatments have always failed—and the low number of horses.

Another study investigated the use of 2.5% iPAAG for the management of joint lameness in flat-racing Thoroughbreds.[24] Forty-nine flat-racing Thoroughbreds with carpal or metacarpophalangeal joint lameness were treated with a single injection of 2 mL of 2.5% iPAAG, at a single training facility. Horses were selected from those presenting for routine veterinary clinical examination for lameness, using a modified American Association of Equine Practitioners lameness scale formatted for the study with a positive response to intra-articular anesthesia. Horses were assessed at day 0 and followed up at weeks 1, 4, 12, and 24 postinjection. Postinjection complications were recorded throughout the entire study period. This study concluded that 2.5% iPAAG was safe and a practical first-line treatment option for lameness associated with the metacarpophalangeal and carpal joints in Thoroughbred racehorses. The percentage of horses free of lameness at 4 weeks, 12 weeks, and 24 weeks postinjection was 43%, 67%, and 65%, respectively. Results of the final statistical model showed a statistically significant improvement in lameness grades at weeks 1 ($p < 0.01$), 4 ($p < 0.001$), 12 ($p < 0.001$), and 24 ($p < 0.001$) when compared to week 0. There were some obvious limitations to the study including the lack of randomization, the lack of blinding, and the lack of controls, which represents the main weakness of the study.

A prospective double-blinded positive control study was performed to compare the efficacy of 2.5% iPAAG in the management of middle carpal joint lameness in Thoroughbreds against treatments of TA or HA.[25] A total of 31 flat-racing Thoroughbreds with lameness (grade 1–3/5) localized to the carpus by intra-articular analgesia were selected. Horses were randomly assigned for intra-articular treatment with either 2 mL of 2.5% iPAAG, 12 mg TA, or 20 mg HA (followed by two further intravenous treatments of 40 mg, at weekly intervals in the HA group only), by a treating veterinarian. All horses were rested for 48 hours posttreatment and then re-entered an unaltered training regimen. Subsequent examinations at 2, 4, and 6 weeks were performed by a blinded examining veterinarian for all groups, while horses treated with 2.5% iPAAG were monitored for 12 weeks for recurrence of lameness. Significantly more joints treated with 2.5% iPAAG were free of lameness (83%) at 6 weeks compared to TA (27%; $p = 0.007$) and to HA (40%; $p = 0.04$). There was no significant difference between TA and HA groups at any time. All the joints treated within 2.5% iPAAG that were free of lameness at 6 weeks (10/12) were still free of lameness at 12 weeks. In conclusion, treatment with 2.5% iPAAG led to statistically superior results compared to TA and HA in the management of selected middle carpal joint lameness in flat-racing Thoroughbreds, with therapeutic effects persisting up to 12 weeks. Several study limitations were apparent in this study and included a relatively low numbers of horses and short study duration. Prestudy power calculations were not used, but the study design allowed for the study's continuation until a statistically significant effect was achieved. Outcome parameters, although based on clear scoring systems, were subjective.

A randomized controlled pilot study using an experimental OA model in the stifle joint (transection of medial collateral ligament, bisection of medial meniscus, and partial-thickness cartilage incisions of medial tibial plateau) in goats showed that 2.5% iPAAG significantly improved the lameness caused by OA, with 75% of the cases becoming sound by 4 months posttreatment evaluation.[28,29] The study limitations included the fact that it was a pilot study with a low number of animals. Nonclinical results of this study will be presented in the section "Mechanisms of Action of 2.5% Polyacrylamide Hydrogel."

4. Safety of 2.5% Polyacrylamide Hydrogel

The use of 2.5% iPAAG has proven to be safe over 10 years of use for the treatment of clinical equine OA[19–26] and also in experimental OA in goats.[28,29] At the 24-month follow-up, no side effects (joint effusion, warm joint, lameness) were observed in the treated joints during the study period.[22] A controlled prospective study comparing 2.5% iPAAG with TA combined with HA in horses with fetlock OA has shown no adverse effects.[21] Another report showed no adverse reactions in any of the 12 horses treated with 2.5% iPAAG for distal interphalangeal joint OA.[20] In a study reported by Bathe et al.[19] involving 20 horses treated with 2.5% iPAAG for proximal/distal interphalangeal joint OA, only one horse had a transient adverse reaction (not specified by the authors) after two treatments. Another study concluded that 2.5% iPAAG is a safe and practical first-line treatment option for lameness related to the metacarpophalangeal and carpal joints in Thoroughbred racehorses.[24] In a prospective double-blinded positive control study performed to compare the efficacy of 2.5% iPAAG in the management of middle carpal joint lameness in

Thoroughbreds against treatments of TA or HA, none of the horses developed any adverse reactions to 2.5% iPAAG.[25] A randomized controlled pilot study using an experimental OA model in goats showed that no adverse reactions were seen following intra-articular injection of 2.5% iPAAG.[28,29]

However, as with any other products when used incorrectly (for example, using a nonsterile technique), some safety concerns may arise. Products with 2.5% iPAAG come in a sterile preloaded luer-lock syringe that reduces the risk of infection and increases safety even further.

Based on the available published studies, the complication rate for intra-articular injection of 2.5% iPAAG is estimated to 0.004%, and the only reported complication was transient (not specified by the authors).

5. Mechanisms of Action of 2.5% Polyacrylamide Hydrogel

Histopathological observations on joint tissue from horses[31] have demonstrated that a part of the 2.5% iPAAG becomes integrated within the synovial membrane. To elucidate mechanisms of action of 2.5% iPAAG in OA joints, a randomized controlled blinded study was conducted on an OA stifle model in goats.[28,29] This study was conducted involving goats with induced OA on the left stifle joint. OA was surgically induced by the transection of the medial collateral ligament, the bisection of the medial meniscus at its midpoint, and partial-thickness incisions of the cartilage of the medial tibial plateau. Goats were allowed free exercise, and 3 months after surgery, they were randomly divided into 2 groups: a treatment group that received 2.5% iPAAG and a control group that received saline solution. The 2.5% iPAAG and a saline solution were injected intra-articularly (1 mL). All goats were videotaped on a treadmill for lameness examination. MRI was performed prior to surgery, as well as 3, 4, 5, and 7 months postsurgery. Seven months postsurgery, gross pathology and histopathology, including immunohistochemistry for nerve endings, were performed on both stifles. Joint capsule elasticity of the stifles was measured in both groups. Following euthanasia, a small piece from the lateral and medial sides of the right and left stifle joint of each goat was removed for evaluation of joint capsule elasticity.

MRI showed reduction followed by stabilization of OA lesions (intra-articular bony and cartilaginous lesions) after 2.5% iPAAG treatment.[28,29] At gross pathology, 2.5% iPAAG was seen present within the joint cavity and adhering to synovial membrane. Histopathology showed that intra-articular 2.5% iPAAG injection added to the thickness of the synovial membrane by allowing increases in angiogenesis, collagen, and synovial cells; 2.5% PAAG was integrated into the synovial membrane. The hyperplasia of the inner capsule/synovial membrane was more significant in the treated goats than in the control goats. In a histological report, a similar tissue reaction was seen in horses with osteoarthritic joints that were injected with 2.5% iPAAG, including cases treated 2 years earlier with 2.5% iPAAG.[31] From the goat model, nerve endings were seen in a similar pattern, whether the goats had had good or minor clinical results from the 2.5% iPAAG gel injection or were in the control group (saline only). In all goats used for nerve staining, the nerves were intact with normal morphology and numbers, and no evidence of neurotoxicity was observed.[28,29] Joint capsule elasticity investigation showed that treated stifles had a higher elasticity when compared to control stifles.[28,29] By integrating the synovial membrane, which may decrease the joint capsule and the joint stiffness, 2.5% iPAAG might relieve pain of the OA joint. This theory is supported by clinical observations in the clinical trials in horses,[21,22] where OA joints that responded well to 2.5% iPAAG also have resolution of the previous positive response to joint flexion.

This study presented preliminary observations regarding the mechanisms of action of 2.5% iPAAG on OA joints:[28,29]

1. Histopathology and joint capsule elasticity suggest that 2.5% iPAAG, by acting on synovial membrane (increasing joint capsule elasticity), may reduce overall joint capsule stiffness, a major source of pain in OA.[32] This represents a mechanical mechanism of action.
2. Gross pathology demonstrated that this gel was present within the joint cavity in all treated animals protecting the articular surface and providing viscosupplementation. The 2.5% iPAAG is a nondegradable and highly viscous product[6] and thus might contribute to protecting the articular surface of an osteoarthritic joint, and hence it could reduce and stabilize the OA lesions. This represents a mechanical mechanism of action. In addition, histopathology demonstrated that 2.5% iPAAG had no effect on articular cartilage and subchondral bone.
3. MRI and gross pathology revealed stabilization of OA lesions in 2.5% iPAAG-treated goats, possibly caused by 2.5% iPAAG's high viscosupplementation and nondegradability.
4. No signs of intra-articular neurotoxicity or fibrosis were observed.
5. Intra-articular treatment with 2.5% iPAAG did not have any influence on hematology, biochemistry, or acute phase proteins.

In addition, in a biomolecular study, equine synovial fluid was analyzed for cytokine/chemokine expression using an ELISA method before and 6 weeks after intra-articular injection of 2.5% iPAAG as treatment for OA.[d] Ten adult horses with fetlock OA were included in the study. Two samples per horse were done, so in total $n = 20$ samples (>1 mL) of synovial fluid were collected from these joints. Samples were collected before and 6 weeks after intra-articular injection with 2 mL of 2.5% iPAAG. The study concluded that there was no evidence

of significant elevation in any of the proinflammatory cytokines like interleukin-6 and interleukin-1 in the OA fetlocks treated with 2.5% iPAAG.[d]

Precise characterization of the mechanism of action of 2.5% iPAAG on OA joints has not yet been fully established; however, preliminary observations from the experimental study in goats[28,29] and horses[31] emphasize (1) the mechanical nature of the mechanisms of action of 2.5% iPAAG and (2) the major role of synovial membrane and joint capsule, as well as the long-acting viscosupplementation of 2.5% iPAAG for the treatment of OA. In addition, no effects on proinflammatory cytokines have been observed.[d] These are new concepts in the treatment of OA.

6. Not All Polyacrylamide Hydrogels Are the Same

There are several iPAAGs available, and although often considered to be the same material, there are clear differences in composition, manufacturing, and injection technique, as well as abilities to interact with surrounding tissues.[33] These characteristics ultimately determine the safety and efficacy profiles of each gel formulation, which should therefore not be used interchangeably.

The 2.5% iPAAGa is produced by a patented technology called In-line Cross-Linking Technology (ILX Technology), forcing water molecules between the cross-linked polymers of polyacrylamide (CAS No. 9003-05-8) that provides the gel with exceptional molecular stability and the ability to retain its viscoelastic properties in situ.

Having undergone extensive analysis for safety, efficacy, toxicology, and manufacturing, 2.5% iPAAG was first approved by the New Zealand regulatory authorities in mid-2019 for veterinary treatment of joint lameness in horses, followed by Australia in 2020. In 2020, the U.S. Food and Drug Administration approved 2.5% iPAAG as a medical device, and not as a pharmaceutical. It is currently marketed as a medical device. In addition, the Federation Equestre Internationale has not included 2.5% PAAG on their controlled or prohibited substance list.

Less is known about the performance or safety of other PAAG products, but widespread and largely indiscriminate use of these products in some countries has caused serious long-term complications, mainly infection and granulomatous reactions.[34,35]

Investigations into 4% PAAG hydrogel[36,c] were based only on improvement in lameness score, as a measure of clinical success. This product is often mistaken for 2.5% iPAAG; however, not only the polyacrylamide concentration but also the manufacturing process is different. Furthermore, 4% PAAG also contains silver ions, the interaction of which within a joint is not known. In comparison, studies on 2.5% iPAAG have consistently used "complete resolution of lameness" as a measure of the primary outcome.

In addition, the 2.5% iPAAG has been shown to be the most stable of the 11 PAAGs evaluated by Narins et al.[33]

Table 1. Recommended Doses to Treat Osteoarthritic Joints in a 500-kg Horse

Joint	Recommended Dose of 2.5% Polyacrylamide Hydrogel (mL)
Distal interphalangeal	2
Proximal interphalangeal	1
Metacarpo/metatarso-phalangeal	2
Antebrachiocarpal	2
Middle carpal	2
Elbow	2–3
Shoulder	2–3
Tarsometatarsal	1
Distal intertarsal	1
Talocrural	2–3
Femoropatellar	2–3
Lateral/medial femorotibial	2–3
Hip	2–3
Temporomandibular	1
Cervical facet joint	1
Thoracic/lumbar joint	1

7. Practical Tips for Using 2.5% iPAAG

Based on clinical experience with 2.5% iPAAG and interpretation of the literature available, the following practical tips for using 2.5% iPAAG are recommended:

- Indicated in early stage to chronic OA.
- 5% iPAAG is a soft (low viscolastic) hydrogel, so it can also be injected using 18- to 20-gauge needles.
- Before using 2.5% iPAAG, lameness must be abolished or significantly improved by intra-articular anesthesia.
- It is of paramount importance to inject this hydrogel into the articular space and not into the synovial membrane, or else the gel, unlike a fluid, will bulge into the synovial membrane and will not diffuse and act properly within the joint space.
- The recommended doses to treat osteoarthritic joints in a 500-kg horse are in Table 1.
- Full response to the treatment begins as early as 1 week postinjection and may, in rare cases, need a few weeks to a few months for a full response.
- If the diagnosis of OA is accurate and 2.5% iPAAG is correctly injected, then only one injection is typically required. If there is no response to 2.5% iPAAG, the diagnosis and/or the injected technique should be revised. It has been stated that the effect of 2.5% iPAAG on OA might occur mainly during the first month after treatment and lasts and increases progressively until 6 months, with a stabilization between 6 and 24 months.[22] If there is an incomplete response to 2.5% iPAAG, it is advised to wait for a repeated injection based on this statement.
- The horse should not have received any intra-articular medication within the 2 months prior to treatment with 2.5% iPAAG.

- 5% iPAAG should be administered alone. No study supports its administration in association with other intra-articular drugs.
- Postinjection management: In the vast majority of cases, 1 week of box rest and hand walking is required, and then horses can progressively resume their normal activity.
- Based on its mechanism of action, 2.5% iPAAG is not listed as a doping product to date.

8. Discussion

Over the last decade, clinical trials have demonstrated that intra-articular 2.5% iPAAG is highly effective, lasting, and safe for the treatment of equine OA.[19–26] No other single medical treatment for OA has such prolonged efficacy.

Most of these clinical studies had some limitations and were either prospective noncontrolled or controlled nonrandomized studies with low number of horses.[19–24] Recently, a double-blinded positive control study in horses demonstrated that significantly more joints treated with 2.5% iPAAG were free of lameness (83%) at 6 weeks compared to TA and to HA;[25] however, the study duration was relatively short. Similar results have previously been reported in an international multicenter prospective noncontrolled study (82.5% free of lameness horses at 2-year follow-up).[22] A randomized controlled study using an experimental OA model in goats was performed; however, it was a pilot study with a low number of animals. The appropriate choice in study design is essential for the successful execution of biomedical studies. All the studies with 2.5% iPAAG are interventional studies (prospective) and are specifically tailored to evaluate direct impacts of this treatment on OA. Each study design has specific outcome measures that rely on the type and quality of data utilized. Additionally, each study design has potential limitations (controlled randomized study, number of horses, outcome parameters subjectivity, etc.) that are more severe and need to be addressed in the design phase of the study. Further randomized controlled clinical studies need to further investigate the effect of this new technology on equine OA.

In horses, all the reported studies to date investigated the efficacy of 2.5% iPAAG in naturally occurring OA, as it was more applicable in the clinical setting than an experimental OA. However, evaluating 2.5% iPAAG in an experimental OA study in horses (e.g., carpal chip model in horses) might contribute to a better understanding of the effect of this new medication on OA. Interest in developing OA models in the horse is driven as much by the clinical importance of the disease in this species as by its utility as a translational model for human disease. Both idiopathic primary OA and posttraumatic OA related to athletic use occur in the horse, and the challenges and expectations that exist regarding early diagnosis and the development of effective treatments that allow return to full function are similar in humans.

A systemic review and network meta-analysis assessing the effectiveness of HA and iPAAG in horses with OA has concluded that iPAAG is an effective alternative therapy, with a long period of action in reducing lameness in horses with OA.[27]

To the author's knowledge, there is no evidence in the literature of drawbacks to using 2.5% iPAAG in the treatment of OA in horses.

The 4% PAAG hydrogel[36,c] is often mistaken for 2.5% iPAAG[a]; however, not only the polyacrylamide concentration but also the manufacturing process is different. Furthermore, 4% PAAG also contains silver ions, interaction of which within a joint is not known.

Two studies have compared 2.5% iPAAG to steroids and sodium hyaluronate for the treatment of OA in horses. A controlled prospective nonrandomized clinical trial compared 2.5 iPAAG with TA and HA for the treatment of OA in horses.[21] This study demonstrated that 2.5% iPAAG significantly improved OA clinical signs when compared to horses treated with TA-HA. A recent prospective double-blinded positive control study compared the efficacy of 2.5% iPAAG in the management of middle carpal joint lameness in Thoroughbreds against treatments with steroids (TA) or HA.[25] This study has demonstrated that treatment with 2.5% iPAAG led to statistically superior results compared to TA and HA in the management of selected middle carpal joint lameness in flat-racing Thoroughbreds.

To elucidate mechanisms of action of 2.5% iPAAG in OA joints, to the author's knowledge, only few studies were conducted.[28,29,31,d] The exact mechanism of action is not fully known, and preliminary observations on mechanisms of action of 2.5% iPAAG emphasize[28,29] (1) the mechanical nature of the mechanisms of action (integration into the synovial membrane, increase of joint elasticity possibly reducing overall joint capsule stiffness, providing lasting viscosupplementation that contributes to protecting articular surfaces); (2) the major role involving synovial membrane and joint capsule, as well as the long-acting viscosupplementation in the treatment of OA; and (3) no effect on proinflammatory cytokines.[d] Studies also suggest that these positive effects occur in the absence of intra-articular neurotoxicity or fibrosis.

The effect on the synovial membrane and joint capsule and the long-acting viscosupplementation represent new concepts in the management of equine OA. However, to fully understand the mechanisms of action of this new technology, this area should be the focus of further studies.

Acknowledgments

Disclaimer

The product used in this study is not an FDA-approved pharmaceutical. It is marketed as an FDA-approved medical device.

Declaration of Ethics

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

Conflict of Interest

The author has completed some research funded by Contura International A/S.

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[a]Arthramid® Vet, Contura International A/S, DK-2860 Soeborg, Denmark.

[b]Arthrosamid®, Contura International A/S, DK-2860 Soeborg, Denmark.

[c]Noltrex® Vet, RC Bioform, LLC, Moscow, Russia.

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Effects of Intra-Articular Injection of an Acellular Equine Liquid Amniotic Allograft in Healthy Equine Joints

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Intra-articular injection of equine liquid amniotic allograft into healthy equine joints resulted in no significant safety concerns. The observed increase in interleukin-1 receptor antagonist in injected joints may provide beneficial effects in the treatment or prevention of joint disease. Authors' addresses: Momentum Equine Veterinary Specialists, 52327 Range Road 213, Sherwood Park, AB T8G 1B9, Canada (Wolkowski); Tufts University School of Veterinary Medicine, 200 Westboro Road, North Grafton, MA 01536-1828 (McCarthy); Oklahoma State University College of Veterinary Medicine, Stillwater, OK 74078 (Schoonover, Taylor); Steinbeck Country Equine Clinic, 15881 Toro Hills Avenue, Salinas, CA 93908-1140 (Eastman); e-mail: danica.wolkowski@gmail.com. *Corresponding and presenting author. © 2023 AAEP.

1. Introduction

Osteoarthritis (OA) is a leading cause of morbidity in horses, with approximately 25% of horses affected in their lifetime.[1] Many common treatments are symptomatic rather than disease modifying,[1] and chondrocytes have limited intrinsic ability to heal, which further potentiates the difficulty of treating joint disease.[2] This has prompted extensive research to investigate regenerative therapies in efforts to alleviate symptoms and alter the disease process.[3]

Biologic formulations are being increasingly utilized in human OA patients with encouraging results.[4] Consequently, these products have been applied to equids in the management of joint disease and yielded similar positive outcomes. Amniotic membrane and fluid are rich sources of bioactive factors with reported anti-inflammatory, anti-fibrotic, and healing properties.[5,6] Molecules commonly found in amniotic tissues and fluid include, but are not limited to, epidermal growth factor, basic fibroblast growth factor, hepatocyte growth factor, tissue inhibitor of metalloproteinase-2 (TIMP-2),[7] as well as interleukin-1 receptor antagonist (IL-1ra), interleukin-6 (IL-6), interleukin-8 (IL-8), and interleukin-10 (IL-10).[8] Equine amnion and amniotic fluid have many successful treatment applications in horses including corneal ulcers,[9,10] distal limb wounds,[11] and tendon/ligament injuries.[12] Amniotic allograft has not been examined as an intra-

Reprinted from Wiley. Wolkowski DD, McCarthy RD, Schoonover MJ, et al. Effects of intra-articular injection of an acellular equine liquid amniotic allograft in healthy equine joints. Vet Surg 2023;52(1):62-68. First published November 21, 2022: https://doi.org/10.1111/vsu.13918. Copyright 2022 The American College of Veterinary Surgeons.

NOTES

articular (IA) treatment in equids, but several studies exist that support the benefits of allogenic amnion in humans[4,13] and rat[14,15] models of OA.

Horses displaying an acute reactive synovitis (joint flare), generally characterized by clinical signs of lameness ranging from mild to severe within 24 to 48 hours of an IA injection with any preparation, is a recognized side effect by equine practitioners and researchers.[16,17] It is noteworthy that the treatment is decellularized; some studies have reported that acellular preparations of mesenchymal stem cell contents are less likely to induce an adverse immunologic event compared to cell-containing counterparts.[18,19] In studies evaluating decellularized extracellular matrix scaffolds of various tissues including cartilage, skin, pericardium, and small intestinal mucosa from various species, it is reported that the presence of intact cells elicits a stronger proinflammatory response.[20,21]

This study aimed to define the clinical effects and synovial fluid cytological changes resulting from IA injection of acellular, equine liquid amnion allograft (ELAA)[a] into normal equine joints. Researchers hypothesized that the injection of 1.5 mL of ELAA IA could be performed safely into the intercarpal joint (ICJ) of horses without inducing a subjective or objective change in gait characteristics. Secondly, the ELAA injection would cause a transient synovitis indicated by an increase in total nucleated cell count (TNCC.) Thirdly, the synovial fluid cytokine profile of joints injected with ELAA would be more anti-inflammatory compared to saline-injected control joints indicated by an increase in IL-1ra concentrations and no change in IL-1α or IL-1β concentrations.

2. Materials and Methods

Using an increase in subjective lameness score (SLS) as the primary observation, a dichotomous power calculation was performed. Using an incidence of number of horses displaying an increase in SLS of 60% for the treatment group and 0% for the control group, and an alpha of 0.05 and a power of 80%, 8 horses would be required for an adequately powered study. The study was approved and performed in accordance with the Oklahoma State University (OSU) Institutional Animal Care and Use Committee (Protocol #IACUC-20-60).

Animals

A blinded, placebo-controlled experimental study was performed on 8 mature horses from the OSU teaching herd (4 mares, 4 geldings; 3–11 years old; 500–630 kg) with the following breeds represented: Quarter Horse (1), Paint (4), Thoroughbred (1), and Warmblood (2). All horses had no recent history of carpal joint injection and had not received any medications for at least 2 weeks prior to the study. Prior to inclusion, each horse was deemed free of systemic disease and carpal pathology based on physical examination, hematological analysis, and carpal radiography. During the study, horses were housed in 3.56-m $\times$ 3.56-m stalls, and a comprehensive physical examination including gait evaluation at a walk was performed daily.

Clinical Evaluation

One ICJ of each horse was randomly assigned to the treatment group (www. randomizer.org), and the opposite ICJ was assigned as control. Subjective lameness evaluation was performed by one blinded investigator experienced in equine lameness evaluation (MJS). Horses were trotted in hand on a firm surface in a straight line and while turning in both directions. Each forelimb was given an SLS according to the AAEP grading scale (0–5).[22] Each horse was then trotted in hand over a recessed stationary force plate at a controlled speed of 2.6 to 3.1 m/second. Six strikes for each forelimb were recorded. The peak vertical ground reaction force (PVGRF) and the vertical impulse (VI), calculated by multiplying the average vertical force by time of stance in seconds, were converted to percentage of body weight (% BW) and recorded. The mean PVGRF and VI from the 6 strikes were used for comparison between days. Comparing to Day 0 observations, a horse was deemed more or less lame on subsequent days if the mean PVGRF and VI deviated more than 2.5 times the standard deviation of all PVGRF or VI observations for all horses on all days. Horses that displayed a mean PVGRF or VI values within Day 0 observations plus or minus this threshold were considered to have no change in lameness. Those horses that displayed a mean PVGRF or VI values below Day 0 observations minus this threshold were considered to be more lame.

Sample Collection and Analysis

Following lameness assessments, the horses were sedated with detomidine hydrochloride (0.01–0.02 mg/kg IV) and butorphanol tartrate (0.01–0.02 mg/kg IV), and the dorsal aspects of both carpi were aseptically prepared. With the limb held in slight flexion, a 20-gauge 1.5-inch needle was inserted into the dorsolateral aspect of the ICJ, and 3 mL of synovial fluid were aspirated. This procedure was performed on Day 0 preinjection and Days 1, 3, 5, 10, 20, and 30 postinjection. On Day 0, 1.5 mL of ELAA (treatment) was injected into the assigned joint, and the opposite limb was injected with 1.5 mL 0.9% sodium chloride (control) via needles used for synovial fluid collection. Both the control and treatment protocols were performed on the same day. Venous blood was collected on Days 0, 1, 3, 5, and 10 postinjection.

Whole blood and synovial fluid (5.0 μL each) were immediately applied to separate test diluents[b] to determine systemic and ICJ synovial fluid serum amyloid A (SAA) concentrations. One milliliter of synovial fluid was transferred to a glass ethylenediaminetetraacetic acid tube for TNCC and differential cell count.[c] One milliliter of synovial fluid was transferred to a cryovial and frozen at -80°C until processed for total protein (TP) concentration and cytokine profiling. Synovial fluid samples were centrifuged at the lab prior to analysis. Synovial fluid cytokine profiling

was performed using an equine specific quantitative multiplex enzyme-linked immunosorbent assay (ELISA) array and individual protein ELISAs.[d] The array (QAE-CYT-1-1) detected 10 cytokines (range of quantitation in pg/mL): interferon gamma (IFNγ; 66.9–4,000), IL-10 (14–148.1), interleukin-15 (IL-15; 202.6–20,000), interleukin-1 alpha (IL-1α; 3.2–1,000), IL-1ra (532.7–20,000), interleukin-2 (IL-2; 3.5–740.7), interleukin-4 (IL-4; 9.9–148.1), IL-8 (3.1–200), monocyte chemoattractant protein-1 (MCP-1; 3.8–200), and vascular endothelial growth factor (VEGF; 11–1,000.) Individual protein ELISAs for tissue inhibitor of metalloproteinase-2 (TIMP-2; ELE-TIMP2-2) and interleukin-1 beta (IL-1β; ELE-IL1b-1) were also arrayed. Synovial fluid TP was measured by bicinchoninic acid protein assay.[d]

Numerical concentrations for each cytokine included in multiplex ELISA were provided by the laboratory performing the analysis even if the concentration fell outside the range of quantitation of the assay. For reporting and statistical analysis, any concentration that was below the lower limit of quantitation (LLQ) for an assay was assigned a value of half of the LLQ. Any concentration provided that was above the upper limit of quantitation (ULQ) for that assay was assigned a value equal to the ULQ. The cytokines evaluated by individual protein ELISA (TIMP-2, IL-1β) had no LLQ or ULQ, so absolute values were used.

Statistical Analysis

Commercial software[e] was used for all data analysis. SLSs were converted to a single variable reflecting whether treated limb was more, less, or equally lame as the control limb on each day of assessment. These values were then ranked within horse by day and assessed using a Friedman's analysis of variance approach. A similar approach was used to assess SAA concentrations in synovial fluid since 87 of the samples had a value of 0 and the remaining concentration values were not normally distributed. Systemic SAA was examined for differences over time using a Friedman's analysis of variance. For other parameters, linear mixed modeling was performed for each outcome of interest, with fixed effects including day, treatment, and treatment $\times$ day interaction. Repeated measures of each outcome were noted as occurring across days within the same joint of the subject. Main effects were examined only if no interaction was detected (at $p < 0.05$). If interaction was present, the SLICE/SLICEBY day option was used to compare treatments within a day. Because of the repeated measures, the ante-dependence covariance structure was used. Residuals were assessed for normality using both visual appraisal and Q-Q plots. When normality of residuals was not confirmed, the outcome was log-base 10 transformed and the corresponding output was analyzed as described above. Statistical analysis was not performed on PVGRF and VI data as no measurements were below the predetermined threshold indicating an increase in lameness. A p value of < 0.05 was considered statistically significant throughout.

Table 1. Subjective Lameness Score (0–5) of the Forelimbs of 8 Horses Before (Day 0) and 1, 3, 5, and 10 Days After Receiving 1.5 mL of an Equine Liquid Amnion Allograft Injected Into One Intercarpal Joint (T) and 1.5 mL of 0.9% Sodium Chloride Injected Into the Contralateral Joint (C)

	Day 0		Day 1		Day 3		Day 5		Day 10	
Horse	C	T	C	T	C	T	C	T	C	T
1	0	0	2	0	2	0	2	0	1	0
2	0	3	0	3	0	3	0	2	0	2
3	1	0	0	0	1	2	1	2	2	1
4	2	0	2	0	3	0	2	0	2	0
5	1	2	1	1	2	2	1	2	1	2
6	2	1	2	0	3	0	3	0	2	0
7	2	0	3	0	2	0	2	0	1	2
8	1	1	0	1	0	0	0	1	0	0
Mean	1.1	0.9	1.3	0.6	1.6	0.9	1.4	0.9	1.1	0.9

3. Results

The only complication encountered during the data or sample collection phases of the study were 4 synovial fluid samples with slight blood contamination.

Mean systemic SAA concentrations measured on each day were not different from each other ($p = 0.62$), with only 1 horse having a concentration above normal (50 μg/mL) on Day 1 (270 μg/mL) and Day 3 (73 μg/mL).

Clinical Response

No difference in mean SLS ($p = 0.75$) was observed on any given day within and between treated and control limbs (Table 1). Compared to baseline scores, mean SLS for the control limb increased at Days 1, 3, and 5 (1.3, 1.6, 1.4, respectively) before returning to baseline (1.1) on Day 10, while the mean SLS for the treatment limb decreased on Day 1 (0.6) and returned to baseline (0.9) on Days 3, 5, and 10.

The calculated thresholds for PVGRF and VI were 5.6% BW and 1.5% BW, respectively. Compared to Day 0 measurements, neither the mean PVGRF nor mean VI decreased by more than their respective threshold on any observation day (Table 2). An increase in PVGRF above the threshold was seen in the treatment limb of 1 horse at Day 5 (6.8%) and 2 horses at Day 10 (5.6% and 8.9%) and in the control limb of 2 horses at Day 10 (6.8% and 6.6%). An increase in VI above the threshold was seen in the treatment limb of 2 horses at Days 1 (1.3% in both), 3 (2%, 1.4%), and 10 (2.2% in both) and in the control limb of 1 horse at Days 3 (1.6%) and 5 (2.5%) and 2 horses at Day 10 (1.9%, 1.6%).

Synovial Fluid Parameters

Assessment of residuals found them normally distributed for TNCC, percentage of granulocytes, SAA, IL-1α, IL-1β, IL-2, IL-8, IL-10, MCP-1, VEGF, and TIMP-2. Residuals for TP, IFNγ, IL1-ra, IL-4, and IL-15 were not normally distributed; therefore, log-10 transformation was performed before analysis for these variables. Assessment of these residuals following transformation confirmed normal distribution.

Table 2. Percentage of Body Weight (% BW) of Mean Peak Vertical Ground Reactive Force (Vertical Impulse) of the Forelimbs of 8 Horses Before (Day 0) and 1, 3, 5, and 10 Days After Receiving 1.5 mL of an Equine Liquid Amnion Allograft Injected into One Intercarpal Joint (T) and 1.5 mL of 0.9% Sodium Chloride Injected Into the Contralateral Joint (C)

	Day 0		Day 1		Day 3		Day 5		Day 10	
Horse	C	T	C	T	C	T	C	T	C	T
1	111.4 (21.4)	111.0 (21.1)	113.7 (20.8)	115.7 (20.1)	111.4 (21.1)	113.3 (21.0)	111.9 (21.0)	115.1 (20.4)	113.0 (21.5)	112.3 (20.9)
2	103.5 (21.5)	101.3 (20.9)	105.3 (21.7)	103.3 (21.1)	107.0 (21.5)	105.9 (21.6)	104.6 (21.0)	103.7 (20.9)	110.3* (22.0)	106.9* (21.5)
3	102.5 (19.4)	97.4 (19.0)	98.7 (20.2)	102.3 (20.3)†	104.4 (20.5)	101.1 (21.0)†	103.2 (19.1)	104.2* (19.9)	107.1 (21.3)†	106.3* (21.2)†
4	96.0 (21.8)	103.1 (22.8)	98.0 (21.7)	102.7 (22.4)	95.2 (21.8)	102.9 (21.6)	100.1 (21.6)	100.1 (21.6)	102.6* (22.0)	104.4 (21.7)
5	91.4 (18.0)	93.6 (18.9)	93.2 (18.9)	95.4 (20.2)†	96.4 (19.6)†	97.5 (20.3)†	96.4 (20.3)†	98.6 (20.6)†	91.7 (19.6)†	97.4 (21.1)†
6	87.9 (18.8)	92.7 (20.0)	90.8 (19.1)	92.8 (19.9)	90.1 (18.7)	92.6 (19.5)	91.0 (19.0)	95.2 (20.2)	89.1 (19.2)	94.3 (20.2)
7	102.3 (18.4)	101.4 (18.9)	102.7 (19.1)	103.7 (19.1)	102.6 (19.0)	102.9 (18.8)	101.5 (18.8)	102.3 (18.9)	103.8 (19.1)	100.1 (18.7)
8	97.3 (18.8)	97.0 (19.1)	95.6 (19.8)	91.0 (20.0)	96.9 (19.9)	98.8 (19.8)	100.0 (19.5)	98.5 (19.6)	98.2 (19.9)	97.2 (19.7)
Mean	99.0 (19.8)	99.7 (20.1)	99.7 (20.1)	101.6 (20.4)	100.5 (20.3)	101.9 (20.5)	101.1 (20.0)	102.2 (20.3)	102.0 (20.6)	102.4 (20.6)

The * denotes an increase of > 2.5 times the standard deviation of all peak vertical ground reactive force observations (5.6% BW). The † denotes an increase of > 2.5 times the standard deviation of all vertical impulse observations (1.2% BW.)

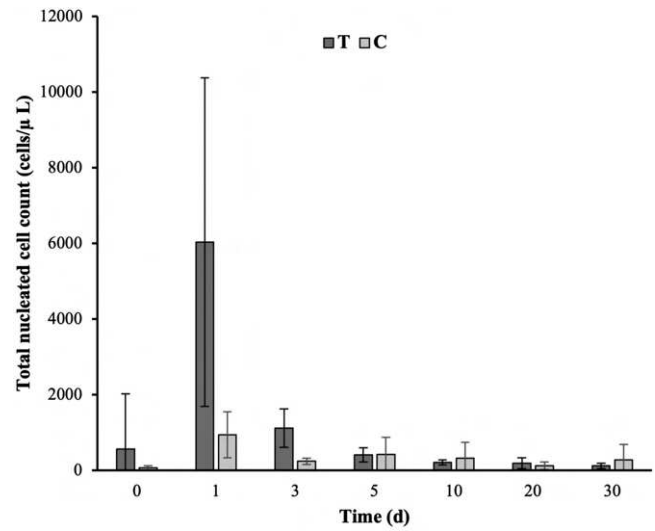


Fig. 1. Mean ± standard deviation total nucleated cell count (cells/μL) of the ICJs of 8 horses before (Day 0) and 1, 3, 5, 10, 20, and 30 days after receiving 1.5 mL of a liquid amnion allograft injected into one randomly selected ICJ (T) and 1.5 mL of 0.9% sodium chloride injected into the contralateral ICJ (C).

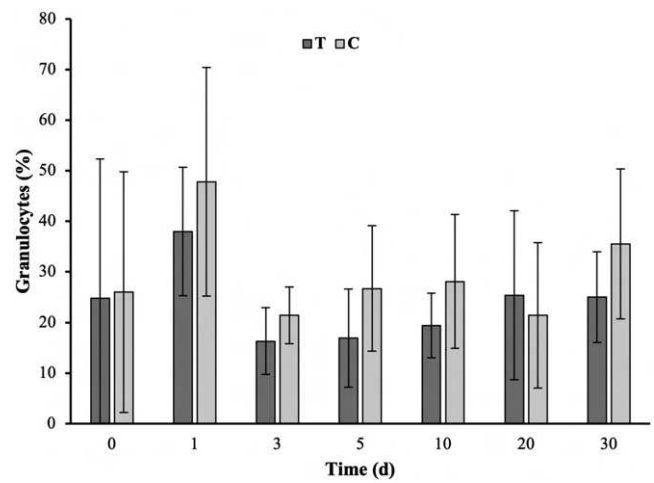


Fig. 2. Mean ± standard deviation granulocyte proportion (%) of the ICJs of 8 horses before (Day 0) and 1, 3, 5, 10, 20, and 30 days after receiving 1.5 mL of a liquid amnion allograft injected into one randomly selected ICJ (T) and 1.5 mL of 0.9% sodium chloride injected into the contralateral ICJ (C).

The mean TNCC of the synovial fluid from the treated joints was higher only on Days 1 ($p = 0.0007$) and 3 ($p < 0.0001$) compared to that from the control joints on the same day (Fig. 1). For percentage of granulocytes, no interaction was present ($p = 0.4$), and there was no difference between treatments ($p = 0.05$), but there were differences across time.

The percentage of granulocytes in the synovial fluid were higher in control joints than treated joints across all days except Day 0 and were higher on Day 1 for both treated and control joints than on all other days (Fig. 2).

The mean synovial fluid TP was higher from the treated joints compared to that of the control joints for

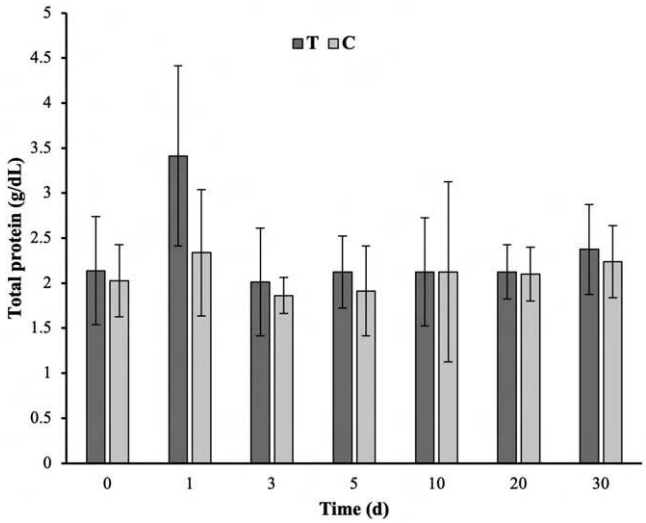


Fig. 3. Mean ± standard deviation synovial fluid total protein (g/dL) of the ICJs of 8 horses before (Day 0) and 1, 3, 5, 10, 20, and 30 days after receiving 1.5 mL of a liquid amnion allograft injected into one randomly selected ICJ (T) and 1.5 mL of 0.9% sodium chloride injected into the contralateral ICJ (C).

all days including Day 0 ($p = 0.02$) and was higher in both treated and control joints on Day 1 compared to all other days (Day 0 $p = 0.002$, Day 3 $p = 0.001$, Day 5 $p = 0.01$, Day 10 $p = 0.04$, and Day 20 $p = 0.03$) except for Day 30 ($p = 0.18$; Fig 3). The relative concentration of SAA in synovial fluid did not vary by day ($p = 0.210$), and mean values ranged from 0 to 9 μg/mL (Table 3).

For IL-1α, IL-1β, IL-2, IL-10, MCP-1, and VEGF, neither interaction of treatment × day nor main effects were significant. Similarly, neither the interaction nor main effects were significant for the log-10 transformed values for IFNγ, IL-4, or IL-15. Treatment × day interaction was significant for IL-1ra ($p = 0.01$) and IL-8 ($p = 0.02$), necessitating examination of treatment differences within each day. Mean IL-1ra was higher in the synovial fluid of treated joints on Days 1 (3542.7 pg/mL) and 3 (2253.9 pg/mL) compared to that of control joints (Day 1: 1902.8 pg/mL, Day 3: 1293.4 pg/mL; $p = 0.01$; Fig 4). IL-8 was higher in the synovial fluid of control joints on Day 20 (5.9 pg/mL) compared to that of treated joints (4.2 pg/mL; $p = 0.003$). For TIMP-2, neither the interaction nor main effect of treatment were significant, but values differed by day for both treatment and control ($p = 0.01$). Measured values of all cytokines are available in Table 4.

4. Discussion

The results of the current study support the hypothesis that injection of 1.5 mL ELAA into the ICJs of healthy horses does not result in a difference in lameness when compared to saline-injected joints in the same horse. Neither SLS nor force plate analysis indicated an increase in lameness in any study horse on any observation day postinjection. Studies investigating various joint injection formulations have had variable results ranging from no change to substantial lameness.[16,17,23–27] Due to the variation in reported incidence of lameness after IA injection, it should be recognized that although none of the 8 study horses displayed an increase in lameness following ELAA injection, it may be a possible side effect. A larger population of horses should be evaluated before conclusions are reached.

Consistent with the second hypothesis, synovial fluid cytology did reflect synovitis as indicated by a transient, self-limiting increase in mean TNCC in the synovial fluid of the ICJ 24 hours after injection with ELAA. In both groups, all cytological abnormalities returned to the normal ranges[28] by Day 5. It should be noted that the mean synovial fluid TNCC was higher in the ELAA-treated joints compared to the

Table 3. Mean ± Standard Deviation Synovial Fluid Total Protein (TP; g/dL), Total Nucleated Cell Count (TNCC; cells/μL), Granulocytes (%), and Serum Amyloid A (SAA; μg/mL) of the ICJs of 8 Horses Before (Day 0) and 1, 3, 5, 10, 20, and 30 Days After Receiving 1.5 mL of a Liquid Amnion Allograft Injected into One Randomly Selected ICJ (T) and 1.5 mL of 0.9% Sodium Chloride Injected into the Contralateral ICJ (C)

Day		TNCC (Cells/μL)	Granulocytes (%)	TP* (g/dL)	SAA (μg/mL)
0	T	567.5 ± 1459.9 (20–4180)	31.1 ± 26.7 (0–66.7)	2.1 ± 0.6 (1.2–2.7)	3 ± 7 (0–20)
	C	66.3 ± 52.4 (20–160)	26.0 ± 23.8 (0–66.7)	2.0 ± 0.4 (1.4–2.6)	7 ± 19 (0–54)
1	T	6038.8 ± 4344.5† (1150–13170)	38.0 ± 12.7 (21.2–57.9)	3.4 ± 1.0† (2.0–4.6)	8 ± 14 (0–31)
	C	936.3 ± 607.6 (110–1800)	47.8 ± 22.6 (18.9–72.7)	2.3 ± 0.7 (1.5–3.2)	2 ± 5 (0–13)
3	T	1118.8 ± 508.3† (250–1800)	16.3 ± 6.6 (7.9–26.6)	2.0 ± 0.6 (1.2–2.3)	7 ± 15 (0–41)
	C	240.0 ± 88.0 (150–440)	21.4 ± 5.6 (15.9–33.3)	1.9 ± 0.1 (1.5–2.2)	1 ± 2 (0–4)
5	T	411.3 ± 186.5 (120–690)	16.9 ± 9.7 (8.6–40.0)	2.1 ± 0.4 (1.6–2.8)	0 ± 1 (0–2)
	C	420.0 ± 449.7 (80–1250)	26.7 ± 12.4 (6.7–38.2)	1.9 ± 0.5 (1.3–2.4)	8 ± 15 (0–43)
10	T	215.0 ± 66.3 (130–350)	19.4 ± 6.4 (5.8–24.0)	2.1 ± 0.6 (1.2–3.2)	0 ± 0 (0)
	C	321.3 ± 424.2 (80–1340)	28.1 ± 13.2 (11.7–50.7)	2.1 ± 1.0 (1.3–4.6)	6 ± 12 (0–34)
20	T	187.5 ± 144.8 (70–420)	25.4 ± 16.7 (0–57.1)	2.1 ± 0.3 (1.7–2.6)	3 ± 6 (0–16)
	C	125.0 ± 100.1 (50–310)	21.4 ± 14.4 (0–46.2)	2.1 ± 0.3 (1.7–2.7)	9 ± 16 (0–38)
30	T	121.3 ± 71.8 (50–230)	25.0 ± 9.0 (14.3–40.0)	2.4 ± 0.5 (1.8–3.4)	0 ± 0 (0)
	C	273.8 ± 415.8 (30–1260)	35.5 ± 14.8 (18.4–58.8)	2.2 ± 0.4 (1.0–2.7)	5 ± 11 (0–32)

The * denotes data that were log transformed for statistical analysis; nontransformed data are presented. The † denotes significant difference of treatment from control on a given day.

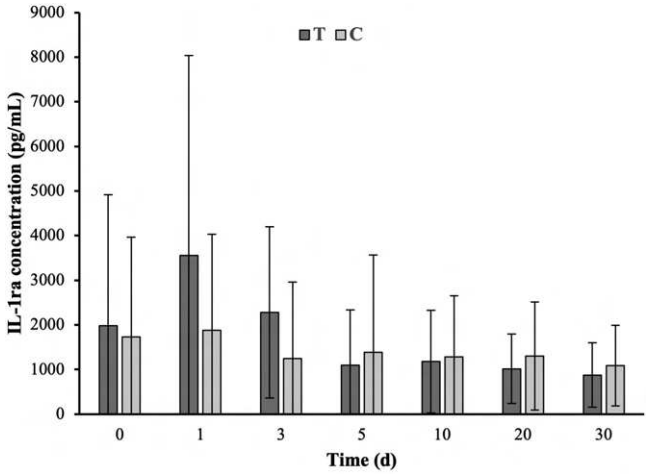


Fig. 4. Mean ± standard deviation (pg/mL) synovial fluid interleukin-1 receptor antagonist (IL-1ra) of the ICJs of 8 horses before (Day 0) and 1, 3, 5, 10, 20, and 30 days after receiving 1.5 mL of a liquid amnion allograft injected into one randomly selected ICJ (T) and 1.5 mL of 0.9% sodium chloride injected into the contralateral ICJ (C).

control joints in the acute period (Day 1, $p = 0.0007$ and Day 3, $p < 0.0001$), indicating a stronger cellular immune response in the treated joints.

Mean synovial fluid TP was highest on Day 1 after injection with both ELAA and saline. Normal synovial fluid TP is reported to range from 0.9 to 3.1 g/dL.[28] Thus, on Day 1, the mean TP of the ELAA-treated joints (3.4 g/dL) was above normal, while the TP of saline control (2.3 g/dL) was not. Both had returned to the normal range on Day 3 and remained normal for the remainder of the study.

The final hypothesis was supported by the cytokine profiles observed in joints treated with ELAA. No changes in synovial fluid concentration of pro-inflammatory cytokines IL-1α, IL-1β, IL-2, and IL-15 were observed between the treatment and control joints at any time point, suggesting that cytokine-mediated inflammatory response was below the range of detection. As expected, the synovial fluid concentration of IL-1ra was found to be higher in the ELAA-treated joints at Day 1 and Day 3 compared to that in the control joints. The manufacturer reports that the concentration of IL-1ra in the ELAA product to be 9,460 ± 1,960 pg/mL. A similar finding has been reported in the synovial fluid of joints injected with autologous conditioned serum in which IL-1ra peaked shortly after IA injection and returned to baseline within 48 hours.[29] The resulting increase in concentration of synovial fluid IL-1ra in the treated joints indicates that ELAA could be beneficial in the treatment of equine OA; however, studies using horses with clinical OA are needed to substantiate this claim.

The current study had several limitations including a small sample size, no variation in aliquot volume, and administration of only a single injection of ELAA. Although the dichotomous power calculation performed indicated adequate power using 8 joints per group, using joints from the same horse for both treatment and control is perhaps a design weakness due to the influence of lameness in one limb on the movement and force applied by the contralateral limb. An adequately powered study to detect a 10% incidence in increased SLS in the treatment group would require separate treatment and control groups, each containing approximately 75 horses. Thus, a large clinical trial evaluating the effect of ELAA in osteoarthritic joints may be indicated. Establishing rate and severity of reactions to varying aliquot volumes of ELAA would also be useful in further elucidating safety and determining optimal volume. Additionally, a heightened immune response after repeat IA injections with ELAA is possible and should also be evaluated to determine the safety of consecutive exposures. Finally, blood contamination of synovial fluid occurred in 4 samples over the course of the study, which has been reported to influence granulocyte proportion if a large volume of blood is present.[30]

In comparison to other products on the market such as autologous conditioned serum, autologous protein solution, and platelet-rich plasma, ELAA has several possible advantages. It is prepared as an off-the-shelf injectable, which is convenient for the veterinarian. Early testing on the product composition indicates that the IL-1ra concentration is higher in ELAA than other biologics. Additionally, consistent product specifications must be met when ELAA is being processed, whereas composition of autologous formulations may vary depending on the components of the individual horse's blood. Finally, the cost of this product is similar to the other biologics. Despite the advantages that ELAA may have, further research needs to be performed on intra-articular use to support these claims and its success as a treatment for joint disease in the horse.

In conclusion, IA injection of 1.5 mL of ELAA into the ICJ produced no increase in lameness but did result in a subclinical inflammatory response within the joint in the study horses. This response peaked at Days 1 and 3 and resolved by Day 5 after injection. No clinical signs of reactive synovitis including increased lameness, joint effusion, or generalized discomfort exhibited by changes in demeanor or physical exam parameters were detected in the study population. Further studies should be conducted to determine the safety and efficacy of ELAA when used in different joints, in diseased joints, at different volumes, and following repeated injections. While there is no optimal dose or volume for the various equine joints or joint diseases yet defined, these data suggest that ELAA can be safely introduced into a healthy joint. While the data obtained from this study are preliminary in suggesting ELAA as a treatment for joint disease in the horse, it can be used by the equine practitioner as the first step to support safe IA use and shows potential beneficial elements that can be applied to the synovial environment.

Table 4. Mean ± Standard Deviation (pg/mL) Synovial Fluid Interleukin-1 Receptor Antagonist (IL-1ra), Interleukin-4 (IL-4,) Interleukin-8 (IL-8), Interleukin-10 (IL-10), Interferon Gamma (IFNγ), Monocyte Chemoattractant Protein-1 (MCP-1), Vascular Endothelial Growth Factor (VEGF), Tissue Inhibitor of Metalloproteinase-2 (TIMP-2), Interleukin-1 Alpha (IL-1α,), Interleukin-1 Beta (IL-1β), Interleukin-2 (IL-2), and Interleukin-15 (IL-15) of the ICJs of 8 Horses Before (Day 0) and 1, 3, 5, 10, 20, and 30 Days After Receiving 1.5 mL of a Liquid Amnion Allograft Injected into One Randomly Selected ICJ (T) and 1.5 mL of 0.9% Sodium Chloride Injected into the Contralateral ICJ (C)

Day		IL-1ra*	IL-4*	IL-8	IL-10	IFNγ*	MCP-1	VEGF	TIMP-2	IL-1α	IL-1β	IL-2	IL-15*
0	T	1990.3 ± 2736.4 (<LLQ-9096.0)	17.5 ± 28.1 (<LLQ-91.3)	6.2 ± 6.2 (<LLQ-21.6)	33.1 ± 44.3 (<LLQ->ULQ)	158.0 ± 209.3 (<LLQ-703.9)	9.3 ± 5.9 (<LLQ-21.3)	34.8 ± 37.2 (<LLQ-126.4)	687.7 ± 79.0 (576.0-799.0)	8.9 ± 11.0 (<LLQ-37.1)	3.9 ± 6.8 (0-21.0)	8.1 ± 10.8 (<LLQ-36.0)	395.8 ± 337.4 (<LLQ-1184.4)
	C	1744.8 ± 2085.9 (<LLQ-7106.3)	13.4 ± 17.2 (<LLQ-58.2)	5.3 ± 5.6 (<LLQ-19.5)	29.0 ± 39.7 (<LLQ-132.8)	119.5 ± 124.8 (<LLQ-434.2)	9.3 ± 5.5 (<LLQ-18.2)	33.8 ± 27.6 (<LLQ-101.2)	781.0 ± 111.3 (569.1-910.3)	7.5 ± 7.4 (<LLQ-25.6)	3.7 ± 8.4 (0-25.9)	6.4 ± 6.4 (<LLQ-22.4)	369.0 ± 300.1 (<LLQ-1070.5)
1	T	3542.7 ± 4207.1† (<LLQ-14296.4)	10.3 ± 14.1 (<LLQ-46.6)	6.8 ± 8.4 (<LLQ-27.8)	33.1 ± 44.9 (<LLQ->ULQ)	184.6 ± 251.0 (<LLQ-836.6)	12.9 ± 8.4 (<LLQ-29.0)	42.0 ± 51.7 (<LLQ-166.0)	112.4 ± 112.4 (592.9-921.1)	11.7 ± 15.3 (<LLQ-50.3)	8.7 ± 10.4 (0-28.8)	10.3 ± 14.1 (<LLQ-46.6)	416.8 ± 387.3 (<LLQ-1314.0)
	C	1902.8 ± 1994.0 (<LLQ-6961.8)	14.6 ± 19.6 (<LLQ-65.5)	4.3 ± 4.9 (<LLQ-16.4)	27.4 ± 35.6 (<LLQ-118.9)	111.8 ± 122.0 (<LLQ-417.7)	13.8 ± 9.9 (<LLQ-33.0)	32.6 ± 31.6 (<LLQ-108.7)	775.4 ± 105.6 (588.3-923.0)	6.8 ± 7.9 (<LLQ-26.6)	6.2 ± 9.6 (0-26.2)	5.6 ± 6.7 (<LLQ-22.7)	313.1 ± 273.1 (<LLQ-953.4)
3	T	2253.9 ± 1823.1† (<LLQ-5133.6)	16.4 ± 16.7 (<LLQ-51.6)	4.6 ± 4.5 (<LLQ-14.7)	35.1 ± 35.0 (<LLQ-111.0)	145.2 ± 160.0 (<LLQ-471.5)	11.6 ± 6.7 (<LLQ-22.6)	35.5 ± 30.8 (<LLQ-105.0)	745.8 ± 65.7 (632.7-859.1)	8.6 ± 9.2 (<LLQ-24.9)	4.7 ± 7.8 (0-24.4)	7.9 ± 8.3 (<LLQ-22.5)	307.7 ± 253.5 (<LLQ-788.7)
	C	1293.4 ± 1571.8 (<LLQ-5262.9)	12.3 ± 14.6 (<LLQ-50.2)	4.0 ± 3.7 (<LLQ-12.3)	28.8 ± 38.8 (<LLQ-128.9)	119.6 ± 144.3 (<LLQ-489.2)	8.6 ± 4.7 (<LLQ-16.6)	34.1 ± 35.9 (<LLQ-120.7)	804.7 ± 79.0 (691.7-956.8)	6.4 ± 8.1 (<LLQ-26.8)	1.8 ± 4.1 (0-12.5)	4.9 ± 5.4 (<LLQ-18.1)	300.9 ± 245.9 (<LLQ-800.9)
5	T	1110.2 ± 1139.4 (<LLQ-3790.8)	9.2 ± 7.7 (<LLQ-26.3)	4.1 ± 2.5 (<LLQ-9.0)	22.3 ± 20.9 (<LLQ-71.8)	97.3 ± 87.6 (<LLQ-302.8)	6.7 ± 3.2 (<LLQ-12.9)	27.9 ± 15.6 (<LLQ-61.5)	747.6 ± 72.5 (650.0-848.9)	5.6 ± 5.0 (<LLQ-15.2)	0.4 ± 0.7 (0-2.2)	4.6 ± 4.1 (<LLQ-14.1)	225.3 ± 167.2 (<LLQ-519.6)
	C	1424.2 ± 2012.1 (<LLQ-6378.1)	11.7 ± 13.5 (<LLQ-45.4)	5.0 ± 4.4 (<LLQ-14.4)	28.3 ± 40.4 (<LLQ-130.0)	133.0 ± 176.3 (<LLQ-564.9)	8.8 ± 3.3 (<LLQ-13.1)	29.1 ± 29.9 (<LLQ-94.8)	760.6 ± 137.7 (561.4-1034.8)	6.3 ± 7.5 (<LLQ-23.1)	0.9 ± 1.8 (0-5.6)	5.0 ± 5.4 (<LLQ-17.6)	282.7 ± 214.7 (<LLQ-647.5)
10	T	1220.1 ± 1033.0 (<LLQ-3681.6)	10.8 ± 9.5 (<LLQ-33.6)	4.5 ± 2.2 (<LLQ-8.1)	26.2 ± 25.8 (<LLQ-87.6)	107.5 ± 104.3 (<LLQ-356.4)	10.1 ± 6.2 (<LLQ-21.7)	32.6 ± 18.7 (<LLQ-64.8)	728.1 ± 110.7 (600.0-974.6)	6.2 ± 5.2 (<LLQ-16.4)	3.6 ± 6.9 (0-21.5)	4.8 ± 4.6 (<LLQ-15.2)	286.1 ± 184.9 (<LLQ-624.4)
	C	1329.3 ± 1240.6 (<LLQ-4077.1)	10.8 ± 9.7 (<LLQ-34.4)	6.3 ± 5.0 (<LLQ-16.6)	25.1 ± 25.8 (<LLQ-84.2)	112.0 ± 112.9 (<LLQ-378.0)	9.6 ± 4.3 (4.1-19.4)	29.0 ± 22.6 (<LLQ-65.9)	725.2 ± 79.0 (605.2-875.3)	6.5 ± 5.6 (<LLQ-17.5)	4.6 ± 10.2 (0-31.3)	5.3 ± 4.6 (<LLQ-15.5)	313.4 ± 202.2 (<LLQ-678.3)
20	T	1023.7 ± 718.4 (<LLQ-2372.7)	9.0 ± 5.7 (<LLQ-20.8)	4.2 ± 2.0 (<LLQ-7.5)	20.0 ± 17.4 (<LLQ-57.2)	89.0 ± 66.3 (<LLQ-241.9)	7.9 ± 4.8 (<LLQ-14.6)	26.7 ± 14.8 (<LLQ-55.6)	694.4 ± 120.6 (493.2-899.5)	5.8 ± 3.9 (<LLQ-12.6)	5.8 ± 8.6 (0-21.1)	4.8 ± 3.2 (<LLQ-10.7)	278.4 ± 174.1 (<LLQ-628.6)
	C	1368.9 ± 1061.9 (<LLQ-3576.5)	10.0 ± 8.2 (<LLQ-30.0	5.9 ± 2.9‡ (<LLQ-10.6)	26.0 ± 24.5 (<LLQ-81.8)	117.3 ± 98.1 (<LLQ-334.3)	8.4 ± 4.4 (<LLQ-15.8)	32.8 ± 20.0 (<LLQ-63.6)	689.9 ± 52.6 (579.9-760.3)	6.0 ± 5.0 (<LLQ-15.0)	6.3 ± 10.1 (0-27.2)	4.9 ± 3.6 (<LLQ-11.1)	310.4 ± 200.2 (<LLQ-665.0)
30	T	862.6 ± 676.5 (<LLQ-2335.5)	7.4 ± 4.4 (<LLQ-16.9)	3.6 ± 2.5 (<LLQ-9.1)	17.9 ± 13.0 (<LLQ-48.5)	83.1 ± 51.7 (<LLQ-193.5)	7.2 ± 4.7 (<LLQ-14.8)	22.2 ± 11.6 (<LLQ-37.0)	665.7 ± 63.1 (522.4-737.1)	6.0 ± 3.9 (<LLQ-13.4)	4.5 ± 7.4 (0-23.2)	4.1 ± 2.6 (<LLQ-8.4)	280.9 ± 131.5 (<LLQ-502.9)
	C	1158.4 ± 762.3 (<LLQ-2057.2)	7.3 ± 4.2 (<LLQ-16.4)	5.7 ± 3.3 (<LLQ-12.2)	20.5 ± 16.0 (<LLQ-50.4)	99.3 ± 68.1 (<LLQ-211.2)	8.2 ± 4.7 (<LLQ-17.3)	25.5 ± 16.2 (<LLQ-58.0)	661.1 ± 81.8 (504.7-729.3)	5.8 ± 3.9 (<LLQ-13.2)	3.1 ± 6.6 (0-20.5)	4.7 ± 2.9 (<LLQ-10.0)	292.6 ± 182.7 (<LLQ-598.5)

The * denotes data that were log transformed for statistical analysis; nontransformed data are presented. The † denotes significant difference of treatment from control on a given day. The ‡ denotes significant difference of control from treatment on a given day. Abbreviation: LLQ, lower limit of quantitation.

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Declaration of Ethics

All authors have adhered to the Principles of Veterinary Medical Ethics of the AVMA.

Conflict of Interest

Equus Innovations funded the research but was blinded to all treatments, and testing was performed at third-party laboratories. Dr. Schoonover has a consulting agreement with Equus Innovations. The other authors have no conflicts of interest.

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[a] RenoVo®, Equus Innovations, Phoenix, AZ 85006.
[b] Stablelab EQ-1 Handheld Reader, Zoetis, Florham Park, NJ 07054.
[c] ProCyte Dx Hematology Analyzer, Idexx, Westbrook, ME 04092.
[d] Raybiotech, Peachtree Corners, GA 30092.
[e] SAS 9.4, SAS, Inc. Cary, NC 27513-2414.

Factors Affecting Body Size and the Incidence of Skeletal Disease in Thoroughbred Foals

Joe Pagan, PhD*; Eileen Phethean, BS, MBA; Megan McFaull, BS; and Steve Caddel, BS

Larger Thoroughbred foals (1-30 d) are at greater risk of developing osteochondritis dissecans (OCD) but not sesamoiditis (SESA). Both parity and month of birth affect foal size and are related to the incidence of skeletal disease. Foals out of primiparous mares are less likely to develop OCD but are more likely to develop SESA. Authors' address: Kentucky Equine Research, 3910 Delaney Ferry Road, Versailles, KY 40383; e-mail: pagan@ker.com. *Corresponding and presenting author. © 2023 AAEP.

1. Introduction

Both osteochondritis dissecans (OCD) and sesamoiditis (SESA) are common skeletal disorders that affect Thoroughbred foals. Depending on location and severity, OCD and SESA may influence performance and sales price. Previous research[1] has shown a relationship between body size and OCD. This study was conducted to evaluate the relationship between size and skeletal disease and to determine other factors related to OCD and SESA risk.

2. Materials and Methods

Thoroughbred foals (n = 1,047) raised on 11 Central Kentucky farms over a six-year period were studied to determine relationships between size, parity, month of birth, and skeletal disease. Body weights and withers heights were measured monthly until they were yearlings.

Each farm used private equine veterinary practices to take and interpret spring survey radiographs. Findings from the survey reports were evaluated for the presence and location of OCD lesions, as well as the incidence of SESA. Incidence and location of OCDs were tabulated. Because of inconsistency in nomenclature used by veterinarians, lesion size was not quantifiable. Therefore, all OCD lesions described within a specific joint were combined. Other non-OCD findings in the joints were also recorded. The severity of SESA, which was based on radiographic changes in the size, shape, and number of vascular canals of the sesamoid bones, was also difficult to quantify because of inconsistency in nomenclature, so all instances of SESA were combined for analysis. Separate reports of surgeries were analyzed. The location of each OCD surgery was categorized by the affected joint (fetlock, hock, shoulder, or stifle). Fetlock surgeries for fragments and chips were categorized separately from fetlock OCD surgeries.

3. Results

Foals with OCD in spring survey reports (15.4%) or with a history of OCD surgery (9.9%) were heavier at 1-30 d than foals with NO OCD ($P < 0.01$) but were not different at older ages. SESA foals (22.9%) were

Research Abstract—for more information, contact the corresponding author

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lighter and shorter than NO SESA foals at 1-30 d ($P < 0.05$) but not at older ages. Foals that had OCD surgery were taller than NO OCD at all age ranges ($P < 0.05$). Birth weights of foals that had OCD surgery were heavier than NO OCD or SESA ($P < 0.05$). Foals with birth weights ≥ 63 kg were at higher risk of OCD surgery (OR 2.16) ($P < 0.01$). Birth weights of foals out of primiparous mares (PARA1) were lower than foals out of multiparous foals (PARA2+) ($P < 0.01$). PARA1 foals were at lower risk of OCD surgery (OR 0.58) ($P < 0.05$) but at higher risk of SESA (OR 1.54) ($P < 0.01$). Foals born later in the season were heavier than early born foals ($P < 0.05$). Much of this difference was due to a larger proportion of PARA1 foals born earlier in the season. Foals born in April were at greater risk for OCD surgery (OR 1.61; $P < 0.05$) but lower risk of SESA (OR 0.56) ($P < 0.01$) than foals born in other months. SESA foals increased body weight percentile to a greater degree from birth through yearling age than NO SESA or OCD surgery foals ($P < 0.01$).

4. Discussion

In this population, heavier and taller foals had a higher incidence of surgical OCD. This size difference was most apparent early in the foal's life, suggesting that OCD may begin earlier in foals than previously believed. Research from Scandinavia[2,3] in both swine and equine samples indicates that the pathogenesis of OCD may be from a disruption of vascular supply to the growth cartilage early in bone development. Results of the current study suggest that both high body weight and withers height early in life may be predisposing factors for OCD. Foals with SESA in spring surveys tended to be smaller than OCD foals early in life, but they had greater increases in body weight percentile over time. Few foals (2.2%) in this study had both OCD and SESA. Factors that favored heavier foals (multiparous and April born) increased the risk of OCD, while factors that favored smaller foals (primiparous and early birth months) increased the risk of SESA.

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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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How to Incorporate Physiotherapy Exercises into Everyday Practice

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This paper will help practitioners develop and incorporate simple physiotherapy exercises into everyday practice, which can improve outcomes of lameness cases, improve overall patient performance, and prevent future orthopedic injury. Author's address: University of Georgia College of Veterinary Medicine, 2200 College Station Road, Athens, GA 30602; e-mail: eav16@uga.edu. © 2023 AAEP.

1. Introduction

Physiotherapy exercises are an extremely effective, although often underutilized, tool to improve equine neuromuscular and musculoskeletal function. Physiotherapy exercises can be used for a broad range of goals including promoting strength, enhancing flexibility, and improving neuromuscular control. While frequently utilized for rehabilitation from musculoskeletal injuries, physiotherapy exercises can also be for muscle development, back pain and dysfunction, promotion of core stability, and enhancement of neuromotor control. Physiotherapy exercises are simple to perform and can easily be taught to the client, making them valuable tools for the equine field practitioner.

2. Materials and Methods

Physiotherapy for Appendicular Musculoskeletal Injury

In cases of rehabilitating a musculoskeletal injury, the exact location, severity, and chronicity of the lesion must first be identified though static palpation and dynamic exam, diagnostic analgesia, and thorough diagnostic imaging. These will provide a baseline to which the horse's progress can be marked and will help tailor the intensity of the physiotherapy plan. It is important for the practitioner to understand the effect of exercise and the process of healing in various tissues, including bone, cartilage, muscle, tendon, and ligament. Specific exercises depend on the tissue or structures involved but are primarily aimed at improving range of motion, reducing scar tissue/adhesion formation, and promoting fiber pattern alignment.[1] Human studies have demonstrated eccentric loading to be beneficial in promoting fiber alignment and neovascularization in cases of tendinopathy.[2] Similar principles can therefore be applied to the equine patient with tendon or ligament injury. These exercises are generally geared toward gradual eccentric and concentric loading of the affected structure, promoting normal range of motion and maintaining symmetrical core strength and endurance. Table 1 outlines physiotherapy exercises that can be used for appendicular musculoskeletal injury, instructions for performing, and goals.

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Table 1. Physiotherapy Exercises for Appendicular Musculoskeletal Injury

Exercise	Indications	Description	Goals Achieved
Fetlock range of motion	Metacarpal or metatarsal flexor tendinopathy or desmopathy; fetlock osteoarthritis	Pick up the horse's left forelimb. Place one hand on the toe and the other over the front of the cannon bone. Gently flex the fetlock until reaching the maximum range of motion. Hold for 5–10 s, then gently unfelt the fetlock. Repeat 30 cycles on the left forelimb and 30 cycles on the right.	1. Restoration of range of motion 2. Stimulation of fiber pattern alignment 3. Reduction of risk of adhesions
Wither pulls	Metacarpal or metatarsal flexor tendinopathy or desmopathy	With the horse standing square, stand on its left side and place both hands over the withers. Gently pull toward yourself until the fetlock extends slightly. Hold for 5–10 s, then gently release. Perform 5 times to the left and 5 times to the right.	1. Stimulation of fiber pattern alignment 2. Core strengthening
Hand walking (surface changes)	Soft tissue injuries	Hand walk the horse in increasing intervals of time (starting at 5–10 min, 1–2 times daily, 5 times per week) based on the horse's severity of injury and comfort level; walking over firm surfaces is ideal in the early phases of soft tissue injury, and then the horse can gradually be walked on softer surfaces to promote range of motion and fiber alignment. Then walk the horse over surface changes to stimulate sensory input and improve proprioception.	1. Endurance 2. Stimulation of fiber pattern alignment 3. Restoration of range of motion 4. Reduction of risk of adhesions 5. Improvement of proprioception
Lateral tail pulls	Soft tissue injuries of hindlimbs, muscle atrophy of stifle/hip region, upward fixation of patella	With the horse standing square, stand on the right side and hold onto its tail. Gently pull to the right and down until it contracts the muscles around its stifle. Hold for 10 s, then slowly release. Repeat 5 times to the right, then 5 times to the left.	1. Stimulation of fiber pattern alignment 2. Core strengthening 3. Strengthening of muscles surrounding stifle and hip
Core-strengthening exercises	Refer to back pain table (Table 2)	Refer to back pain table (Table 2)	Refer to back pain table (Table 2)
Forelimb protractions/ retractions	Compensatory stiffness in neck and shoulder musculature	With the horse standing square, pick up the left forelimb. Extend the limb in front of the horse, holding at the pastern (do not interlock fingers). The examiner should always engage their core in case the horse leans forward or back. Hold the limb so the foot is approximately at carpus height. As the horse gets better, lower the limb. Hold for 5–10 s. For the retraction, pick up the left forelimb and stand facing the same way as the horse. Place one hand on the cannon bone and the other over the front of the radius. Gently retract the limb as far as possible and hold for 5–10 s. Repeat the protraction/retraction 5 times with the left forelimb and 5 times with the right.	1. Stretching of shoulder and neck musculature 2. Core strengthening 3. Eccentric loading of opposite forelimb

(continued on next page)

Table 1. (Continued)

Exercise	Indications	Description	Goals Achieved
Hindlimb protractions/ retractions	Compensatory stiffness in lower back, gluteal, and hip/ stifle musculature	With the horse standing square, pick up the left hindlimb. Extend the limb in front of the horse, holding at the pastern (do not interlock fingers). The examiner should always engage their core in case the horse leans forward or back. The limb should be held so the foot is approximately at hock height. As the horse gets better, lower the limb. Hold for 5–10 s. For the retraction, pick up the left hindlimb and stand facing the opposite way as the horse. Place one hand on the cannon bone and the other on the hock. Gently retract the limb as far as possible and hold for 5–10 s. Repeat the protraction/retraction 5 times with the left hindlimb and 5 times with the right.	1. Stretching of lower back, gluteal, and hip/stifle musculature

Example of Incorporating Physiotherapy Exercises for Appendicular Musculoskeletal Injury

A 12-year-old Quarter Horse gelding used as a team roping head horse was recently diagnosed with a right forelimb deep digital flexor tendon injury within the pastern region. The horse underwent tenoscopy, and the digital flexor tendon sheath has been treated with a biologic. At suture removal, the owner is asking for detailed exercise recommendations for the horse. A sample plan is as follows:

- Controlled hand walking daily for 10 minutes on firm, even ground, increasing by 5 minutes each week until recheck
- Physiotherapy exercises:
    - Wither pulls to promote eccentric loading and forelimb strength
    - Right front fetlock range of motion to promote flexibility and prevent adhesion formation
    - Sternal lifts and lumbosacral tucks to maintain core strength
    - Icing of the right forelimb, local/systemic anti-inflammatories
    - Recheck in approximately 4 weeks

Physiotherapy for Back Pain and Core Strengthening

Primary back pain can be due to numerous pathologies, causing a cycle of pain and dysfunction to occur. This inhibits appropriate muscle activation and leads to disuse muscle atrophy. As the main postural muscle of the thoracolumbar spine, the multifidus muscle, atrophies and becomes dysfunctional, the job of stabilizing the spine is taken over by the longissimus. Because the primary job of the longissumus is dynamic movement of the back, rather than stabilization, the muscle becomes fatigued and painful. Therefore, a critical part of breaking the pain cycle and preventing longissimus fatigue involves strengthening the multifidus muscle.[3,4] Specific physiotherapy exercises have been shown to increase the multifidus cross-sectional area when used consistently for 4 to 12 weeks.[5,6] Additionally, generalized core weakness, including paraspinal and abdominal muscles, can predispose the horse to orthopedic injury. Improved postural stability has been shown to have multiple benefits in humans including protection of the spinal column[7,8] and enhancing the ability to respond to destabilizing forces.[9,10] Physiotherapy exercises that encourage the horse to lift its abdomen, round its back, and engage its core can improve muscle activity of the stabilizing back and abdominal muscles.[11] Table 2 outlines physiotherapy exercises that can be used for core strengthening, instructions for performing, and goals.

Example of Incorporating Physiotherapy Exercises for Back Pain

A 15-year-old Warmblood mare used for dressage has been diagnosed with osteoarthritis of the lumbar

Table 2. Physiotherapy Exercises for Back Pain and Core Strengthening

Exercise	Description	Goals
Sternal lifts	Use fingertips to scratch under the horse's belly. The horse should lift its back. Once in this position, maintain pressure to get the horse to hold this position for 5–10 s. Always stand by the horse's shoulder, as it will sometimes kick out with the hind leg.	1. Core strength 2. Flexibility of thoracic region
Lumbosacral tucks	With the horse standing square, apply pressure with fingertips on either side of the tail base. The horse should lift its back and tuck the pelvis. Get the horse to hold this position for 5–10 s. If the horse is reluctant to tuck the pelvis with digital pressure alone, apply pressure with two capped pens. Always stand to the side when performing this exercise, as some horses will kick out.	1. Core/hind-end strength 2. Flexibility of lumbosacral region
Caudal tail pulls	With the horse standing square (in crossties or with someone holding it), stand behind the horse, holding the tail. Pull backward until the horse engages the gluteal muscles and begins to pull against you. Hold for 5–10 s, then gently release.	1. Hind-end strength 2. Stretch of topline
Elastic resistance band training[a-c]	Apply according to system directions. Horses should be introduced to these systems gradually, so as to not cause excessive work and back pain.	1. Hind-end strength 2. Core and abdominal muscle strength
Ground poles and cavaletti	Ground poles should initially be used and can then be raised 2–3 inches off the ground. Increased promotion of neuromotor control can be achieved by placing the poles at various angles or configurations, requiring the horse to have more precise control of the limbs and body in order to navigate the more complicated pole arrangement.	1. Stimulate proprioception and neuromotor control 2. Core and abdominal muscle strength
Lateral bending to the stifle	Use a carrot or treat to encourage the horse to bring its head and neck around to the left and then the right to the level of its stifle. It should keep its head straight without rotating. If the horse starts to rotate, encourage it to bend as far as it can while its head is straight, and hold in this position for 5 s. Taking the treat out wider will often help it keep its head straighter. Repeat 5 times to the left and right.	1. Core strength 2. Flexibility of cervical and thoracic spine
Ventral flexions to the fetlocks	Use a carrot or treat to encourage the horse to lower its nose down between its front fetlocks until it lifts its back. This exercise will help stretch the horse's entire topline. It should keep all four legs straight and should not step backward. If this occurs, perform this exercise with the horse's hind end in the corner of its stall. Repeat 5 times.	1. Core strength 2. Stretch of topline 3. Flexibility of cervical and thoracic spine
Back wiggles	Stand on the horse's left side. The examiner should place their right hand at the tail base and their left hand on top of the lumbar spine. Move hands in opposite directions (i.e., the right hand pushes while the left hand pulls, then the right hand pulls while the left hand pushes, etc.) while moving the hand toward the horse's head and then back toward the tail. This should create a serpentine-like movement through the back, neck, and head. Perform on each side at least 3 times or until the horse relaxes.	1. Flexibility of back

articular process joints as well as sacroiliac pain. The horse has moderate atrophy of the topline musculature. The back and sacroiliac regions have been treated with corticosteroids, and the owner is now looking for guidance to bring the horse back into full work. A sample plan is as follows:

- Once the pain cycle is broken (1–4 weeks after injections or other treatment), consider an aid geared toward promoting core strength,[a-c] introducing it very slowly, beginning with walking under saddle or in-hand for 10 to 15 minutes daily.
- Physiotherapy exercises:
    - Sternal lifts to promote core strength and flexibility
    - Caudal tail pulls to promote hind end strength
    - Back wiggles to promote flexibility
    - Lateral bending to the stifle to promote core strength and flexibility
    - Ventral flexions to the fetlock to promote core strength and flexibility

Example of Incorporating Physiotherapy Exercises for Core Strengthening

A 17-year-old Thoroughbred gelding was recently purchased for use as a low-level eventer. The horse has recovered from a right hind proximal suspensory injury 2 years prior. The horse has minimal back pain. The horse has moderate core weakness, particularly in the right hindlimb, and the new owner would like advice on how to prevent reinjury. A sample plan is as follows:

- Consider incorporating an aid geared toward promoting core strength,[a-c] introducing it very slowly, beginning with walking under saddle or in-hand for 10 to 15 minutes daily.
- Physiotherapy exercises:
    - Sternal lifts to promote core strength
    - Lumbosacral tucks to promote core and hind-end strength
    - Lateral tail pulls to promote hindlimb strength
    - Lateral bending to the stifle to promote core strength
    - Ventral flexions to the fetlocks to promote core strength

Physiotherapy for Neurogenic and Disuse Muscle Atrophy

When the neural input to a muscle is abnormal, neurogenic muscle atrophy can occur, causing weakness and lack of neuromotor control.[12] In cases of pathologic or disuse atrophy, proprioceptive signals are lost and the animal lacks not only voluntary movement control but also control of muscle tone and postural reflexes.[13] Specifically targeted rehabilitation exercises can stimulate the nervous pathway, causing the muscle to fire, which can ultimately restore neuromotor control and strength. Table 3 outlines physiotherapy exercises that can be used to enhance muscle development and promote neuromotor control, instructions for performing, and goals.

Example of Incorporating Physiotherapy Exercises for Muscle Atrophy

A 10-year-old Quarter Horse gelding intended for use as a barrel racer was diagnosed with equine protozoal myeloencephalopathy 3 months ago. The horse was successfully treated and no longer has neurologic deficits. However, the horse has moderate atrophy of the left biceps femoris and middle gluteal musculature. The owner would like recommendations for promoting muscle development. A sample plan is as follows:

- Hand walking daily for 10 minutes, depending on horse's level of fatigue
- Physiotherapy exercises:
    - Lateral tail pulls to the left to promote muscle development, proprioception, and strength. Different angles (30° between lateral and caudal, 45° between lateral and caudal, etc.) may be needed to see where the desired muscles fire most effectively.
    - Caudal tail pulls to promote muscle development, proprioception, and strength
    - Weight shifting to the left to promote strength and proprioception; advance to picking hindlimb perturbations once strength allows
    - Sternal lifts to promote core strength
    - Lumbosacral tucks to promote core/hind-end strength
    - Consider adding in proprioceptive aids when the horse's strength allows (elastic therapeutic taping, elastic resistance band training)

3. Results and Discussion

Physiotherapy exercises are an extremely effective but frequently underutilized tool to improve equine neuromuscular and musculoskeletal function. As detailed above, these exercises provide a broad range of benefits including strengthening, stretching, and improving neuromuscular control, making them very effective adjunct tools for the equine practitioner. Physiotherapy exercises are easily accessible and implementable to every equine practitioner. Of utmost importance to note, in cases of musculoskeletal injury rehabilitation and generalized strengthening regimens, it is critical that the veterinarian perform an initial assessment and take serial

Table 3. Physiotherapy for Neurogenic and Disuse Muscle Atrophy

Exercise	Indications	Description	Goals Achieved
Caudal tail pulls	Atrophy/weakness of gluteal muscles	With the horse standing square (in crossties or with someone holding it), stand behind the horse, holding the tail. Pull backward until the horse engages the gluteal muscles and begins to pull against you. Hold for 5–10 s, then gently release.	1. Stimulation of muscle contraction of glutes 2. Improvement of proprioception
Wither pulls	Atrophy/weakness of stabilizing muscles of scapula, shoulder, and/or elbow	With the horse standing square, stand on its left side and place both hands over the withers. Gently pull toward yourself until the fetlock extends slightly. Hold for 5–10 s, then gently release. Perform 5 times to the left and 5 times to the right.	1. Stimulation of muscle contraction of scapula, shoulder, and elbow stabilizers 2. Improvement of proprioception
Lateral tail pulls	Atrophy/weakness of stabilizing muscles of the hip and stifle	Lateral tail pulls: With the horse standing square, stand on the right side and hold onto its tail. Gently pull to the right and down until it contracts the muscles around its stifle. Hold for 10 s, then slowly release. Repeat 5 times to the right, then 5 times to the left.	1. Stimulation of muscle contraction of hip and stifle stabilizers 2. Improvement of proprioception
Weight shifting	Generalized atrophy/weakness of stabilizing muscles in front or hind end	With the horse standing square, gently push on the shoulder (or hip) until the horse shifts its weight to the contralateral limb. Hold for 5–10 s, then slowly release.	1. Fore/hind-end strength 2. Neuromotor control 3. Stimulate proprioception
Foot lifting plus perturbations	Generalized atrophy/weakness of stabilizing muscles in front or hind end	Pick up one foot and while holding, gently push on the horse's shoulder (or hip) until it shifts weight to the contralateral limb. Hold for 5–10 s, then slowly release.	1. Core, fore/hind-end strength 2. Neuromotor control 3. Stimulate proprioception

qualitative and quantitative notes of the horse's progress throughout the duration of the physiotherapy program. This will ensure that the regimen is effective and provides a continuous level of challenge for the horse. In addition, the practitioner can also ensure there are no deleterious effects or injury setbacks due to overconditioning or other factors.

In addition to physiotherapy exercises, numerous other rehabilitation modalities geared toward improving the quality of tissue healing and the chance of return to athletic performance are available. A nonexhaustive list includes administration of biologics, laser therapy, therapeutic ultrasound, extracorporeal shockwave therapy, pulsed electromagnetic field therapy, vibrational therapy, and neuromuscular electrostimulation, to name a few. The beautiful thing about physiotherapy is that it requires no purchase of expensive equipment or repeated visits to perform treatments, like many of the aforementioned modalities. In conclusion, physiotherapy exercises can be performed by owners, with adequate training, to help horses not only rehabilitate but also maintain a level of core strength and fitness to prevent future injuries.

Tips for incorporating physiotherapy exercises:

1. The number of prescribed physiotherapy exercises should be tailored to the client's time availability. In general, no more than 3 to 5 physiotherapy exercises should be prescribed to maximize client compliance.
2. Physiotherapy exercises should be performed at least 3 to 4 times weekly to have an effect but can be performed daily.
3. Demonstrate the exercises to the owner, then have the owner try them as well with your guidance.
4. Have videos of the exercises available for the owner to review or suggest that the owner take a video performing the exercises.
5. Have the owner check in after 1 to 2 weeks to make sure they are not having difficulty performing the exercises. If some are difficult for the owner to perform, provide alternative exercises that will accomplish the same goals for the horse.

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.

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[a]Equiband, Equicore Concepts, Lansing, MI 48912.
[b]ProSix, Eagle ProSix, Bark River, MI 49807.
[c]Pessoa, English Riding Supply, Scranton, PA 18505.

Short-Term Use of Balance Pads on Postural Sway and Multifidus Muscle Cross-Sectional Area in Horses

Jessica Cathcart, BS*; Valerie Moorman, DVM, DACVS-LA; and Katherine Ellis, DVM, MS, DACVSMR

Implementation of balance pads for 4 weeks can improve postural stability and increase the multifidus cross-sectional area in horses. Authors' address: University of Georgia, 501 D.W. Brooks Drive, Athens, GA 30602; e-mail: jessie.cathcart@gmail.com. *Corresponding and presenting author. © 2023 AAEP.

1. Introduction

Horses and humans with musculoskeletal injury have reduced postural stability and asymmetry/atrophy of the paraspinal muscles. The hypothesis of this study was that use of balance pads would improve both postural stability and the multifidus muscle cross-sectional area (CSA) and symmetry.

2. Materials and Methods

Six American Quarter Horses stood square on balance pads for 5 minutes twice daily, 5 days per week, for 4 weeks. Lameness (inertial sensor system), postural stability (portable media device), and ultrasound were collected at baseline and at study completion. Postural sway data were collected during normal square stance and on balance pads. Ultrasound of the multifidus muscle was performed bilaterally at T12, T14, T16, T18, L2, and L5. Data were analyzed using mixed-model analysis of variance.

3. Results and Discussion

At baseline, there was significantly more medial-lateral and cranio-caudal motion when horses stood on pads compared to the square stance. At 4 weeks, there was a significant decrease in motion on the pads compared to baseline measurements. There was a significant increase in the multifidus muscle CSA at T14 at 4 weeks compared to baseline. When comparing the CSA at baseline and 4 weeks, there was no significant difference in multifidus muscle asymmetry.

4. Conclusion

These findings suggest that implementation of balance pads for 4 weeks can improve postural stability in horses and increase the CSA. Longer duration of use may be needed for additional changes to paraspinal musculature.

Research Abstract—for more information, contact the corresponding author

NOTES

Acknowledgments

Declaration of Ethics

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Conflict of Interest

The authors have no conflicts of interest.

How to Use Barefoot Methodology as a Viable Farriery Option

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The equine foot with healthy structures is superior in its natural or barefoot state as opposed to being shod with regard to accepting the weight of the horse, shock absorption, and dissipating the energy of impact.[1–3] Furthermore, the structures of the foot have an inherent ability to change shape, strengthen, and improve over time through the process of adaptation.[1,3] Author's addresses: Virginia Therapeutic Farriery, 833 Zion Hill Road, Keswick, VA 22947 (O'Grady); Large Animal Clinical Sciences, College of Veterinary Medicine, Michigan State University, East Lansing, MI 48824 (Clayton); e-mail: sogrady@look.net. *Corresponding and presenting author. © 2023 AAEP.

1. Introduction

Horseshoes became a necessity in the 19th and 20th centuries when horses worked/competed long hours on paved roads or abrasive surfaces. With the decline in working horses and the rise in popularity of equestrian sports performed on deformable synthetic surfaces, shoeing should no longer be regarded as a necessity. Indeed, at the 2020 Tokyo Olympics, the Swedish team won the gold medal in show jumping with 2 of their 3 horses jumping barefoot over 18 rounds in 4 days. And again, in 2022, a Swedish horse won the FEI World Championship in show jumping barefoot. The fact that sport horses can perform at the highest levels without shoes challenges traditional practice that regards a shod foot as the normal state. The author does not infer that traditional farriery using horseshoes should be abandoned but that barefoot methodology presents another viable option in equine foot care.

2. Perspective

Horseshoes provide protection when wear on the solar surface of the foot exceeds growth at the coronet. They maintain or enhance functionality by providing traction, and lastly, therapeutic shoes are used to improve compromised structures of the foot and treat disease/lameness. However, there are some negative consequences of a horse being shod. A horseshoe has very different mechanical properties than the hoof wall and should not be regarded as an extension of the horse's foot. The shoe replaces the single interface between the hoof capsule and the ground with two interfaces (Fig. 1).[4,5] Within the musculoskeletal system, transitions between tissues with different mechanical properties are accomplished by a series of gradual transitions in tissue type that helps to smooth force transmission. The abrupt transitions from hoof wall to shoe and shoe to ground, together with the material properties of the shoe, alter concussion and dampening by the foot and lower limb, ultimately increasing impact intensity on the hoof.[5–7] Furthermore, applying a standard horseshoe to the horse's foot increases the force exerted on the navicular bone by the deep digital flexor tendon by up to 14%.[5,8]

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Fig. 1. The red arrow shows the first interface between the hoof and the shoe. The blue arrow shows the second interface between the shoe and the ground.

There is rivalry between traditional farriers and barefoot trimmers. Certainly, traditional farriery using horseshoes can be performed in a physiological manner with minimal damage to the horse's foot,[9–11] but a successful outcome in transitioning a horse to barefoot methodology requires a different approach. This paper will distance itself from the conventional trim and outline a simple and easy method of "shaping" the foot for a barefoot lifestyle based on basic farriery principles.[10,11]

The primary intent of this paper is to describe a method to improve hoof conformation and to transition a horse from being shod to remaining barefoot. The author has been successful using this method to improve the deformable soft tissue structures in the palmar/plantar section of the foot in shod horses that have distorted hoof capsules by leaving the horse barefoot for a given time frame.

3. Indications for Barefoot

In equine practice, a permanent or temporary transition to barefoot should be considered for horses that:

- Have good-quality hooves and are not required to perform a large amount of exercise on abrasive surfaces. These horses can transition from shod to barefoot and be maintained permanently in the barefoot state.
- Will be out of work for a period, i.e., while being rehabilitated from an injury.
- Have poor limb conformation leading to hoof capsule deformation.
- Have chronic foot lameness associated with farriery.
- Have chronic foot lameness with an unexplained cause.
- Have a low heel "bull nose" conformation in the hind feet.
- Have abnormal gait associated with forging, interfering, and overreaching.
- Are rehabilitating hoof tissues such as:
    - Hoof capsule distortions involving compromised heel structures in the palmar/plantar foot.
    - Sheared heels.
    - Frogs that are either recessed or prolapsed relative to the ground surface of the foot.

4. Benefits of Barefoot

Maintaining horses in a barefoot condition should not be regarded as a fad that is rooted in minimalist ideas of equine management, nor should it be regarded as a cure-all. There are, however, many aspects of going barefoot that pose a feasible and practical option to traditional farriery with practical and functional benefits to the horse and owner.

- In comparison with being shod, the barefoot hoof shows a superior ability to absorb shock, dissipate energy, and accept the weight of the horse.[1–3]
- The structures of the foot have an inherent ability to change shape, strengthen, and improve over time through the process of adaptation when not confined by a rigid shoe.[1,3]
- A shoe elevates the hoof off the ground and loads it peripherally, which places the bulk of the load on the hoof wall, whereas a barefoot horse loads the entire foot, and this affects the wear pattern due to friction between the hoof and the ground.
- It allows natural movement and physiological function of the foot including greater heel expansion and vertical movement of the heels in the unshod hoof.[7,12]
- Hoof growth and wear often allow the barefoot horse to maintain the shape of its feet by friction and wear between the entire solar surface of the foot and the ground.
- When a horse is shod, friction/wear is localized between the heel of the hoof capsule and the shoe, which induces greater wear at the heel than the toe and changes the conformation of the foot between shoeing cycles.[5,12]

An ongoing research project at the Swedish University of Agricultural Sciences in Sweden is evaluating and comparing barefoot versus shod conditions in elite equine athletes.[a] The research project was divided into three stages: prestudy research (survey), data collection on jumping horses (with and without shoes), and general kinematics (with and without shoes). Preliminary findings in the second stage showed that the hoof mechanism (expansion and contraction) is restricted with shoes compared to barefoot, a finding that was not unexpected. Interestingly, the researchers found that the foot contracted at the quarters prior to impact and again during breakover, which did not occur in the shod horse. Furthermore, they found that when working in a circle, the vertical movement of the heels is restricted in the shod horse, while in the barefoot horse, each heel is independent (separate) of each other in a proximal and distal direction. This

finding will certainly have implications for horses with an asymmetrical landing pattern or sheared heels and horses prone to developing a quarter crack. This study will ultimately lead to greater understanding and acceptance of the structural and performance benefits associated with being barefoot.

The success of the author and others in producing a limited but growing number of barefoot horses implies that this is a feasible farriery option. However, success in transitioning horses to being barefoot is dependent on understanding the process, using the appropriate farriery principles, and allowing time for the necessary changes to occur.

5. The Barefoot Trim

The preparation of a foot that will remain barefoot, either temporarily or permanently, differs from the preparation of a foot prior to being shod.

> ***When the horse will be shod, the foot is trimmed. When the horse will be barefoot, the foot is shaped.***

The biggest differences in preparing the barefoot hoof are listed below:

- The horny sole remains intact.
- The heels are placed in a load sharing state.
- The hoof wall is left 3 to 5 mm longer to provide maximal protection.[11,13]
- A thick bevel is created around the perimeter of the hoof wall.

Briefly, the solar surface of the foot is cleaned briskly using a wire brush; a hoof knife is generally not required to shape the foot. Excessive hoof wall when present, usually at the toe, is removed using hoof nippers. Rather than cutting horn on the same horizontal plane as the sole, the nippers are angled at approximately 45° to the sole with the cut starting at the outer edge of the sole-wall junction (white line; Fig. 2). The goal is to bevel the bearing surface of the hoof wall and then form a thick rounded peripheral edge.

After removing excessive horn or toe length, the heels of the hoof capsule are rasped horizontally across the frog until the heels are on the same horizontal plane as the frog. This ensures that the palmar section of the foot is "load sharing." Starting at the heel quarter, the rasp is then used at a 45° angle to the sole around the circumference of the foot peripheral to the sole-wall junction (Fig. 3). The angle of the rasp creates a sharp edge at the bevel on the hoof wall, which is removed by laying the rasp against the outer hoof wall surface and rasping in a rounding motion from proximal to distal on the hoof wall. This produces a thick rounded perimeter continuous with the outer hoof wall (Fig. 4). Excessive hoof wall flares are removed using the rasp in the same manner to blend the flared area into the rounded perimeter of the hoof wall. This shaping protocol differs from the usual direction of rasping a foot during a routine trim, and farriers often find the technique awkward or cumbersome.



Fig. 2. Nippers being used at a vertical angle starting the cut dorsal to the white line. This will create a thin mound of hoof wall and a thin white line (red arrow) on the bearing border of the foot.



Fig. 3. Rasp being used on a 45° angle dorsal to the white line. Note the mound of hoof wall (3–5 mm) being formed and again the thin white line (red arrow) around the perimeter.

Regardless of whether the horse will be barefoot temporarily or is being transitioned to remaining barefoot, it is important to leave all the horn/mass on the solar surface of the foot.

The Transition from Being Shod to Remaining Barefoot

The author has been an advocate of maintaining horses, including upper-level competition horses, barefoot when this is feasible, possible, or warranted. Many factors/variables should be considered before deciding whether a horse is a candidate for the barefoot lifestyle. These include the type and amount of work performed, the surfaces on which the horse works, genetics, current hoof conformation, the integrity and

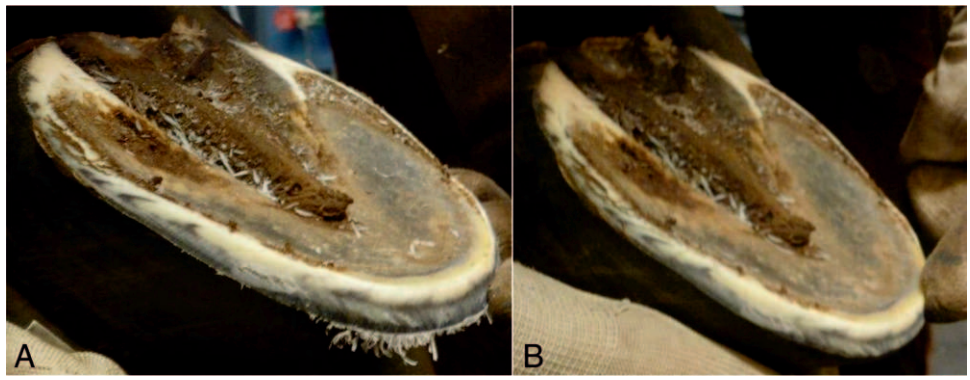


Fig. 4. A shows the sharp edge created when using the rasp vertically. B shows the thick rounded perimeter that was created by using the rasp against the outer hoof wall to remove the sharp edge.

mass of the hoof wall, and especially the condition of the soft tissue structures in the palmar foot. The severity of any of these factors or combination of these factors may make the horse unsuitable to remain barefoot. The prerequisites for transitioning a horse to barefoot are listed below:

- An adequate transition period to allow the feet to adapt
- Good foot structures or foot structures that will improve
- A change in farriery ("shaping" vs. trimming)

When the horse wears shoes, the hoof is elevated off the ground and the loading is concentrated on the periphery of the hoof wall. The sole-wall junction, sole, bars, digital cushion, and frog are deprived of interaction with the ground, resulting in a loss of structural integrity, strength, and mass. These structures will adapt to changes in their environment, but an adequate transition period is necessary for the tissues to strengthen and improve their density in response to removal of the shoes. If the hoof walls are thin and the sole at the toe deforms markedly when hoof testers are applied across the dorsal sole, the use of a modified hoof cast can assist by adding mass, stability, and protection to the hoof capsule during the transition period without interfering with the physiological function of the foot.

Removing the horse's shoes without a transition period will seldom be successful. After removing the shoes, all the foot structures are involved in weight acceptance, and these structures adapt to withstand changes in the biomechanical forces/load now placed on the foot.[5] The shoes are generally removed toward the end of the shoeing cycle (4–5 weeks) when there is maximum hoof wall growth on the bottom of the foot. The length of the transition time depends on the quality of the hoof capsule structures when the shoes are removed; the author generally recommends that the horse be walked daily in hand or under saddle for the first week. If the horse remains comfortable walking, then the routine progresses to turn out in a small paddock or round pen for a few hours daily and/or slow ridden exercise through the country on firm footing for the next few weeks. At 3 to 4 weeks, if sound, the horse is started back to arena work on firm (such as turf) or deformable footing. The feet are shaped at 3- to 4-week intervals as outlined in the trim protocol above, ensuring the hoof wall at the heels and the frog remain on the same plane to ensure that the palmar/plantar section of the foot "shares the weight."

The length of the transition period depends on the condition of the feet when the shoes are removed and how the horse responds to being barefoot during the transition period. The author has had some horses go back to training in as little as 3 weeks and back to competition in as little as 5 weeks. This process is likely to be shorter when the horse goes back to work on a synthetic deformable surface versus some type of firmer footing.

Characteristics of horses that transitioned successfully from shoes to barefoot:

- The foot develops a hard hoof wall, possibly because moisture or urine were not being retained under the shoe.
- A thick sole callus formed at the sole-wall junction of the toe.
- The hoof wall-bar junction became stronger.
- The frog became thicker and wider.
- The foot changes shape by developing an increased depth (cup/concavity; Fig. 5).

Using a Modified Hoof Cast

Applying a modified hoof cast at the onset or during the transition period may augment the process and, in some cases, decrease the time necessary to transition to barefoot.[14] When removing the shoes, the condition of the hoof wall is one of the critical factors that determines if and how long it takes to transition to barefoot. The hoof wall may be thin, have poor consistency, have multiple deep hoof wall separations, and have vertical cracks around the bearing border. Furthermore, there may not be sufficient hoof wall at the bearing border of the foot to allow it to extend a few millimeters distal to the sole. The recently described modified hoof cast affords stability, provides additional mass, and protects the hoof capsule without interfering with any physiological functions or the



Fig. 5. This foot is from a competition horse that is in full work. The lateral view (left panel) shows very nice hoof conformation. The solar view (right panel) shows callus at the toe, the thick broad frog, and the depth concavity of the foot.

adaptation process. The cast is applied to the outer hoof wall so that at least 4 to 5 millimeters of the cast extends beyond the perimeter of the hoof capsule (Fig. 6). The farrier or the trainer can readily apply the modified hoof cast on a barefoot horse if indicated.

Although a modified hoof cast may be a useful aid, it should be emphasized that boots should be avoided during the transition phase as "boots are not barefoot." Boots place an interface between the foot and the ground, which changes the forces on the foot and interferes with adaptation.

Providing Traction

Most hunters, jumpers, and dressage horses perform on synthetic deformable surfaces, and traction has not presented a problem. However, some high-profile jumper classes are held on turf arenas, and horses may require additional traction, especially if the surface is wet or muddy, and this may present a problem for the barefoot horse and the safety of the rider. This can be managed by fitting a pair/set of shoes to the horse without trimming or changing the solar surface of the foot. The shoes are attached using four small nails, and when the horse has finished competing, the shoes are removed and the horse continues barefoot. This scenario requires a little more work on the part of the farrier but has been shown to fulfill the need or necessity for additional traction.

6. Veterinary Applications of Barefoot Methodology to Improve the Palmar Foot

Equine veterinarians are often confronted with horses that have lameness associated with distortion of the palmar/plantar part of the foot, especially the deformable soft tissue structures.[15] Two common problems are a sheared heel or low/under run heels combined with a negative angle of the solar border of the distal phalanx. Although many farriery techniques have been described to address these types of abnormal hoof conformations, none have shown consistent documented success.

Sheared heels are generally caused by abnormal limb and or foot conformation that leads to an



Fig. 6. Lateral (A) and solar (B) views of a modified hoof cast. On the solar view, note the layer of cast around the perimeter of the hoof wall and the palmar section of the cast removed so the cast does not interfere with the physiology of the foot.

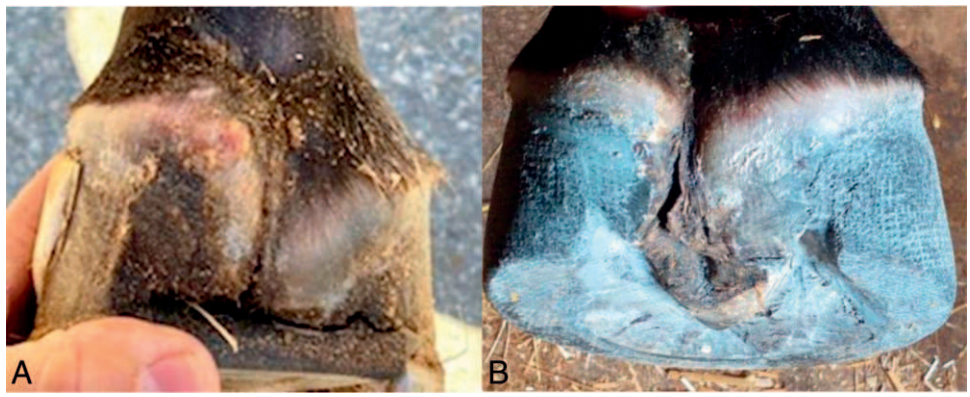


Fig. 7. A and B show a case of a sheared heel with an infected quarter crack, which is draining at the heel bulb. B shows the foot 1 week after the shoes had been removed and the heels trimmed as described in the text. A modified hoof cast was applied to stabilize the hoof wall.

asymmetrical landing pattern that overloads one side of the foot and causes proximal displacement of one heel/heel quarter at the coronet. This predisposes the foot to various injuries including bruising and quarter cracks.[15,16] Removing the shoes for as little as 7 days will redistribute the weight on the bottom of the foot and allow the displaced heel to open, relax, and descend into a more acceptable position. When a quarter crack is present, the coronet will be displaced proximally at the origin of the defect. Removing the shoes allows the coronet to settle distally into normal alignment before any type of repair is considered (Fig. 7).

Low or underrun heels develop when the heels migrate forward to a position dorsal to the base of the frog, and these cases are often shod with shoes that are too small. As the heels migrate forward, the loads applied during locomotion are distributed over a smaller surface area. The resulting increase in heel pressure reduces heel growth so the frog, which is now situated palmar/plantar to the heels of the hoof capsule, prolapses distally between the branches of the shoe. The horn at the heels is worn down further when the heels of the hoof capsule expand against the surface of the shoe. The author has consistently improved the palmar foot structures by taking the horse out of work and giving them time without their shoes.

For horses that have either sheared heels or low heels, the shoes are removed, and the feet are trimmed as outlined in the protocol above with a few differences. When shoes are removed from a horse with underrun heels, the frog will generally be located below the level of the hoof wall. The first objective is to get the frog and the hoof wall on the same horizontal plane so this section of the foot is "load sharing." This is accomplished by the sheer weight of the horse standing/walking on a firm surface during the first week after removing the shoes. Any excessive toe length is reduced using the hoof nippers as described above, taking care to preserve all mass on the solar surface of the foot and then creating a bevel in the toe. The heels can be rasped in a horizontal direction, i.e., across the frog within 10 to 14 days, allowing the



Fig. 8. A and B show a foot with underrun heels and a prolapsed frog below the level of the hoof wall. The toe length was reduced, and the horse was handled as described in the text. At 10 days, the frog was on the same plane as the heels and the heels could be trimmed. B shows the foot 4 weeks later. Note the improvement in the heel base.

folded underrun horn at the heels to be removed and the bars/angle of the sole will begin to become apparent (Fig. 8). During the period without shoes, the horse is managed as described for the transition to the barefoot state. Improvements in the integrity of the hoof wall and sole thickness can be verified with hoof testers across the dorsal sole and/or lateral radiographs. The amount of time necessary without shoes varies and is determined by the owner/trainer, farrier, and clinician. When shoes are replaced, strict attention is paid to the trim and to the size, type, and placement of the shoe using guidelines such as the hoof-pastern axis, the position of the center of rotation, and trimming to the base of the frog or to the same plane as the frog.[10]

When given the opportunity and time, the author has always rehabilitated distorted hoof capsules or poor hoof conformation without shoes and has had consistently good results over the years. Based on the records of 70 horses, 50 of which were actively competing, only 2 horses that met the prerequisites could not be transitioned from wearing shoes to barefoot. Both horses had chronic lameness issues. The average time to improve sheared heels was 7 to 10 days, and it was 4 to 6 weeks to improve low or underrun heels.

7. Conclusions

Success in transitioning horses from shod to barefoot is based on the veterinarian, farrier, trainer, and owner understanding and being willing to adhere to the entire transitional process. The essential steps are below.

- Select horses with good hoof structures or hoof structures that can improve and strengthen.
- Change the farriery from trimming the foot to the concept of "shaping" the foot.
- Be prepared to allow an adequate transition period for the feet to adapt, strengthen, change shape, and improve the integrity of the hoof capsule structures.

The authors have had consistent success in transitioning horses to barefoot primarily due to the cooperation of all parties involved. Trainers/riders state that stride kinematics change when the horse is barefoot, and they show greater clearance over the jumps possibly because of the leverage exerted at the distal end of the limb by horseshoes.

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.

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[a]Lidbeck S. (personal communication) Sweden, January 2023.

Validation of a Smart Textile System for Long-Duration Heart Rate Variability in Horses

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This study demonstrates that smart textiles can be utilized to identify arrhythmias and obtain heart rate variability (HRV) data that is of the same quality as gold-standard devices. Authors' addresses: Department of Animal Biosciences, University of Guelph, Guelph, ON N1G 2W1, Canada (McCrae, Moorehead, Pearson); Department of Research and Development, Myant Inc., Toronto, ON M9W 1B6, Canada (McCrae, Mahmam, Bashura); e-mail: pmccrae@uoguelph.ca. *Corresponding and presenting author. © 2023 AAEP.

1. Introduction

Smart textiles have been developed as a user-friendly and inexpensive alternative to standard telemetric devices, though limited validation work has been conducted for their use in horses.

2. Materials and Methods

Electrocardiograms (ECGs) were simultaneously recorded using a smart textile and a telemetric device in eight healthy Warmblood horses for 6 hrs at rest. Data were analyzed to identify arrhythmias and calculate HRV metrics [average RR intervals, the axial and perpendicular dispersions from the line of identity from the Poincaré plot (SD1 and SD2, respectively), root mean square of successive differences (RMSSD), percentage of successive RR interval differences (pNN50), and oscillations in the very-low frequency (VLF), low-frequency (LF), and high-frequency (HF) bands]. Data were compared using Bland-Altman analysis and Pearson coefficients.

3. Results and Discussion

Only physiological arrhythmias were observed, which were identified in recordings from both devices. Excellent agreement with small biases were calculated and perfect correlations ($r = 1.0$, $p < 0.0001$) were found for all metrics except for VLF and HF. Bland-Altman tests revealed a mean bias of -1.28 ms (-8.77 to 6.22) for RR intervals, 0.10 ms (-2.68 to 2.89) and -0.01 ms (-4.36 to 4.34) for SD1 and SD2, respectively, and -0.07 ms (-3.92 to 3.77) for RMSSD.

4. Conclusion

A smart textile system is a practical alternative to standard telemetric devices for arrhythmia detection and assessment of HRV in resting horses.

Research Abstract—for more information, contact the corresponding author

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Acknowledgment

Declaration of Ethics

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

Conflict of Interest

Dr. McCrae, Dr. Mahnam, and Ms. Bashura are employees of Myant Inc., the company that manufactures and commercializes the smart textile system utilized in this study. Dr. Pearson and Ms. Moorehead have no conflicts of interest. No fees were received for the data collection, analysis, or preparation of this abstract.

The Use of Heart Rate Variability to Understand Affective State of Horses: Validation of Heart Rate Monitors

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Veterinarians and researchers in the field can be confident that data collected from telemetric heart rate monitors provide accurate information to assess the autonomic nervous system, for both parasympathetic and sympathetic activity. Authors' address: Atlantic Veterinary College, University of Prince Edward Island, 550 University Avenue, Charlottetown, PE C1A 4P3, Canada; e-mail: lmcduffee@upei.ca. *Corresponding and presenting author. © 2023 AAEP.

1. Introduction

Horse-human interactions occur in many different environments under different circumstances and especially during veterinary procedures. In these interactions, the horse perceives each experience as either positive, neutral, or negative. Moreover, assessment of equine welfare during the horse-human interaction (HHI) extends beyond the animal's physical health and includes evaluation of their emotional state. HHIs can therefore have a permanent effect on establishing a horse-human relationship (a human-animal bond) that is mutually beneficial.

Negative HHIs are precursors to stress in the horse and can lead to aggressive or fearful behaviors, which can result in dangerous conditions for both the horse and the human. Recognizing that the HHI is stressful is imperative to mitigate the likelihood of injury to either the horse or the human. However, stress is a latent variable and can only be measured indirectly with either physiological estimators of autonomic nervous system arousal or by observations of specific behaviors.

Heart rate variability (HRV) describes the variation between consecutive heart beats measured as interbeat intervals. Because the irregularity of interbeat intervals arises from the dynamic interplay among the sympathetic (SNS) and parasympathetic nervous systems (PNS) in cardiovascular control, HRV measures can be used to assess the balance of the two branches of the autonomic nervous system. HRV has been used to assess stress and well-being of farm animals, including horses, under various conditions. Therefore, HRV is one measurement approach to determine, physiologically, the level of stress through autonomic nervous system arousal in horses during HHIs.[1] Equine HRV can be measured in the field with either an equine telemetric heart rate monitor or a portable electrocardiogram (ECG), where the latter technique is considered to be the gold standard.

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Fig. 1. Simultaneous placement of the ECG and heart rate monitor.

However, ECG monitors are often cost-prohibitive and inaccessible for use by clinicians, ambulatory-care veterinarians, and researchers. Conversely, the equine heart rate monitor is considered controversial by some and suggested that it be validated for each application.

The objective of this study was therefore to demonstrate the validity of a telemetric equine heart rate monitor compared to a portable electrocardiogram for analysis of HRV measures during 3 daily equine activities: standing in the stall, while in crossties, and during walking. Each of the routine activities was generally considered to be nonstressful for horses.

2. Materials and Methods

Nineteen horses were instrumented with both a telemetric heart rate monitor[a] and a portable electrocardiogram,[b] simultaneously, for 30 minutes during each activity (Figs. 1–3). Heart rate, including r-r intervals, was recorded for each device, and the data sets were downloaded and processed using heart rate variability analysis software[2] to produce time and frequency domain estimates along with nonlinear estimates of PNS and SNS activity based on Poincaré plots. Each of these estimates not only provides a comparative estimate for each monitor but also can be used to show the magnitude of autonomic nervous system control based on r-r intervals. Estimates of both PNS and SNS activity are provided as nonlinear estimates by the HRV processing software. Descriptive statistics were used to show the characteristics of the data produced by each monitor during each activity. Independent-samples *t* tests were used to compare the selected physiological variables between the heart rate monitor and the portable ECG. The measures of agreement between the heart rate monitor and the portable ECG were evaluated for each activity, independently.

The strap closest to the elbow includes the electrodes for the heart rate monitor. The strap behind that secures 3 electrodes of the ECG, while 2 are secured on the chest with superglue.



Fig. 2. Heart rate data collection while the horse is restrained in crossties.



Fig. 3. Heart rate data collection while the horse is led at a walk.

Table 1. Descriptive Statistics for Selected Heart Rate Variability Measures in Heart Rate Monitors and Portable ECGs

Activity	Variable	Portable ECG $M \pm SD$	Telemetric HR Monitor $M \pm SD$	Independent t Test
Stall	Mean HR	44.00 ± 8.9	45.79 ± 8.28	t test = 0.64 (p = 0.53)
	PNS	3.19 ± 1.81	2.53 ± 1.22	t test = 1.30 (p = 0.20)
	SNS	−2.01 ± 0.73	−1.86 ± 0.66	t test = −0.65 (p = 0.52)
Crossties	Mean HR	40.58 ± 6.32	40.94 ± 6.09	t test = −0.17 (p = 0.86)
	PNS	3.67 ± 1.89	3.21 ± 1.34	t test = 0.85 (p = 0.40)
	SNS	−2.20 ± 0.62	−2.15 ± 0.56	t test = −0.24 (p = 0.82)
Walk	Mean HR	55.72 ± 7.98	58.68 ± 8.58	t test = −1.09 (p = 0.28)
	PNS	1.24 ± 0.83	1.27 ± 0.81	t test = −0.11 (p = 0.92)
	SNS	−0.97 ± 0.62	−0.90 ± 0.63	t test = −0.33 (p = 0.74)

Abbreviations: M, mean; SD, standard deviation; ECG, electrocardiogram; HR, heart rate; PNS, parasympathetic nervous system; SNS, sympathetic nervous system.

3. Results

The results presented in Table 1 show descriptive statistics for the time domain estimate—mean heart rate, along with two nonlinear estimates, PNS and SNS measures, for each monitor, within each of the 3 activities. Independent t tests used to compare the consistency between measures showed that there was no significant difference between the heart rate monitor and the portable ECG for the selected estimates.

Measures of agreement between the portable heart rate monitor's selected measures and corresponding values from the portable ECG were evaluated with Bland-Altman plots for the variables mean heart rate, SNS, and PNS. The results presented in Fig. 4 show

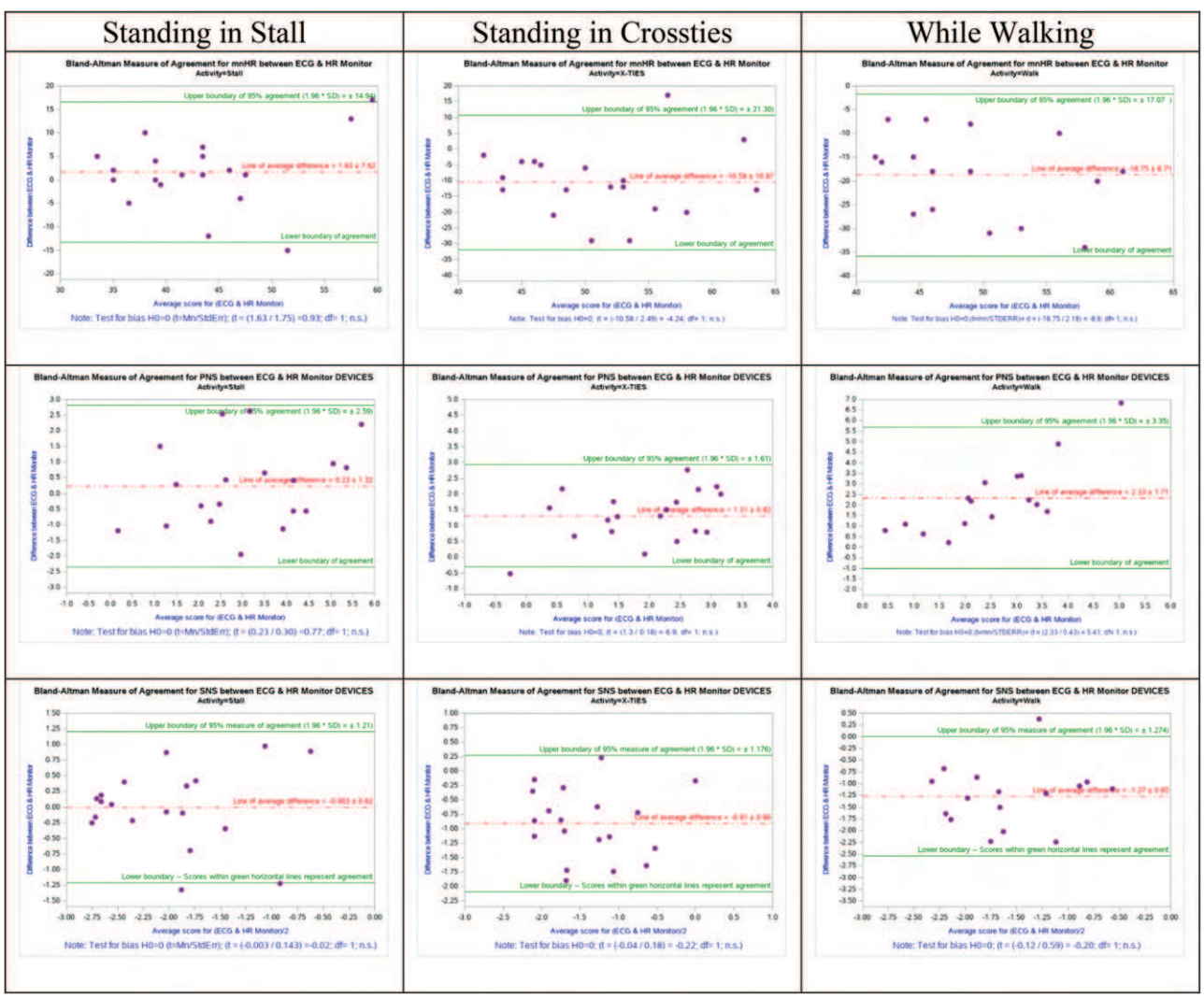


Fig. 4. Bland-Altman plots for agreement for selected HRV measures between heart rate monitors and portable ECG across activities.

that there was strong agreement (indicated by data points between the green lines in graphs) between the selected estimates of HRV for the portable ECG and portable heart rate monitors, for each of the 3 activities: standing in the stall, standing in crossties, and during the walk.

4. Discussion

Overall, the findings demonstrated that the equine telemetric heart rate monitor is comparable in accuracy to that of the "gold standard" portable ECG in obtaining heart rate variability data in horses during routine low-level activities. Results from the previous studies using the heart rate monitor during the same activities also showed good intraclass correlation estimates of reliability for most HRV measures, indicating statistical stability in a test-retest approach.[3] Heart rate monitors are inexpensive and easy to use compared to portable ECG equipment and therefore may be more practical for field and clinical applications. Most adult horses are habituated to a girth so the application of the heart rate monitor that is an elastic belt with electrodes does not cause a reaction. Based on this study, veterinarians and researchers in the field can be confident that data collected from equine heart rate monitors provide accurate information to assess PNS and SNS activity. This information can be used to assess pain and/or stress as indicators of affective state leading to improved assessment of equine welfare under various clinical conditions and environmental circumstances. For instance, HRV measures have been used as objective consistent measures in assessment of pain in horses with laminitis during short- and long-term treatments.[4] Moreover, HRV measures may be most helpful in assessing pain and/or stress in horses that have a high pain tolerance and/or passive copers that do not show obvious behavioral signs of pain and stress, respectively. While heart rate can be displayed stall side continuously using the heart rate monitor, other HRV measures require further analysis; therefore, future research should include development of a stall-side application for easier access to PNS and SNS index measures and real-time results.

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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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[a]Polar™ (V800), Polar Electro Oy, Kempele, Finland.
[b]Holter™, Forest Medical LLC, East Syracuse, NY 13057.

Understanding Practice Expenses: Where Do 100 Pennies of Income Go?

Ann E. Dwyer, DVM

Equine veterinary practices deliver a wide range of services and products to a diverse group of patients and horse owners. Equine practices also vary in size, ranging from solo ambulatory practices to hospital practices that employ dozens of veterinarians. However, all equine veterinary businesses spend their income on a finite, consistent set of expense categories. The proportion of income that is spent on these expenses is remarkably similar in all carefully managed practices, no matter the size or shape of the business. Understanding "where the money goes" is an essential part of practice management that also provides the foundation for understanding the dollars that are available to be spent on veterinary compensation. Author's address: Genesee Valley Equine Clinic, LLC, 925 Chili Scottsville Road, Scottsville, NY 14546-9751; e-mail: adwyer7579@gmail.com. © 2023 AAEP.

1. Practice Income

Ordinary veterinary practice income is derived from fees for professional services. Income related to fees for veterinary services is received in the form of credit card payments, checks, and cash. This revenue is deposited in a practice bank account and recorded in the practice bookkeeping system as well as whatever practice management system the practice uses to keep track of medical records and bill clients. The most common financial accounting bookkeeping system used by equine practitioners is Quickbooks®[a].

It should be noted that "practice income" only occurs when revenue is actually paid to the business. Many equine practices offer extensive credit to their clients and thus carry significant "accounts receivable," or ledgers of monies owed for services rendered but not yet paid for. "Gross billings" do not equal "income" until currency actually changes hands.

Many veterinary practices also receive minor amounts of revenue from activity that is unrelated to veterinary practice operations. These sources include gain on sale of assets, seminar or sponsorship revenues, fees for participation in clinical trials, client billing fees, bank account interest revenue, and discounts or rebates from suppliers for volume purchases or timely payment. Accounting software programs[a] track such revenue on the profit and loss statement (also known as the income statement) separately from income related to the delivery of veterinary services. For this paper, only income related to the actual provision of veterinary services will be discussed.

2. Practice Expense

Practice management analytics are simplified if the practice bookkeeping system is set up so that all routine business expenses are coded and tracked consistently. A comprehensive Equine Veterinary Practice

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Chart of Accounts (EVPCOA) is available as an inexpensive publication.[1] This publication presents guidelines for the organization of the practice bookkeeping system that segregates every penny of practice expense into simple, logical categories enumerated by numeric codes that reflect the operation of the equine practice. Practice expenses related to the delivery of veterinary services in equine practice can be grouped into 5 categories as outlined in the EVPCOA:

1. Cost of professional services (or cost of goods sold)
2. Facility expense
3. Office expense
4. Labor expense
5. Depreciation expense

Integrating the categories listed in the EVPCOA with the practice's system[a] provides a powerful tool for practice financial analytics. As long as income and expenses are entered in a timely and consistent fashion, the accounting software program[a] provides reports that analyze the percentage of income that is spent on these 5 categories with the click of a mouse for any given year, quarter, month, or other interval and readily compares the results to the preceding interval.

Cost of professional services (COPS), also known as cost of goods sold (COGS), is one of the largest expense categories of any equine practice. It captures the practice costs that are directly related to the delivery of veterinary services. In the delivery of their services, equine practitioners routinely do examinations, treatments, and surgeries. They also perform a variety of imaging procedures and administer and dispense many pharmaceuticals. They order laboratory tests in house and send samples to outside laboratories. Delivery of care involves the consumption of a variety of supplies including bandages, catheters, suture, gloves, syringes, needles, etc. Hospital practices incur costs to purchase feed and bedding. All these expenses fall into the category of COPS/COGS, which can be thought of as the direct costs relating to the "hands-on" delivery of patient care. Examples of expenses that qualify as COPS/COGS include bills paid to pharmaceutical distributors, bills paid to reference laboratories, the cost of vaccines, and the expenses related to archival and retrieval of digital images.

Facility expense, as defined by the EVPCOA, is the cost involved in upkeep of the various elements of the practice that allow equine veterinarians to deliver their services. These elements include the day-to-day expenses, rent, taxes, and repair costs of any "brick-and-mortar" structures associated with the business, the expenses involved in operating and maintaining ambulatory vehicles,[a] the telephone and internet costs associated with the business, and the costs to insure the variety of elements mentioned. Examples of facility expenses include monthly rent, utility bills, vehicle fuel and repair bills[b] cell and landline phone bills, business insurance bills, and property taxes.

Office expense details the direct costs involved in running the business part of the practice. These costs can be thought of as the expenses that are incurred that are *separate* from the direct delivery of patient care—costs that any business would require just to "operate" as a business that charges fees for services. Office expense details the costs of providing access to veterinary service and collecting money. It includes costs to advertise and promote the business and expenses charged by bank accounts, credit card processers, and collection agencies. It also includes the cost of purchasing computer and general office supplies, postage and printing costs, and the fees paid to payroll companies, accountants, and legal advisors.

Labor expense includes all the costs of employing and supporting the employees of the practice. Wages make up the largest portion of this part of this practice expense and include both the wages paid to veterinarians and the wages paid to various support staff. Payroll taxes, including Social Security, Medicare, state and federal unemployment insurance, and other mandatory state insurance programs related to payroll, make up an often overlooked but significant portion of labor costs. Other expenses relating to practice labor costs include the costs of workers compensation insurance, professional liability insurance, and expenses related to employee continuing education. Finally, premiums paid by the employer for employee health insurance programs and contributions made to employer sponsored retirement plans round out the large amount of money that all practices spend on labor expense to compensate their veterinary and support staff.

Depreciation expense is a system that is used for accounting and tax purposes to spread out the cost of equipment and other fixed assets over time. It requires a little accounting knowledge to understand. Unlike the other categories that involve paying a bill from a bank account, depreciation expense is a method of cost allocation, and the expense entries for depreciation require accountant oversight as well as management decisions related to prevailing tax laws and codes.

Depreciation expense relates to the purchase of items known as "fixed assets," large purchases that will be used in the business for more than 1 year. Accountants vary in their guidelines for what equipment/items constitute a depreciable asset versus small items that can be written off the year they are purchased, but in general, any item that costs more than a few hundred dollars and is expected to last more than a year is considered for the depreciation schedule. Fixed asset categories of depreciable items commonly used in equine practice include professional equipment (ultrasound machines, digital radiology equipment, laboratory equipment, etc.), computer hardware and software, office equipment, furniture and fixtures, facility maintenance equipment, and practice vehicles. Large practices may also have livestock (e.g., a herd of embryo transfer mares) and buildings. Some may have leasehold or land improvements as depreciable fixed assets.

The concept of "straight-line depreciation" relates to Internal Revenue Service (IRS) rules that assign an annual portion of the original cost of the item as an expense that approximates the ordinary wear or life span of that item. The concept can be understood by thinking about what happens when a set of truck tires is purchased. Assume for this example that this set of 4 tires costs $1,500 and is expected to last 50,000 miles. The tires are mounted on a truck that travels an average of 10,000 miles per year. If the tire tread is inspected each year, it will be apparent that 20% of the tread has worn away; thus, the useful life of each tire has reduced by 20%. Simple math predicts that the tires will need to be replaced in 5 years. If the tires were a depreciable business asset, the practice could account for 1/5 of the asset's cost over the 5 years of the asset's useful life.[c] The accounting system would make an entry of a $300 expense every year for 5 years to reduce taxable income by the amount of estimated wear and tear on the asset. The costs of purchase would be accounted for over the estimated life of the item through $300 of "depreciation expense" on the tax returns for the 5 years that include and follow the purchase of the tires.

The IRS has rules that dictate the economic life of various types of fixed assets for tax and accounting purposes. Most veterinary equipment purchases, computers, and vehicles are classed as "5-year assets" by the IRS (meaning that the costs are accounted for over a span of 5 years), while office furniture and fixtures are classed as "7-year assets" (costs are accounted for over a span of 7 years). There are other forms of accelerated depreciation that are involved in practice financial management, including a so-called "bonus depreciation" as outlined by Section 179 of the IRS tax code, that are beyond the scope of this presentation, but the concept of "straight-line depreciation" is one that every practitioner should understand.

Bookkeeping for depreciation expense is overseen by the practice accountant, but decisions on fixed asset purchases as they relate to the percentage of practice income that a practice can afford to invest over time to keep up with technology, replace broken or outdated equipment, and offer advanced services are the responsibility of the practice owner(s). In this lecture, the economics of arriving at a reasonable budget for investment in fixed assets over time will be discussed; this budget results in a relatively fixed and predictable amount of depreciation expense annually.

3. Where Does Practice Income Go?

All equine practices must take in at least several hundred thousand dollars of income in order to deliver patient services and compensate the owners and employees. The largest practices take in several million dollars of income. These numbers are intimidating for the associate practitioner whose primary concern is clinical management of cases and for young veterinarians contemplating practice ownership or compensation negotiations. But just as the concept of depreciation can be simplified by thinking about the tangible example of tread wear on a tire, the "many zeroes" of practice finance can be simplified by scaling the big numbers down to an easily imagined level.

Practices that take in hundreds of thousands to millions of dollars do it essentially one dollar at a time. Each dollar of income can be thought of as 100 pennies. Attendees for this talk will confer in small groups to arrive at an educated guess of "how many pennies" of an imaginary dollar of income are spent on each of the categories listed above. The following worksheet can be used for attendees to record their discussion group's best guess as to the allocation of how each 100 pennies of practice income is spent. After the groups present their "best guess" of expense allocations, allocations from sample practice data will be presented.

Category	Your Best Guess (# Pennies out of 100)	Real Practice Data (# Pennies out of 100)
Cost of professional services		
Facility expense		
Office expense		
Depreciation expense		
Labor expense		
Do any of the 100 pennies go toward something else?		

This lecture will use representative data reflecting typical annual expenses in a mid-sized practice to demonstrate how these predictable expenses relate to practice profit and veterinary compensation. The data is consistent with metrics published or observed by professional analysts who have tracked expense statistics[d] and net income from a broad spectrum of equine practices.[2,3]

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.

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[a]Quickbooks®, Intuit, Inc., Mountain View, CA 94093.

[b]The EVPCOA categorizes the costs associated with operating and maintaining practice vehicles as facility expenses. Some accounting ledger systems classify these costs, which include

fuel, repair, and maintenance of ambulatory vehicles, as COPS/COGS. Either way, the money the practice spends operating ambulatory vehicles that transport veterinarians as they deliver patient care is captured on the income statement. When evaluating published data about equine practice benchmarks, readers should note how vehicle expense is coded, as such costs are usually a major line item. Businesses that code vehicle costs under facility expense will see that the percentage of income spent in this category is higher compared to that with businesses that code vehicle costs under COPS/COGS. Businesses that code vehicle costs under COPS/COGS will see that the percentage of income spent in this category is higher compared to that with businesses that code vehicle costs under facility expense.

[c]Tires were chosen for this example because "tire tread wear" is an easy concept to visualize when thinking about the useful life of an item. In reality, the IRS allows a practice to expense (deduct) the full cost of a set of tires on a practice vehicle in the tax year of purchase.

[d]The paper cited as reference 3 is being presented at this conference by John Chalk. Mr. Chalk is a Certified Public Accountant with extensive experience in the equine veterinary community. His firm, Trinity Portfolio Advisors, LLC, uses a slightly different expense categorization system than the EVPCOA. In his system, expenses relating to fuel costs and repair and maintenance of practice vehicles are captured under COPS, while the EVPCOA tracks these costs under facility expense. Thus, the ratios reported for these two categories in the two systems differ (see also the first footnote in this paper). However, the EVPCOA and the Trinity systems calculate a similar final percentage for practice net income and have arrived at similar data for resultant practice labor budgets and profitability.

Veterinary Compensation: How Many Pennies Are Spent on Me?

Ann E. Dwyer, DVM

Equine practice economics dictate that approximately 26 to 27 cents out of every 100 pennies of revenue collected are available for veterinary compensation. Of each incoming dollar, 21 to 22 cents are typically spent on W-2 veterinary wages, and about 5 cents are spent on veterinary benefits, perquisites, payroll taxes, and payroll-associated employee insurance programs. Practice owners and associates will benefit from understanding practice economics as they relate to compensation agreements. Knowledge of the laws and limitations that apply to a given employment situation will help both sides agree on fair and affordable compensation plans. Author's address: Genesee Valley Equine Clinic, LLC, 925 Chili Scottsville Road, Scottsville, NY 14546-9751; e-mail: adwyer7579@gmail.com. © 2023 AAEP.

1. Veterinary Compensation Essentials

The word "compensate" is derived from the Latin word "compensationem," which means a weighting of one thing against another, a balancing. In simple terms, veterinarians employed by equine practices spend their professional time providing veterinary goods and services to patients. The animal owner(s) pay the practice money in exchange for those goods and services; this money is practice income. As was explained in the previous talk, practice income is spent on many different things, including the cost of drugs and supplies, the costs of support staff labor, and the costs involved in operating an office, providing ambulatory or hospital services, and purchasing equipment and assets. The mathematics of good practice economics reveals that 26% to 27% of practice revenue is available for veterinary compensation. Veterinary compensation expense includes a variety of benefits and perquisites in addition to W-2 paychecks. The total costs of compensation also include the employer withholdings for payroll taxes and federal and state insurance programs linked to wages.

Most equine veterinarians are not trained in economics or business and so are easily overwhelmed when thinking about the dollars involved in managing a practice, as the numbers quickly amount to hundreds of thousands, if not millions, of dollars. But any veterinarian can understand the tangible reality of a stack of 100 pennies that adds up to a single dollar. This talk will frame the elements of affordable and fair veterinary compensation by explaining how a portion of each dollar of revenue that is taken in is spent on compensation, as well as how every dollar that a practice spends on compensation can be broken down into pennies that are spent on W-2 wages, employee benefits, payroll taxes, and employment-related government insurance programs.

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2. Compensation Has Many Elements

Wages

Wages, which are equivalent to the "W-2 income" reported to the Internal Revenue Service, are the largest portion of veterinary compensation expense. Veterinarians who work for well-managed equine practices are typically paid 21 to 22 cents out of every dollar of income in wages.[1] The timing and formula of how wages are distributed varies between practices, but the stated percentage of income available for veterinary wages is consistent. Most veterinarians receive the bulk of their compensation as weekly or biweekly paychecks, but many practices also issue additional W-2 income that is linked to income production, employee performance, or provision of emergency services. Such compensation may be issued on a monthly, quarterly, or annual basis, depending on individual contractual agreements.

Benefits and Perquisites

In addition to the 21 to 22 cents of every dollar that is paid to associate veterinarians as wages, equine practices typically spend 2.5 to 3 cents on employee benefits and perquisites.[a] Practices vary in their exact compensation packages, but common nonwage benefits include employer-paid portions of health insurance premiums and employer contributions to retirement accounts. In addition, employer-paid "time off"—paid time that is used for vacation, holidays, family, or medical leave—is considered as an employee benefit. Most practices pay some compensation for the employee's professional continuing education costs and have an allowance for professional association dues and veterinary license expense. Equine practices that offer ambulatory services may allow and pay for limited personal use of a practice vehicle and may either provide a cell phone or subsidize a portion of the costs of phone and internet usage. Many practices also offer a discount on veterinary goods and services that are purchased for personally owned animals or subsidize a portion of the costs of veterinary medical insurance policies for personal animals.

The largest sums that practices spend on employee benefits go toward health insurance premiums, contributions to retirement plans, and paying for the costs of continuing education, but the costs of other perquisites such as association dues and discounts on veterinary services are not inconsequential. An example of representative total dollar costs of common annual benefits and perquisites from a sample practice is listed in Table 1. The sums listed are discretionary and vary from one practice to the next, but the numbers in the table are reflective of the costs of benefits commonly reported in budgets of prominent equine practices.

Getting back to the "big numbers" of practice finance, a practice that spends $100,000 on the W-2 wages of an employed associate veterinarian typically also spends $11,000 or more on various programs that benefit that team member.

Table 1. Sample Practice Annual Expense for Benefits Provided to Employed Veterinarians

Benefit or Perquisite	Sample Practice Expense per Veterinarian (Varies With Individual Practice and Employee Circumstances)
Health insurance premium	$3,000
Retirement plan contribution	$3,000
Continuing education registration/travel	$2,000
Professional dues	$800
Professional licenses	$600
Cell phone and internet access	$600
Personal use of practice vehicle (commuting and errands) while on call	$600
Veterinary service discounts for personal animals	$600
TOTAL	**$11,300**

3. Employer Payroll Taxes and Payroll-Associated Insurance Programs

Employer payroll taxes and withholdings for mandatory insurance programs that are based on W-2 wages comprise another significant element of the costs of compensation; such costs typically consume another 2.5 cents of every dollar of revenue. These expense costs are tied to every dollar of taxable wage that is paid out. Depending on the state of employment, these costs may exceed 11 cents for every dollar of W-2 wages. Thus, a practice that issues $100,000 of income to a veterinarian is also assessed more than $11,000 in additional costs to cover payroll taxes and insurance programs.

Table 2 outlines the current (2023) costs of payroll taxes that go to support the Social Security and Medicare programs as well as representative employer costs levied by New York State (home state of this author) for various mandatory programs. The payroll taxes and insurance costs listed in this table are automatically deducted from the practice bank account with each payroll cycle.

These are true "costs of compensation" as these programs were created for the benefit of the employees over their lifespan. The programs are in place to act as financial repositories that will provide compensation to the employee from the government in the event of retirement, unemployment, medical needs in old age, disability, or workplace injury.

4. Employee Payroll Taxes, Income Taxes, and Elected Wage Deductions That Can Save Taxes

Payroll Taxes

Payroll taxes are levied on individual employees as well as employers. In fact, employees pay exactly the same number of pennies to the government for Social Security and Medicare that employers do! This money is withheld automatically from the employee's

Table 2. Sample Costs of Government Payroll Taxes and Mandatory Payroll-Related Insurance Programs per Dollar of W-2 Wages Paid to an Associate

Payroll Tax or Insurance Program	Pennies Owed per Dollar of Veterinary W-2 Wage Paid Out	Does Cost Vary by State or Insurance Claim History?
Social Security	6.20 cents	No, federal mandate
Medicare	1.45 cents	No, federal mandate
Federal unemployment insurance	0.60 cents	Yes
State unemployment insurance	1.11 cents	Yes
Workers compensation insurance	2.12 cents	Yes
TOTAL	**11.48 cents**	**Yes**

paycheck and is deposited to the respective government account. Thus, out of every dollar of taxable W-2 wage paid by the practice to the employee, the government withholds 6.2 cents for social security and 1.45 cents for Medicare, so each "dollar of pay" is reduced to 92.45 cents before any other withholdings. Employees also may see entries for minor withholdings from their paycheck for other state-mandated programs for disability or unemployment. Since 2018, many employees have seen additional deductions subtracted from their paychecks due to laws relating to the expansion of "Family and Medical Leave" compensation programs.

Income Taxes

In addition to payroll taxes, all employees must pay annual federal income taxes, and many states (including the author's state of New York) assess income taxes as well. Employees who receive W-2 wages have an amount that approximates the predicted taxes that will be owed on each dollar of payroll deducted from the gross pay issued at every paycheck as income tax "withholdings." This amount is paid to the respective government entities, and then the total is reconciled every year when the individual files their tax return; in some cases, additional money is owed to the government, and in other cases, the government owes the individual a refund. The amount that is withheld from the paycheck is based on marital status, the number of dependents that will be claimed by the employee on their tax return, as well as the applicable tax bracket that is anticipated for the annual wages of the employee. Individual circumstances and the state of residence will dictate the amount of income tax that is withheld from an employee's paycheck, but the amount often exceeds 15% to 20%, or 15 to 20 cents of every dollar.

Employee-Elected Payroll Deductions That Reduce Social Security, Medicare, and/or Income Taxes

In today's financial world, the costs of the two largest workplace benefits, health insurance and retirement plans, are rarely borne entirely by the employer. The cost of insurance premiums for most employer-sponsored health plans is shared between employer and employee, with the employee's premium portion paid through wage withholdings. Many employers also offer employees tax advantaged programs such as individual Health Savings Accounts that can be used to pay for other costs associated with health care. Retirement plans such as 401Ks or SIMPLE IRA plans allow enrolled employees to contribute a portion of their wages to a retirement account that will provide income in their old age; depending on the plan provisions, employee contributions may be matched or exceeded by the employer.

Employees who participate in such programs can save a considerable amount of income and/or payroll taxes. The portion of wages that the employee allocates for such benefits are withheld from the paycheck by the employer's payroll service and applied toward the employee's health insurance premiums or deposited directly into the employee's retirement and/or Health Savings Accounts. Applicable payroll and or income taxes are taken out of the income that is "left over" after deductions have been made for the elected benefit program(s). Health Savings Account contributions and employee wage withholdings for a portion of the premiums of qualified health insurance programs are made with "pre-tax dollars"; no Social Security, Medicare, or income tax is withheld from the wages earmarked for these programs. Employee contributions to most retirement plans established by the employer are made with "pre-income tax" wage dollars; Social Security and Medicare taxes are withheld, but the funds put into these accounts do not incur income taxes.

An example of payroll tax savings when "pre-tax" dollars are earmarked for health benefit programs from a dollar of a typical paycheck is outlined in Table 3. The table compares the payroll tax basis of an employee who elects typical pre-tax deductions with that of an employee with no elected deductions.

The combined Social Security and Medicare taxes on $0.95 of payroll for the employee who opts for pre-tax deductions are $0.0727. The taxes on $1.00 of payroll for the employee who does not opt for deductions are $0.0765. Electing to pay the employee portion of the benefits cited in the example above would result in payroll tax savings of $38.25 for every $10,000 of gross pay, which translates to a savings of $382.50 in Social Security and Medicare payroll taxes on an annual W-2 income of $100,000. The total effect on Social Security and Medicare taxes in this example is a savings of 7.65%; the effect that similar deductions would have on income taxes varies with individual circumstances and state.

Table 3. Comparison of the Amount of a "W-2 Wage Dollar" Subject to Social Security and Medicare Payroll Tax if Pre-Tax Health Benefit Programs Are Elected or Not

	Employee Who Elects Pre-Tax Deductions	Employee Who Declines Pre-Tax Deductions
Original W-2 wage amount	100 cents	100 cents
Employee share of qualified health insurance premium	(3 cents)	0
Employee contribution to Health Savings Account	(2 cents)	0
Amount of W-2 wage subject to payroll taxes	**95 cents**	**100 cents**

5. The Reality of a Paycheck

The mandatory costs that both employer and employee pay for payroll taxes have been explained in the previous section, and the advantages realized when employees elect to pay their portion of certain employment programs through deductions of pre-tax payroll dollars are outlined above. The costs that all employers pay to provide common benefits and perquisites have also been described. These bare facts of compensation mean that no matter whether $1.00 or $100,000 is spent by the practice on associate W-2 payroll wages, the original amount does not translate to equal additions to the employee wallet or equal subtractions from the practice bank account! There are a number of hidden costs of compensation as described previously. Both employees (veterinary associates) and employers (practice owners) must understand the "reality of a paycheck," which can be summarized as follows:

For every dollar of W-2 wage that is paid to an associate out of practice income revenues:

1. The employee (associate veterinarian) takes home 25% to 30% *less* cash, depending on income taxes, employee payroll taxes, and pre-payroll tax (health insurance and health savings account) and pre-income tax (retirement savings) W-2 compensation that the employee earmarks to spend on benefits such as retirement savings, health insurance, or a health savings account.
2. The employer (practice) spends 25% to 30% *more* cash, depending on the amount paid out for employer payroll taxes, government-mandated insurance programs linked to payroll, and the costs of practice benefit programs and perquisites.

Employers and employees who keep these simple financial facts of life in mind during compensation discussions will be at an advantage when negotiating a compensation agreement that is affordable to the practice and fair for both parties.

The other fact that all parties must understand is that equine practices can afford to spend about 26% to 27% of practice income on the total costs of compensation paid out for veterinary work. The exact number may vary a little depending on the scope or size of the practice, but this "26% to 27% rule" is a useful benchmark to keep in mind when budgeting for practice labor expenses or entering compensation negotiations. That figure represents the full cost of compensation, including wages (21–22%), benefits and perquisites (2.5–3%), and payroll taxes and employment-related insurance costs (2.5%).

6. W-2 Wage Compensation for Veterinary Associates—How Are Wages Paid?

Practices use a variety of methods to pay associate veterinarians. Common plans include straight salary arrangements, income production pay, and hybrid methods that combine a guaranteed base salary with incentive pay linked to production or other metrics. The compensation terms are usually spelled out in a contract agreement or employment offer.

Veterinarians who are paid W-2 wages through a straight salary arrangement know that their wages for a given fiscal year of employment will be a set amount. A certain salary amount is agreed to be paid out for a defined time interval, usually a year, but sometimes broken down into a weekly or monthly sum. W-2 wage compensation for any subsequent year that follows is negotiated between the employer and the employee. The employer may base decisions on changes in compensation on the length of tenure the employee has with the practice, on practice profitability, on the individual income that is produced by the employee, on team or individual performance metrics, or on some combination of these analytics. The employee may negotiate for changes in the base salary in sequential years by citing measurable performance metrics that have been met or by some other criteria.

Veterinarians who are paid W-2 wages that are based solely on income production receive variable pay, depending on the amount of income that is collected in a specified period. The practice management and accounting software tracks the income that the individual bills for and collects, and the veterinarian's paycheck is adjusted at regular intervals, based on the income that is generated. In some practices, the pre-agreed W-2 wage amount that is linked to collected veterinary service income is different from the W-2 wage amount that is linked to the sale of veterinary products. The amount of monetary compensation linked to veterinary services is usually higher than that linked to product sales because recent changes in the delivery and cost of drugs and certain supplies has reduced the profitability of product sales. In large practices, the production income that is paid to hospital clinicians and/or specialists may be based on a

scale that is different from that used for ambulatory clinicians.

Veterinarians who are paid on a hybrid "base plus" compensation agreement are guaranteed a base W-2 wage that is specified as an annual, weekly, or monthly salary. This base amount is paid out no matter what level of income production is generated by the employee. However, the compensation agreement promises the employee additional compensation if a certain performance threshold is exceeded. The most common performance threshold is a specified amount of collected income within a set time period. That period may be tracked monthly, quarterly, or annually. Veterinarians who enter into employment agreements with relatively low base salaries may be eligible for bonus checks on a monthly or quarterly basis. Veterinarians who have agreements with relatively high base salaries may only be eligible for an annual bonus check. In either case, if the individual generates income for the practice that exceeds the specified threshold, the employee realizes significant increases in take home pay. Veterinarians who qualify for bonus payments usually reach their threshold income goals through a combination of clinical skills, efficiency, and consistent client interactions that promote repeat business and loyalty.

The main advantage of a straight salary compensation method is that it provides a fixed income that is guaranteed. This method is often used for new hires or young associates who are cultivating their clinical skills and efficiency. Disadvantages to the employee include the risk of being underpaid for the contribution that is being made to the practice. The employer, on the other hand, risks overpaying a poorly producing employee by guaranteeing a salary that may exceed the employee contribution to the practice financial picture.

Advantages of wages that are strictly based on production are that "pay" is linked to actual practice income, which can be enhanced through effort on the employee's part, including strong clinical skills, efficient work habits, and the cultivation of client loyalty. Thus, the employee has a lot of control over the outcome, but as compensation expense is directly linked to actual revenue, the system protects the employer from paying too much. There is no "ceiling" for the total sum that can be earned by the employee beyond the volume of services that the practitioner can realistically provide and the fees that the practice charges for those services. However, living on pay based solely on production can be challenging due to the seasonal nature of equine practice, which always includes a "slow time" where income lags and the resultant W-2 income for the associate may be low.

Various hybrid "base plus" compensation methods are common in equine practice because they provide the comfort and steady cash flow of a guaranteed weekly or biweekly paycheck yet also offer the incentive of extra pay for high-performing employees. Though any production-based compensation method can foster unhealthy competition where team members volley for clients, cases, and income, practices that craft thoughtful "base plus" compensation schedules can create agreements that reward individual excellence and efficiency without undermining collegial teamwork and cooperation.

7. Clarifying Compensation Expectations

Whatever compensation method is agreed on between employer and employee, the specifics should be spelled out in writing. The various elements including wages, benefits, and perquisites that the practice offers are outlined for a given employment period, usually 1 year. Whether in the form of a contract or an employment offer, documentation of compensation terms should be clear and specific. Prior to renewal of any employment agreement, both employer and employee should sit down and discuss compensation so that both are "on the same page" as to how and when the various costs of compensation will be paid out. The employee should be updated about opportunities available for participation in various pre-tax payroll deduction programs. Both employer and employee should be clear on issues like reimbursement or direct payment for professional licenses, association dues, and cell phone usage. Options for retirement and health plan contributions must be discussed and chosen. Payment of registration and travel costs for continuing education, as well as time off for vacation, medical, or family leave and discounts/limits on services for personal animals, should be clearly understood. In a nutshell, the practice should "say what it is going to do, and do what it says," and the employee should do the same!

The employee must have a clear picture of what money and benefits the practice has promised and should not be surprised by any allotments of practice resources or money as the year unfolds and the various elements of compensation are paid out. The employee must also have a good grasp of the expectations that the practice has for their contribution to the business. Associates and practice owners both benefit from well-designed, regular reports that share data on the costs of compensation as well as individual production figures that track how well W-2 wages and benefit costs are linked to the economic value that the employee provides to the practice.

8. Final Comments on Veterinary Compensation

A variety of strategies are used to craft compensation policies that are fair to the associate veterinarian and affordable for the practice, but both employer and employee must be careful in calculating the costs/outcomes of various "what if" scenarios. The key fact to keep in mind is that a practice can afford to spend about 26% to 27% of the income an individual generates on direct veterinary compensation costs, which include wages, benefits and perquisites, and payroll taxes/payroll-affiliated insurance programs. Some practices may pay a bit more and some a bit less,

depending on desired profit and other factors, but no practice can afford to pay costs of compensation that total a *lot more* than 26% to 27% of income generated, and no practice should shave the costs of compensating an associate to a number that is a *lot less* than 26% to 27% of income generated!

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 and Footnote

1. Chalk J, Maixner A, May M. Equine financial statement benchmarks, in *Proceedings*. Am Assoc Equine Pract 2023:69:275-282.

[a] The percentage quoted here is derived from the author's experience as an owner and from examining data shared by other practice owners during her former membership in Veterinary Management Group 7. It is supported by data tabulated in the paper by John Chalk cited herein. Mr. Chalk's data are being presented during this meeting in a separate session.

The Use of Support Staff to Maximize Veterinarian Effectiveness

Mike Pownall, DVM, MBA

With the chronic shortage of veterinarians facing the equine veterinary profession, thoughtful practice owners and managers will need to investigate ways to improve veterinarian efficiency while upholding the highest standards of patient and client care. While many equine veterinary practices use support staff, such as credentialed veterinary technicians, veterinary assistants, and receptionists, there are a growing number of veterinarians who are exploring additional ways these support team members can be used to increase their time seeing patients while improving professional and personal satisfaction.
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1. Introduction

Veterinary practices everywhere are struggling with a shortage of equine veterinarians entering and staying in the equine veterinary profession. As a result, fewer veterinarians have to care for more patients, leading to an increased chance of veterinary burnout and a further increase in those leaving the profession. This ongoing veterinary shortage has become self-perpetuating, and the only way to interrupt this negative feedback loop is to look at the options available to veterinarians to see more horses efficiently while maintaining quality patient and client care.

With the growing popularity of a 4-day work week in the veterinary profession, the demand for work–life balance to attract and retain veterinarians, and increasing compensation, there are further demands on the profession to challenge the traditional delivery of equine veterinary care. This need is of particular importance to equine ambulatory veterinarians since the use of support staff in hospital settings is standard.

In the 2018 AAEP/AVMA Economic Survey, it was found that the ratio of support staff to veterinarians is 1.7, 16% of practices used no support staff at all, and only 35.2% of practices used licensed veterinary technicians (LVTs) or veterinary assistants (VAs) on ambulatory calls.[a]

The author's veterinary practice and those of some colleagues have been exploring how to expand the roles of LVTs, veterinary assistants VAs, and receptionists to have more client- and patient-facing roles to offload responsibilities from veterinarians so they can see more patients during a normal work day or have fewer post-patient care responsibilities at the end of the day like medical records, client communication, or preparing laboratory submissions. Some veterinarians are using more than one LVT or VA when they see patients, while others are using them to see patients independently for bandage changes, suture removals, or therapeutic laser appointments. Finally, in discussions with veterinarians, many see the value of

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working with a support team to help deal with challenging cases or clients. Knowing that they have someone they can commiserate with after an appointment or a tough day has an immediate emotional benefit for veterinarians.

What these practices have in common is their willingness to find those procedures that do not require a veterinarian to perform and utilize trained support staff to complete these procedures.

2. The Solution

For a practice to begin using support staff, or to enhance their use, there are 5 factors to consider that will improve the success of these initiatives: economics, practice culture, training, regulations, and client expectations.

3. Economics

There is a cost associated with hiring extra employees, and the uncertainty of knowing if the additional expense can be justified is often a limiting factor in hiring for a new role. In the same AAEP/AVMA economic survey mentioned earlier, single vet practices without a support staff employee had annual gross sales of $205,000, while those with support staff grossed $125,000 more, for a total of $330,000. In other words, veterinarians with support staff were 1.6 times more productive than those without. While only a correlation, it isn't hard to make an argument in favor of support staff bringing a positive economic impact to a practice.

At the same time, there are other factors that have a less direct economic impact that should be considered:

- Reduced chance of injuries from having a trained assistant holding a horse.
- Reduced veterinarian dissatisfaction with many technical and administrative processes taken off of their plate, like invoicing, laboratory submissions, and client follow-up communication.
- Reduced risk of items not being billed because someone other than the veterinarian can invoice appointments or track inventory usage.
- Use of support staff to perform non-veterinarian required procedures like bandage changes, suture removals, or therapeutic laser appointments.
- These examples all have a fee charged to the client, so support staff can be revenue generators on their own. Several practices known to the author use LVTs or VAs in this manner. They charge a reduced call fee since a fully stocked veterinary truck is not needed.

4. Practice Culture

Over time a practice develops a culture, an unwritten way of doing things in a business. When a practice has not used, or has underutilized, support staff, there is a way of thinking, or way of doing things as a solo veterinarian that will need to be addressed when support staff are introduced.

Initially, veterinarians will worry about the risk of mistakes happening as they use another person to assist them. Proper training, as discussed in the next section, can greatly reduce the chance of this happening, but changing how one works during an appointment is a big adjustment for some. Usually, this apprehension is short lived as veterinarians quickly realize the benefits of a LVT or VA when they help them on the road or a receptionist that can create new client/patient files, follow up on payments, coordinate prepurchase exams, or prepare laboratory submissions.

In addition, veterinarians that are used to working independently will have to adjust their communication skills while working with a veterinary technician. For example, they will have to develop a habit of introducing their assistant to clients as well as develop comfort in directing the technician in the required activities for appointments. When once the veterinarian had to bring equipment from their vehicle, they will have to direct or help their assistant to do the same. Some veterinarians who are not used to having a technician will continue managing an appointment like they did when on their own, and they will need to get used to using their new technician to their fullest ability.

5. Training

As discussed, there will be some veterinarians who are so used to working independently that introducing a new person to the workflow can be quite disruptive. Usually, there is a fear that mistakes will be more prone to happen with a new person involved. This is why proper training of a new employee in a new role is necessary. Not only does it set standards for all of the various tasks performed during a day, but it also gives the employee confidence in their role because they know what is expected of them, and they know what it takes to perform the job well. Proper training also helps facilitate the integration of the new role into the workday by showing immediate value of what they offer to the veterinarian.

6. Regulations

Every jurisdiction has their own regulations as to what LVTs and VAs can do with or without supervision. Some states and provinces offer a broad scope as to what they can do, while others are very restrictive. Before sending out a support staff member to perform an appointment on their own, familiarizing oneself with the appropriate regulations is important.

7. Client Expectations

Just as veterinarians who are used to working independently have to adjust to having help, clients will have their own concerns about someone else helping the vet. Usually, this is very short-lived once they

realize the value they get from the extra person too. There are many examples of the benefits clients receive when a veterinarian uses support staff:

- Not having to hold or move their horse for procedures. This allows them to fully participate in the appointment and not be stuck holding or jogging their horse. This allows for better client communication and compliance since they are fully engaged.
- Barn owners and trainers are facing their own challenges hiring employees, so they value those veterinarians who bring their own staff to help with appointments. This means the veterinarian is not using farm employees during procedures. One colleague had a barn manager tell them that they prefer working with the vets of their practice because they came with assistants, so his employees can focus on cleaning stalls and turning out horses. He started paying less overtime when he began using their practice because his barn employees weren't being pulled away from their own work.
- LVTs and VAs can play an integral role in client communication. They can often recognize when the veterinarian is not getting through to a client or when the client is confused and can act as a kind of interpreter between veterinarian and client in some situations, making for a better client experience and compliance in patient care.

8. Conclusion

There are several economic, safety, and quality of life benefits with using support staff in equine veterinary medicine. While the majority of practices use support staff, many don't use them at all, and many don't use them to their full potential.

Not only will using support staff demonstrate economic benefits to a veterinary practice, they will also play an important role in professional and personal satisfaction for veterinarians so that they potentially stay longer in a practice. At the same time support staff usage can be a major factor in hiring a new veterinarian as they are becoming an expectation for new veterinarians.

Acknowledgments

Declaration of Ethics

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

Conflict of Interest

Dr. Pownall is a partner in McKee-Pownall Equine Services.

Footnote

[a]American Association of Equine Practitioners. Economic Report (4_1_2019). https://aaep.org/sites/default/files/Documents/2019%20FINAL_AMVA_AAEP_Equine_Report.pdf

Purchase Exam Considerations for the Western Performance Horse

Sherry A. Johnson, DVM, MS, PhD, DACVSMR*; and Angie M. Esselman, DVM

Being at least peripherally aware of sport-specific considerations, expectations, and terminology will enable the equine veterinarian to navigate western performance horse purchase exam interpretations and assist in subsequent buyer recommendations. Authors' addresses: Equine Sports Medicine and Rehabilitation, 8386 FM 455E Pilot Point, TX 76258 (Johnson); Department of Clinical Sciences, Orthopaedic Research Center at the Translational Medicine Institute, College of Veterinary Medicine and Biomedical Sciences, Colorado State University, Fort Collins, CO 80526 (Esselman); e-mail: sherryjdvm@gmail.com. *Corresponding and presenting author. © 2023 AAEP.

1. Introduction

As horses continue to be utilized in a wide range of highly competitive equestrian sports, the importance of purchasing horses orthopedically, medically, and behaviorally suited for particular athletic demands places the veterinarian in a pivotal position to help advise acquisition decisions. The veterinarian's role in the purchase examination is to medically assess a horse's suitability to perform the intended or projected athletic task and identify abnormalities that may preclude a horse from performing its desired use. In doing so, the veterinarian is commonly asked to speculate on future orthopedic or medical issues that may arise based on particular examination findings, which are impossible to predict yet inevitably requested by buyers. The purchase exam scenario carries inherent liability to provide sound medical recommendations to a buyer, but having sport-specific knowledge and at least a broad understanding of expected athletic demands positions the veterinarian much more favorably to provide useful insight to their client. Additionally, in a recent survey conducted by the American Association of Equine Practitioners (AAEP), sport familiarity was acknowledged by owners as being important to their overall satisfaction with their veterinarian.[1] Comparable to human athletes, a gymnast's suitability to play football (or vice versa) would be incredibly difficult to assess if the doctor was unaware of inherent sport-specific demand differences and colloquial terminology. Similarly, purchase considerations for western performance horses differ from that of English sport horses, for example, due to the nuances of competing in western sports, owner/trainer expectations and industry-specific, stylistic considerations. Therefore, the objective of this overview is not to exhaust evaluation protocols for a purchase examination but rather highlight the nuances of assessing the western performance horse in the purchase exam scenario.

2. Defining a Western Performance Horse

While the American Quarter Horse Association (AQHA) remains the single largest breed registry in

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the world,[2] horses descending from the Quarter Horse lineage have since spawned into several different associations (APHA, NRHA, NRCHA, etc.) that compete successfully in a variety of specific events. Subsequently, differences in conformation and body type have been selectively prioritized according to the horse's desired discipline. In a recent investigation, a "western performance horse" was defined as a horse "actively competing in or intending to compete in any American Quarter Horse Association (AQHA), American Paint Horse Association (APHA), National Reined Cow Horse Association (NRCHA) or National Reining Horse Association (NRHA)-recognized class."[3] This updated definition recognizes that there are now several disciplines (other than that of just roping or barrel racing, for example) for which Quarter Horses or lineages thereof compete in that differ significantly in athletic demand and oftentimes clinical presentation.

Cutting horses are bred for agility and the ability to perform quick, torsional movements secondary to intrinsic cow sense (the ability to directionally anticipate a cow's movement). Cutting horses (Fig. 1A) tend to be smaller in overall body frame and not as heavily muscled as roping horses that require additional power and explosive strength. Barrel horses (Fig. 1B) are often descendants of sprint (racetrack) Quarter Horses but can often have mixed bloodlines from roping as well. Reining horses are typically smaller in frame (similar to the cutting horse) but are built to perform dynamic, calculated maneuvers such as sliding stops (Fig. 1C) and spins. The cow horse was bred to be a mix of both cutting and reining styles with additional endurance to control a cow working down the fence (Fig. 1D).[4] Western pleasure horses (Fig. 1E) have a less angular body type with little lower limb action allowing them to perform collected soft gaits.[5] All-around western performance horses have been defined as those horses competing in a combination of at least two of the following events: western pleasure, western riding, western horsemanship (Fig. 1F), or trail (Fig. 1G), and represent the vast majority of western "show" (non-cow or speed-specific) horses in use today.[3,6] These horses, while bred the same as western pleasure horses for slow gaits and lower limb action, are usually selected for a larger frame and the ability to elongate or extend their stride while performing particular maneuvers such as flying lead changes or trail patterns involving obstacles. Halter horses (Fig. 1H) are bred for their large, heavily muscled stature and straight limb conformation. All of these unique disciplines within the western performance industry require the equine athlete to utilize various physical qualities to compete optimally.

3. Understanding Western Performance Competition Levels and Prospective Use

When it comes to AQHA-sanctioned events, three major divisions for human competitors exist: Youth, Amateur (adult non-professional), and Open. A youth exhibitor is aged 18 years or younger whereas an amateur (adult non-professional) exhibitor is at least 19 years of age and has not shown, judged, trained, assisted in training a horse or instructed/coached a non-family member for compensation within three calendar years.[7] Within the amateur division a further classification exists which includes amateur exhibitors older than 50 years of age, referred to as a "Select Amateur." Additionally, AQHA classes are leveled according to exhibitor and horse records, based on both points and awards earned.[7] The open division levels are based on a horse's individual points whereas the youth, amateur, and select amateur divisions are categorized by the exhibitor's show record. The levels include Rookie (most novice rider), Level 1, Level 2, and Level 3 (highest competition).[7]



Fig. 1. Quarter Horses competing in a variety of western performance horse disciplines. A, cutting; B, barrel racing; C, reining (sliding stop); D, working cow horse (taking a steer down the fence); E, western pleasure (jog); F, western horsemanship (pivoting during a pattern); G, trail (a walk-over); H, halter. Photos courtesy of the American Quarter Horse Association (AQHA).

Not only are riders divided by experience level, but horses are as well to foster well-matched competition. For both amateur and open levels, horses are classified as "junior" or "senior" horses according to their age. Other than weanling and yearling classes, a horse is considered a "junior" horse if it is 5 years of age or younger while a "senior" horse is 6 years or older. Additionally, the "green" horse classification designates a horse that has not earned more than 25 points in a respective class.[7–8] The "green" horse designation facilitates competition of horses of similar experience levels in specific classes.[7–8] A horse can be considered "green" in one class and not in others. A seasoned western pleasure horse can be considered "green" in the western riding, for example.

The specific division and level a horse will be expected to perform at is important because an advanced level of skill is needed to be successful at higher levels of competition. For example, a much higher caliber of horse that can perform gaits and maneuvers effortlessly with good "rail presence" is needed for a level 3 open rider to be competitive, compared to a level 1 amateur select rider that can be successful with a horse that is able to perform its job well, but maybe not as well stylistically. Oftentimes, horses will be purchased to be used by both an amateur owner and the open level trainer. Competing at both the open and amateur levels will require the sustainment of a much larger workload, with more classes to prepare for and subsequently compete in.

Lastly, it is crucial for a veterinarian to fully understand a buyer's motivation and comfort in terms of purchasing a well-established athlete already competing at the intended level compared to a prospect that will have to undergo a significant increase in workload to eventually compete. For example, a horse with pathologic changes on radiographs that is already successfully competing at the intended level may be considered lower risk for a potential buyer compared to a much younger prospect with the same radiographic abnormalities because the prospect's ability to sustain an increase in workload is unknown. Additionally, clarifying a buyer's motivation for re-sale compared to retaining ownership is a key piece to being able to help interpret the importance/relevance of exam abnormalities. Current use, intended use, buyer motivation and future marketability are crucial things to understand, particularly for the purchase exam of western performance horses. Through understanding and helping buyers navigate this decision-making tree, the veterinarian will be better positioned to help provide key insight for buyers to hopefully make more informed acquisition decisions and estimate potential risk.

4. Gathering a Thorough History: Key Questions to Ask

Similar to purchase exams for other disciplines, understanding a horse's history, behavioral characteristics, and other nuances is the key to building a foundation of knowledge for both the buyer and veterinarian. The authors acknowledge this is not an exhaustive list nor is it exclusive to only the western performance horse, but in the authors' experience, provides a base of information particularly pursuant to the western horse that can help focus the discussion regarding the horse's previous health and orthopedic history.

Although sometimes tedious, gathering and documenting the most information possible regarding all aspects of the horse's history helps ensure a comprehensive purchase exam is performed. Recent systemic medication administration, joint injection histories, vices (cribbing, weaving, hauling, clipping, etc.), previous surgeries, and results of previous examinations and/or radiographic evaluations are routinely documented (when available). Comparing current radiographs to previous radiographs (if released by the seller) can be beneficial to qualify the progression of previously diagnosed osteoarthritis, for example. The horse's age at the time of purchase exam is also an important consideration. The spectrum of orthopedic abnormalities will vary quite substantially when considering a yearling, 3-year old, 7-year old, or 20-year old horse, for example. Compared to English Sport horses, western performance horses tend to compete at much younger ages (the 3-year old year has a high earning potential for reining horses, for example).

Genetic lineage and 5-panel test results (if available) of the horse in consideration for purchase are also noted during a western performance horse purchase exam. The key genetic diseases included in a 5-panel test that AQHA recognizes for horse registration include: Hyperkalemic Periodic Paralysis (HYPP), Glycogen Branching Enzyme Deficiency (GBED), Hereditary Equine Regional Dermal Asthenia (HERDA), Malignant Hyperthermia (MH), and Polysaccharide Storage Myopathy (PSSM).[9] HYPP was first identified in the Quarter Horse stallion "Impressive" who competed successfully for many years as a halter horse because of his superior muscle definition and conformation. Horses affected by HYPP have sodium channel defects, leading to detrimentally high levels of systemic potassium. The most common clinical sign of HYPP is muscle fasciculations.[10] According to AQHA, approximately 4.4% of Quarter Horses are HYPP carriers.[9] Also according to AQHA, approximately 10% of Quarter Horses are carriers of GBED, and it is most commonly found in the western pleasure and cutting horse bloodlines.[9] HERDA, the disease known for loose and hyperextensible skin has been traced back to the stallion Poco Bueno and is most commonly reported among cutting horses.[11] MH has not been linked to a specific sire lineage but is most common within Quarter Horses.[12] PSSM, more specifically PSSM type 1, has been found to be a cause of exertional rhabdomyolysis among Quarter Horses and related breeds.[12–13] The most recently identified genetic disease affecting Quarter Horses and related stock horse breeds is Myosin Heavy Chain Myopathy (MYHM). MYHM can have two different clinical presentations, that of non-exertional rhabdomyolysis and immune-

mediated myositis (IMM), with the latter being most prevalent in reining and working cow horse disciplines.[14–15]

Lastly, it is imperative to consider the horse's previous, current, and anticipated athletic use. As previously discussed, it is essential for the veterinarian to consider if the horse is a prospect being purchased to compete at the same or even lower (amateur) level. Additionally, it is important to know if the buyer plans to continue competing in the same events or transition to a new event(s). The results of the passive and active evaluation often help guide the determination as to whether that is realistic or likely to be hindered by identified orthopedic abnormalities.

5. Passive Examination Considerations

As with the purchase exam of any equine athlete, a thorough physical examination that evaluates general systemic health, conformation, dental occlusion, weight, hair coat, hoof quality, shoeing, and all body systems including cardiopulmonary, reproductive, ophthalmic, and gastrointestinal is recommended for western performance horse purchase exams. Submitting blood to identify and quantify the presence of systemic medications is commonly utilized during western performance horse purchase exams to confirm the presence or absence of any pharmaceuticals at the time of examination, with particular emphasis being given to pain relieving medications, sedatives, and long-acting tranquilizers. Analgesics, performance modulating medications or sedatives may mask physical or negative behavioral attributes of a horse during a purchase exam. Further hematologic testing (complete blood count, chemistry, metabolic panel, etc.) is performed as indicated by the physical examination and/or at the buyer's request.

In addition to standard limb palpation, functional assessment of the axial skeleton (cervical, thoracolumbar, and pelvic regions) is also strongly encouraged. The functional evaluation of the axial skeleton should include an assessment of spinal motion quality, muscular timing, and neuromuscular control (i.e., core stability).[16] It is also important to evaluate lateral cervical bending, ventral cervical flexion, and the ability to flex and extend the entire head and neck region from both quantitative (e.g., range of motion) and qualitative (e.g., ease and fluidity) perspectives.[17] Tail function as a means to identify inappropriate cosmetic alteration is also routinely assessed during a western performance horse purchase exam via rectal stimulation to remain in accordance with standards set forth by the AQHA. According to the AQHA rulebook, normal/acceptable tail function is defined as "being able to raise the tail to or above the horizontal plane."[7] Lastly, a horse's overall disposition should be considered in terms of their intended use at the time of purchase exam. A buyer's decision to proceed with the transaction (or not) is ultimately their choice, but at minimum, a discussion of observed behavioral vices or attitude (particularly for amateur owners) is often warranted if the intended use does not align with the perceived temperament of the horse.

6. Active Examination Considerations

Following a comprehensive passive (palpation) evaluation, an active examination typically is performed. Ideally, the authors prefer to evaluate horses on various surface types (lunging on an arena surface and performing flexion tests on asphalt, if situationally appropriate). Evaluation of all gaits is typically pursued with the horse on a lunge line to be able to evaluate gait symmetry, transitions, and overall temperament. Stylistic considerations and quality of movement are usually considered in light of lameness and/or asymmetry (loping more comfortably one direction than the other, for example). Additionally, the horse may be evaluated under saddle, but this is situationally dependent as is the evaluation of sport-specific maneuvers. Following lunging evaluation, flexion tests are a routine aspect of the active exam. The number and type of flexion tests performed are clinician dependent and situation-based. In the authors' opinion, clinical soundness at the time of examination in absence of systemic medications and relative to proximity of intra-articular therapies is one of (if not the most) important attribute to consider during the purchase exam of a western performance horse.

From a clinical lameness perspective, several investigations have reported both the prevalence and characteristics of western performance horse lameness.[3,18–22] Swor et al. reported that cutting horses examined for lameness or poor performance had a higher prevalence of musculoskeletal problems affecting the hind limbs (63%) compared with the forelimbs (31%).[18] Authors also noted that synovitis or osteoarthritis of the stifle and distal tarsal joints were the most common musculoskeletal abnormalities.[18] Additional reports of distal tarsal osteoarthritis as a source of lameness in several western disciplines have been well documented.[19–22] Interestingly, Johnson et al. reported reining horses' hindlimb lameness more commonly localized to the distal tarsus than the stifle, in comparison to all-around western performance horses that localized more frequently to the stifle than the distal tarsus.[3]

Several studies have also described the forelimb of western performance horses to be the most common source of lameness or poor performance.[3] In a study that looked at lameness evaluations and diagnostic blocking of 2512 western performance horses, authors concluded that 56% of cases were primarily forelimb in origin.[3] Of those cases, forelimb lameness localized to the distal limb in 40% of cases. Interestingly, trends of forelimb vs hindlimb lameness were noted according to specific western disciplines.[3] For example, the most common type of lameness with all-around western performance horses was hindlimb lameness (26.5% prevalence) in contrast to reining horses that presented with a single forelimb lameness (22% prevalence).[3] Additional studies have documented the

forelimb in barrel racing and roping horses to be the most common source of lameness.[21–22] In barrel racing horses, forelimb foot pain and osteoarthritis of the distal tarsal joints were the most commonly identified abnormalities[22] compared to the metatarsophalangeal joint osteoarthritis in heeling horses.[21]

7. Radiographic Evaluation: What is the "Norm"?

Following active evaluation, radiographic examination is typically pursued, the extent of which is buyer dependent and often guided by pertinent findings during the passive and active exams. For western performance horses, the most commonly radiographed regions for purchase exam purposes include the front feet, tarsi, stifles, and fetlocks (both forelimb and hindlimb). Carpal radiographs may also be warranted based on examination findings. Standard radiographic projections are recommended, but financial constraints may warrant more limited exams. Additional (specialty) views may also be acquired to provide a more comprehensive evaluation of particular anatomic regions. A dorsoproximal-dorsodistal (flexed skyline) view of the metacarpophalangeal joint can provide additional information regarding the distal metacarpal/metatarsal condyle, for example. Cervical and thoracolumbar radiographic evaluations are also performed, if indicated, based on active/passive examination findings. The clinical relevance of identified radiographic abnormalities at the time of purchase exam remains subject to interpretation based on several factors including the horse's clinical soundness, signalment/intended use of the horse, and buyer-seller negotiations.

Pursuant to western performance horse disciplines specifically, two previous investigations have documented radiographic findings of various anatomic regions.[23–24] When Contino et al evaluated radiographs of 458 cutting horse prospects, 89% of horses had abnormalities on purchase exam survey radiographs.[23] The majority of abnormalities were noted in the tarsi (69.4%), followed by the stifles (44.5%), hind fetlocks (43.7%), fore fetlocks (36.3%), and carpi (7.9%).[23] Subsequently, this same research group then investigated the potential association between these radiographic findings and subsequent performance of Quarter Horses competing in cutting events.[24] Specifically, the presence of mild distal tarsal osteophytes was associated with lower mean earnings as a 4-year-old, while the presence of hind pastern osteophytes was associated with increased odds of earning money as a 4-year-old.[24] Interestingly, radiographic lesions of the medial femoral condyle of the stifle joint were not found to be significantly associated with subsequent performance.[24] Authors then concluded that most abnormalities identified on repository radiographs were not significantly associated with subsequent performance.[24] Lastly, King et al reported large osteochondral defects (>1cm) were found more frequently in the forelimbs of Quarter Horses used for western performance events compared to other types of horses and the most common locations were the proximal aspect of the proximal phalanx and the medial condyle of the third metacarpal bone.[25] With continued reporting of western performance horse purchase exam findings, further insight into specific considerations can be expected.

8. Additional Diagnostics

The need for additional diagnostics such as limb ultrasound and/or upper airway endoscopy is dictated by abnormalities noted during the active and/or passive examination or at request of the potential buyer and vary according to the situation. Ultrasound of soft tissue structures is commonly pursued when mineralization is identified radiographically or when periligamentous thickening/flexor tendon swelling is noted during the passive exam, for example. Upper airway endoscopy is recommended if respiratory noise is noted during examination, or if indicated by a history of exercise intolerance. With increasing availability of advanced imaging techniques, particularly those systems that do not require general anesthesia, some potential buyers may request magnetic resonance imaging (MRI) or computed tomographic (CT) imaging prior to purchasing a horse. Reproductive and/or full intraoral dental evaluations are also performed as indicated, in addition to the previously described genetic and systemic blood panels.

9. Conclusion

As with all athletic disciplines, nuances exist in assessing the western performance horse in the purchase exam scenario. In a perfect world, all clinical evaluations would reveal soundness, and radiographic examinations would be deemed normal, but rarely is that the case in the purchase exam scenario.

Acknowledgments

Declaration of Ethics

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

Conflict of Interest

Dr. Sherry A. Johnson is a senior partner and managing rehabilitation veterinarian at Equine Sports Medicine and Rehabilitation (Pilot Point/Whitesboro, TX).

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Imaging Considerations in the Sport Horse Purchase Examination

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Proficiency at the sport horse purchase examination requires experience in individual disciplines and clear communication between the veterinarian and client. Author's address: Miller & Associates, 120 Nichols Road, Brewster, NY 10509; e-mail: kit@miller-dvm.com. © 2023 AAEP.

1. Introduction

The sale of individual horses to both professionals and amateurs within the sport horse industry often hinges on the purchase examination, typically comprised of clinical, laboratory, and imaging evaluations. The advent of portable digital radiography and ultrasound has greatly expanded the veterinarians' capacity to acquire images, and, in some sport horse markets, the number of anatomic regions examined during a routine purchase examination has increased considerably. The added information afforded by these images does not always facilitate decision making, however. There is little to no objective data on performance or soundness outcomes of sport horses correlated to the image findings during the purchase examination. The wide variation in rider experience, competition and training schedules, and the varied ages of the horses being subject to a purchase examination make such assessments problematic.

2. Lack of Guidelines and Definitions

Unlike horse sales at public auction, there are no industry guidelines for the veterinarian or client in the performance of a sport horse purchase examination. In fact, the AAEP specifically declines to establish any such standard.[1] This can be a source of confusion for buyers, many of whom are not industry professionals and often rely on the counsel of their representatives in the transaction, their trainer, and their veterinarian. The goal of the purchase examination should be to assess the horse's ability to meet the buyer's expectations in the intended discipline, and the examining veterinarian must have a clear understanding of those expectations to help guide the client in the decision of which images, if any, are indicated. It is an essential part of the sport horse purchase exam process for the buyer to be made aware of the available options. If the buyer wishes to have imaging performed, the veterinarian should discuss which anatomic regions to radiograph and whether or not to perform an ultrasound examination or other ancillary procedures and document the buyer's decision. This is extremely important and can help protect the veterinarian should any dispute arise subsequent to the examination. Many show horses have protracted athletic careers and may undergo multiple purchase examinations. The lack of an industry guideline enables a scenario in which an extensive imaging series on one purchase exam may reveal an abnormality previously unknown to the seller, which can cause frustration and possible recrimination against the seller's veterinarian. The best way to defend a practitioner in such a circumstance is to have a record of

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the conversation with the buyer regarding available diagnostics and a thorough explanation of findings.

There is a lack of consensus among veterinarians who regularly perform sport horse purchase examinations about what constitutes a "standard" imaging protocol. At the larger horse shows in south Florida, for example, it is commonplace to include survey radiographs of the cervical, thoracic, and lumbar spine despite the fact that interpretation of cervical and thoracic or lumbar spine radiographs is often ambiguous.[2,3,4] Survey ultrasounds of multiple limbs are also commonly performed, regardless of clinical exam findings. It is this author's opinion that interpretation of survey ultrasound images is difficult unless there are associated clinical exam findings. The varied ages and performance histories of actively competing sport horses can also complicate image interpretation. As the show horses age, their radiographs and ultrasound scans may reflect performance related orthopedic changes that occur with time and use, and it is incumbent on the veterinary practitioner to convey to the client whether the imaging findings are appropriate for the horse's age and experience versus pathologic.

3. Imaging Recommendations

A thorough knowledge of the discipline should help to guide the imaging recommendations by the examining veterinarian. In the jumping and dressage disciplines, fetlock joint pathology is a frequent diagnosis and can be a performance limiting condition. A complete radiographic evaluation of the fetlock should include DP, lateral, and oblique views. Additional fetlock radiographs, including DP views with differing incidence angles, flexed laterals, and flexed skylines, will often provide important information about the joint margins and subchondral bone.[5] Similarly, stifle joint arthrosis is an important performance limiting condition in the jumping and dressage athletes and can be thoroughly evaluated using field imaging. Standard radiographic evaluation of the sport horse stifle typically includes CdCr, lateral, and craniolateral to caudomedial oblique views. Additional information can be acquired with flexed lateral oblique radiographs[6] and with ultrasound evaluation. Conditions of the cervical and thoracolumbar spine are frequently implicated in sport horse lameness and commonly imaged in purchase examinations, though, as previously discussed, accurate image interpretation of these anatomic regions is difficult.

It is this author's experience that upper airway endoscopy is rarely requested or performed in the absence of any related clinical exam finding, such as an abnormal respiratory noise or the appearance of a surgical scar. As with other modalities, however, the client must be made aware that the endoscopic evaluation is available and the decision to perform the exam must be documented.

Clinic based imaging, such as scintigraphy, computed tomography (CT), and magnetic resonance imaging (MRI) are occasionally employed during a show horse purchase examination. These additional modalities are typically used to provide information regarding the physiologic status of a specific lesion or to better visualize an anatomic region with limited imaging access such as the hoof or the spine.

The report of image findings to a buyer must be done very carefully. The clinical and prognostic significance of many image findings is frequently subjective. Opinions frequently reflect a veterinarian's bias based upon prior clinical experience, and the purchase exam summary should reflect this. In addition, it is advisable to seek the opinions of specialists or other practitioners in the case of controversial or ambiguous image findings and to include their opinions in the exam summary.

4. Conclusion

The sport horse purchase examination should formulate an opinion for the examiner regarding the horse's ability to perform the buyer's intended task and to provide sufficient information to facilitate the decision. It is imperative that the veterinarian communicate clearly with the buyer and include the buyer in the decision as to which images are indicated to achieve this objective. The images should supplement the veterinarian's clinical findings and should be interpreted based upon the exam findings and the examiner's clinical experience. Potential controversy lies in the lack of consensus regarding the appropriate images and the significance of specific findings in predicting performance outcomes. The veterinarian bears the burden to communicate the image exam findings accurately and effectively.

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.

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Communicating with the Purchaser Before, During, and After the Purchase Examination

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Buyers expect much from the veterinarian examining a prospective horse for purchase. The examining veterinarian must determine precisely what the buyer's expectations are for the examination and for their new horse. How findings are communicated is critical for helping them make a purchasing decision. Author's address: Grand Prix Equine, 143 Mt. Pleasant Road, Newtown, CT 06470; e-mail: mbaus@grandprixequine.com. © 2023 AAEP.

1. Introduction

Equine veterinarians are the gatekeepers in the highly unregulated business of buying and selling horses. There are very few financial transactions that have less security than buying a horse. Gone are the days when a "vetting" was looking at the eyes, listening to the heart, and jogging the horse for soundness. Today's buyers expect that everything is known about the horse they are interested in purchasing. No stone may be left unturned.

Historically, buyers would evaluate a prospective horse for soundness and health rather than engaging a veterinarian. As veterinary science matured and veterinarians' knowledge of horse health exceeded that of an experienced horseperson, veterinarians began to perform the purchase evaluation.

Although many horses are sold in good faith and are fairly represented, many are not. Therefore, it is incumbent on veterinarians to ensure that clients are fully informed before making a purchase decision. The term "vetting" is now synonymous with a thorough investigation of every potential acquisition, from the purchase of a business to the selection of a political candidate.

Who Influences the Buyer's Decision to Purchase a Horse?

The trainer, or buyer's agent, often does the heavy lifting in finding a horse for a prospective buyer. They are typically rewarded with a commission, but only after the horse is purchased. Consequently, when the buyer's agent has selected a horse for the buyer and the purchase exam has been performed, there may be significant pressure placed on the buyer to finalize the purchase decision.

The seller has the most significant conflict of interest when representing the virtues of a horse for sale. As far as they are concerned, the horse they are selling is perfect for the buyer, and if the client does not want to purchase the horse, they claim to have many buyers who will. It is, therefore, important to expedite the final purchase exam review to reduce the pressure sellers place on buyers.

The veterinarian remains the most objective source of information regarding purchasing a horse. The veterinarian will receive a set fee regardless of the

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outcome or sales price, and most veterinarians care deeply that their clients purchase the right horse.

Before the Examination

What a buyer expects from a purchase examination can be daunting. Buyers may be willing to live with imperfections, but surprises are unwelcome. The veterinarian must answer the following questions before proceeding with the examination:

- At what level will the horse be ridden or competed?
  - Does the buyer intend for the horse to compete in the same discipline it currently does?
  - Depending on the horse's gender, will it also be used for breeding purposes?
  - Does the buyer intend for the horse to do more or less than it currently does?
- What is the experience level of the intended rider?
  - An advanced rider will expect more from a horse athletically.
  - A novice rider will expect more from a horse behaviorally, and safety is paramount.
  - Is the horse expected to bring the rider to the next level of competition?
  - The veterinarian must not opine on the horse's suitability to the rider unless a potentially unsafe behavior to the rider and others is witnessed.
- Where will the examination take place, who will be in attendance, and who will ride the horse?
- Is the horse intended to be resold?
- Is the prospective buyer represented by an agent (trainer), and are they allowed access to all information from the exam?

Likewise, there is information the prospective buyer must know before formalizing the purchase exam:

- Does the veterinarian have a thorough knowledge of the equine discipline in which the horse will be involved?
- Are there any conflicts of interest between the veterinarian and the horse, the owner of the horse, or the agent selling the horse?
- Which ancillary services are offered by the veterinarian?
  - Radiographs
  - Ultrasound
  - Endoscopy
  - Gait analysis with inertial sensors
  - Blood tests
  - Reproductive exam
  - Photographs and video
- How will the findings be communicated?
- When will they be communicated?

The seller is asked to disclose the medical history and all previous diagnostic images from all providers. Some veterinarians will only proceed with a purchase examination with a complete medical history from the prior and existing veterinarians. It is also possible to search online for performance records within the sanctioning body in which the horse competes. It is not the responsibility of the examining veterinarian to search for a horse's performance record, but the veterinarian should inquire if a horse has rested from riding or competing due to an injury.

Documentation and Communication

It is important to obtain signed documents from the buyer and seller before the examination. The following documents are recommended:

- Client Agreement Form: this document formalizes the relationship between the buyer and the veterinarian. This should be done for all new clients, particularly those who will not use the veterinarian's services after the purchase exam.
- Veterinary Care Plan: this document outlines the services recommended by the veterinarian and the cost of those services. Potential buyers can select or decline specific services such as imaging and bloodwork.
- Buyer Agreement Form: this signed document states that the buyer understands the scope of the services offered by the veterinarian and how they intend to pay for the examination. This form allows the buyer to assign their trainer or buying agent to legally have access to the information generated at the purchase exam.
- Seller Agreement Form: this signed document is a disclosure from the seller stating the horse's past use, competition, and medical history. The completed Seller Agreement Form will allow the veterinarian to obtain the medical history from the horse's past and present veterinary caregivers and farriers. This form also provides consent for the purchase exam to be performed, including non-invasive or personally selected diagnostics, without further permissions required. It clearly indicates that the medical information obtained during the purchase exam is the confidential property of the buyer, and discloses that any access to this information is at the permission of the buyer.
- Release of Liability by the rider or handler: this signed form mitigates the veterinarian's risk if the horse's rider or handler is injured during the examination.

A quick phone call to the client on the way to the appointment is always appreciated. It is an opportunity for the veterinarian to summarize what they will be doing for the client, and it allows the client to express any last-minute concerns about purchasing the horse.

Many newly purchased or leased horses will be insured for mortality and major medical events. The veterinarian should know before the examination if the horse will be insured so the findings can be adequately identified on the required veterinary certificates of examination. The veterinarian must be aware that their findings might lead to an exclusion on the major medical or mortality policy. It is not the veterinarian's responsibility to know which findings will lead to an exclusion, but it is important to alert the buyer to those findings which may lead to an exclusion. It is recommended that the examining veterinarian report all abnormalities to the insurance company with an appropriate explanation as to the abnormality's clinical relevance. Simply put, fully answer all questions but provide proper perspective. This approach will minimize the possibility of an exclusion by the insurance company while, at the same time, providing full and honest disclosure.

Performing a Purchase Exam for a Non-Client

It is much easier to understand the needs of a buyer if they are a longstanding client. Conversely, understanding the expectations and risk-taking abilities of a new or out-of-town client is far more difficult. It is even more important that the veterinarian point out any conflicts of interest that might exist between them and the seller, the seller's agent, and the horse for the out-of-town client. This includes any interaction with the horse and the veterinarian's practice. Since the veterinarian does not have a relationship with the buyer, completing the buyer and seller forms before the examination is crucial. It is also essential that the veterinarian communicates all findings to the buyer, their agent, and the buyer's veterinarian.

The Lease Examination

The lease examination is performed with more and more frequency in lieu of the purchase examination. In the author's practice, pre-lease examinations are performed with the same frequency as purchase examinations. So, what is the difference between these two examinations? The short answer is nothing. The client seeking a lease examination is doing so to reduce the risk of legal custody of a depreciating asset. Even though they wish to reduce said risk, they are more willing to take chances with a horse's soundness. It is necessary to identify those risk factors as carefully for the lease examination as for a purchase examination. Clients also prefer lease agreements because they only need a horse for a preset period of time.

Clients will use the findings of the lease examination to negotiate the terms of the lease agreement between the lessor and the lessee. Some findings will be used to determine clauses in the lease agreement acknowledging preexisting conditions. For example, if a finding leads to lameness that renders the horse unusable, and it was noted in the lease agreement, the lease may be terminated with or without a return of a portion of the lease payment. It is important to remember that insurance companies may require a copy of the lease agreement for mortality and major medical policies. Clauses in the lease agreement pertaining to a specific soundness issue may be disclosed to the insurance company and result in unwanted exclusions to the policy.

The term of the lease agreement (the length of time for the lease) is also a factor that clients use to determine how much risk they can assume for a prospective lease. Less risk will be assumed for shorter lease periods. Although one year is the typical term for leasing horses, shorter terms are common.

Lessees will often decline diagnostic imaging of horses for a lease examination, making it even more important to review existing radiographs. A horse's history is also critical to obtain before the examination to forecast the need for routine joint injections and to help the client determine if preexisting conditions need to be included in the lease agreement.

During the Examination

If the prospective buyer is present for the exam, it is important that after the clinical portion of the exam, the veterinarian summarizes the findings before proceeding with imaging and blood tests. If the buyer is not at the exam, a phone call to them or their agent is important, especially if there is an equivocal finding. The details of this conversation, including any questions or concerns expressed by the buyer or their agent, should be included in the purchase examination report.

After the Examination

Once the examination and all ancillary services are concluded, the veterinarian will complete the purchase report and send it to the prospective buyer as quickly as possible. The report represents the highest level of accountability for the veterinarian, so its accurate and timely completion is vital. Since buyers are awaiting the examination findings before making a final purchase decision, it is essential that they have a chance to review the written report and have a follow-up conversation with the veterinarian within a day of performing the examination.

The report can be drafted on a paper template, in a digital format such as Microsoft Word™, Excel™, or on the practice management software. Once completed and signed, the final version can be scanned or converted into a secured PDF format and emailed to the buyer along with other documents, photographs, and videos. The report can be sent to the buyer in many different ways. It may be copied and pasted into the body of an email message or scanned and sent as an attachment. It is important not to send the report in a format that is alterable, such as Microsoft Word™ or Microsoft Excel™. It is advisable that an

ink-signed report be mailed to the buyer along with other paper documents such as Coggins test results.

Technology allows for photographs and videos to be taken as needed and sent to the buyer to make an informed purchase decision and as a baseline for future reference. Sending media as an email attachment will quickly exceed the file-size limit. File-sharing programs such as FileShare™ and Dropbox™ will allow for folders to be created with unlimited storage capacity and are easily shared with other users. A link to these folders can be emailed to the buyer, which will allow them to view all documents, photographs, and videos taken during the purchase examinations.

Once the prospective buyer has received all data from the examination, except for blood test results, the veterinarian and buyer must talk to review all material, most notably the report generated from the examination. A face-to-face meeting, phone conversation, or Zoom meeting should be scheduled and open-ended. It is important that the buyer ask whatever questions they may have and that the veterinarian answer these questions as thoroughly as possible. Again, the details of this conversation should be summarized and archived.

The last piece of information before a purchase decision can be made is the drug test result. Veterinarians should inform the buyer as soon as possible when this result is returned so they can inform the seller when the final purchase decision can be made.

In the author's opinion, the purchase examination represents the highest level of responsibility that equine veterinarians have to their clients. Consequently, it is incumbent on the practitioner to understand what the prospective horse buyer requires and expects from the purchase examination process. Once established, the purchase exam will proceed with fewer conflicts and a better outcome for the buyer.

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.

Purchase Exams for the International Sport Horse Buyer

Dr. Charlotte Seifert

More than 40,000 horses are imported into the United States each year.[a] Regarding sport horses, it is well known that many of the finest are raised and exported from a few European countries. Before purchasing and importing these horses, buyers have myriad ways to get the information they need to make an informed purchase decision confidently. Author's address: Olmenlei 53, Zoersel 2980, Belgium; e-mail: seifertcharlotte@hotmail.com. © 2023 AAEP.

1. Introduction

It is unknown how many horses from overseas are purchased without the benefit of a purchase exam. Still, a significant number are examined for purchase in the country of origin. The overseas purchase exam can be performed by the buyer's veterinarian or a veterinarian local to the horse. There is no doubt that the buyer's usual veterinarian would be the most objective source of information before making a purchase decision, but this is quite expensive for the buyer, and it is difficult for the veterinarian.

Using a local veterinarian to perform a purchase exam is undoubtedly fraught with conflicts of interest. Most European veterinarians use a standardized form to report the purchase exam, providing the buyer with little or no helpful information. Furthermore, since the veterinarian is local to the seller, they are reluctant to provide information that could negatively impact the outcome of a sale. Conflicts of interest are a problem with any purchase exam, but they are more common when the veterinarian does not have an ongoing relationship with the buyer. The overseas purchase exam is even more precarious since the buyer has little recourse if they believe the veterinarian misrepresented the horse's health.

The role of the overseas veterinarian performing a purchase exam is critical for the person purchasing a horse they will likely not see or ride before making a purchase decision.

The purchase exam performed overseas is similar to the purchase exam performed elsewhere, but several challenges are unique to the overseas purchase exam veterinarian. The first challenge is the language barrier. Although most overseas veterinarians speak English, it is not their first language; hence, information is more difficult to relay under these circumstances. The next challenge is the time difference. Most locations in Europe are five to eight hours ahead of the time in the United States. The best times to talk may be when either veterinarian is otherwise engaged. Another significant challenge is familiarity. Veterinarians within any country are more likely to interact with each other in some fashion and, in many cases, are preceded by their

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reputation. That familiarity is usually nonexistent when the two veterinarians are far apart.

The network of people purchasing a horse overseas is often similar to those involved in buying a horse within the United States. The buyer often involves a trainer and a purchasing agent or broker. These roles may be filled by one individual. If they are separate individuals, the trainer usually has a connection with the person overseas who will function as the broker. The overseas broker will usually deal directly with the seller, but the seller may also be represented by their own broker. The overseas broker(s) who work for the purchaser and the seller play a critical role in the purchase process.

Between the buyer, their trainer or broker, the European broker, and the examining veterinarian, it is important that all parties function with a high degree of trust. This trust is necessary because the buyer is considerably removed from the seller and has little recourse if something goes wrong.

Purchasing a horse overseas usually begins with the U.S. trainer contacting the international broker. It is most common for trainers to reach out to brokers they have worked with in the past or who have been recommended by someone they know and trust. The overseas broker must understand the requirements of the horse sought by the buyer. The broker may evaluate horses proposed by the buyer and/or suggest horses for the buyer to consider. The broker may help to facilitate a visit from the buyer to see and ride the horses that they are considering. The broker may also suggest a veterinarian to perform the purchase examination, assuming the buyer, trainer, and local, regular veterinarian of the buyer do not have their own preference. Therefore, trust between the broker and the examining veterinarian is important.

For example, the U.S. trainer contacts their European broker looking for a horse for one of their junior riders. The rider's parents will decide whether to send the trainer and the rider overseas to try the horse. In many cases, the purchase will often proceed without making this trip. The European broker will then contact their trusted veterinarian nearest the horse for a purchase exam. Understanding the relationship between the veterinarian, the seller, and the horse to be examined should be discussed early in the process. Any potential conflicts of interest should be disclosed.

The veterinarian will usually proceed with the purchase exam with very little documentation other than the name of the buyer, the name of their veterinarian, and a credit card number. To facilitate the transfer of information from the overseas veterinarian to the buyer, a person should be assigned to speak directly with the examining veterinarian after the exam. The buyer's veterinarian is typically the most appropriate person to pass along this information.

It is necessary for the examining veterinarian to find out which radiographic views are requested and which procedures not performed routinely are requested, such as specific flexion tests or neurologic tests.

2. Exam Protocol

Once communication between the overseas veterinarian and the buyer's veterinarian has been established, the purchase examination can proceed. Usually, the static or standing exam is performed first. This allows the veterinarian to identify findings that should be looked at more closely on the dynamic or moving examination. Once the static exam is completed, the veterinarian begins the dynamic exam.

Occasionally, a finding will be of enough clinical significance to affect the buyer's decision to purchase the horse. It is important at that time that the examining veterinarian call the buyer's veterinarian to see if the exam should proceed or be terminated. Typically, this is only possible if the buyer's veterinarian has discussed the examination with the examining veterinarian ahead of time.

3. Dynamic Exam

Examining the horse in motion may be the most important part of the purchase exam process. This usually starts in hand or on a lunge line and will be repeated on hard and soft surfaces. Although not performed routinely in European purchase exams, it is important to also examine the horse under-tack. If the seller is reluctant to do this, the veterinarian should explain that the horse is being purchased to be ridden, not to be lunged or exercised in hand. The under-tack exam can proceed with the following in mind:

- Keep the under-tack exam short, simple, and repeatable.
- Trot with moderate or normal contact with the reins.
- Trot in each direction on large and small circles.
- Posting trot in each direction on the correct and incorrect diagonals.
- A forward canter in each direction on a larger circle followed by a collected canter in smaller circles.
- Mature, fully trained horses can be asked to perform lead changes at the canter, but this is not expected for younger, less trained horses.
- After cantering, the horse and rider are asked to trot in a figure-8 pattern; initially with close contact with the reins followed by a loose rein.
- The horse returns to the walk and the under-tack portion is completed unless a procedure needs to be repeated.

4. Video Protocol

Videos of the dynamic exam, including the flexion tests, are important. The following are suggestions for producing meaningful videos of the examination:

- It is important for the examining veterinarian to have someone other than themselves record video during the exam.

- Record video far enough away to capture the entire circle and not get too close.
- Record transitions between the walk and trot and from the trot to the canter. Likewise, downward transitions are also useful.
- Video the moving horse from the point of view of the examining veterinarian, i.e., from the front for front limb flexion tests and from behind for hind limb flexions.
- A video of the entire length of the flexion test, versus just the limb release and trot, is unnecessary and makes viewing the videos of the flexion test more time-consuming. A video of the entire first flexion test to demonstrate to the viewer the duration of each flexion test can be useful. Subsequent videos may only record the limb release and trotting.
- The most common method of sending video clips is with the messaging application WhatsApp. This allows as many videos of any length as necessary to be sent to all parties. They can download this content to their own folder for future reference.

5. Radiographic Imaging

- Quality images with appropriate patient identification and labeling are very important.
- Findings such as arthrosis, OCD, subchondral bone defects, and sclerosis can be obscured due to poor positioning.
- Digital radiography makes it easy to retake images that are off-angle or show significant artifacts.
- Radiographs at the time of purchase are a valuable tool for future comparison, for both diagnostic purposes and resale.
- Images should always be sent in DICOM format versus JPEG format to prevent post-processing alteration and ensure embedded patient data.

6. Ultrasound Imaging

- There is no set protocol for performing an ultrasound exam for a purchase examination.
- Since there are no protocols for which structures should be imaged or saved, the examining veterinarian can choose to only ultrasound regions as dictated by the clinical exam or ultrasound all relevant structures of each limb.
- Horses should be clipped only with the seller's permission; since most sellers will not allow this, the quality of images may be compromised.

7. Diagnostic Bloodwork

- Always take blood samples for drug testing and for export (including swabs for contagious equine metritis for mares and stallions).
- Taking blood samples acts as a deterrent or reminder to the sellers that drug testing is to be assumed for horses examined for purchase.
- Depending on communications with the buyer or their veterinarian, these samples can be submitted depending on the decision to purchase.

8. Reporting Findings

A detailed report is generated as soon as possible after the examination is concluded. If time allows, this report is sent to the seller's veterinarian, followed by a conversation between the two veterinarians. Once the buyer's veterinarian has reviewed the report and talked to the examining veterinarian, the report can be sent to the buyer. The buyer will then have a conversation with their veterinarian and, if necessary, with the examining veterinarian.

9. Conclusion

As with a routine purchase exam, the overseas purchase examination demands that the veterinarian keeps their integrity intact throughout the examination process. This will require the full disclosure of all conflicts of interest before the exam and the frank, unvarnished explanation of all findings from the examination.

Very few buyers have ever complained that the examining veterinarian communicated too much. Due to the importance of the purchase exam, it is incumbent upon the veterinarian to communicate as much as possible with the buyer and their veterinarian.

The golden rule for sharing purchase examination information is to only send information that one would want to receive. A clearly understood report, high-quality radiographic images, and easily viewed video clips are essential to the buyer and their veterinarian to make an informed decision.

Of all the responsibilities of the examining veterinarian, the most important is maintaining their integrity throughout the purchase exam process. It is distressing to see a horse buyer end up with a horse whose shortcomings could have been disclosed before a purchase decision was concluded and additional transportation costs assumed.

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.

Footnote

[a]Liz Cornell, "Importing Sport Horses and Their Acclimation to America", The Plaid Horse, Aug. 6, 2019

Seasonal Idiopathic Hepatitis in Midwestern Horses

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Although an etiologic agent has not been identified, an apparently seasonal equine hepatitis syndrome was characterized by fever, systemic inflammation, increased liver enzyme activity, and histologic evidence of hepatitis. An infectious cause is suspected based on histology and outcome. Authors' address: College of Veterinary Medicine, Purdue University, 625 Harrison Street, West Lafayette, IN 47907; e-mail: taylo248@purdue.edu. *Corresponding and presenting author. © 2023 AAEP.

1. Introduction

Since early 2021, horses with fever and clinicopathologic evidence of hepatitis were presented to the Purdue University Veterinary Hospital (PUVH) during winter seasons. Hepatitis was confirmed by histologic examination in all horses presented to the PUVH. Despite exhaustive efforts, a bacterial or viral cause has not been identified. The objective of the case series reported here was to report signalment, history, physical examination findings at admission, clinicopathologic findings, diagnostic test results, treatment, and outcome in horses with a seasonal idiopathic hepatitis syndrome.

2. Materials and Methods

A retrospective case series of horses presented to the PUVH in 2021 and 2022 with presumptive seasonal idiopathic hepatitis syndrome was performed. Inclusion criteria included complete medical records, fever, increased serum gamma-glutamyl transferase activity, and histologic evidence of hepatitis. Histologic lesions were characterized and scored from 0 (not detected) to 4 for hepatocellular necrosis, biliary epithelial injury, inflammation, and fibrosis. Data were evaluated descriptively using ratios in this retrospective case series. Data were presented as median and range.

3. Results

Thirteen horses met the inclusion criteria including 10 geldings and 3 mares (median age 13 years; range 3–30 years). The number of affected horses that were presented in this time frame exceeded what was expected based on historical admissions by approximately 8 times. Additionally, other practices and institutions in the Midwest experienced a similar increase in horses presented with fevers and evidence of hepatic disease. Fever and anorexia were reported as recent complaints in all horses. All horses had an increase in gamma-glutamyl transferase activity (inclusion criteria), and approximately 50% had an increase in succinate dehydrogenase activity. Serum amyloid A concentration was increased in 83% of

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cases. Hepatocellular necrosis with infiltration of neutrophils and/or macrophages was a feature of all initial biopsy specimens. Although not every test was performed on every horse, testing of serum and liver for bacterial and viral pathogens, including SARS-Cov-2, did not identify an etiologic agent. Horses responded clinically to nonsteroidal anti-inflammatory drug administration, but cyclic fevers were observed in 92% of horses, with a maximum of 4 fever cycles in 1 horse. The duration of fever cycles ranged from 2 to 14 days each, with the average duration of normothermia between cycles being 6 days. The median peak rectal temperature was 104.9 °F (range 103.0–107.2 °F). There was no difference in disease progression or outcome among horses treated with antimicrobial drugs. Repeat liver biopsies in some horses showed persistence of histologic lesions for up to 27 weeks after initial presentation. All horses recovered clinically and returned to their previous work.

4. Discussion

An idiopathic equine hepatitis syndrome has been identified in horses that have been presented to PUVH during the winter months since 2021; cases presented during the first 2 years are reported here. Given the presence of high fevers that were biphasic in the majority of affected horses, along with evidence of systemic inflammation and histologically confirmed multifocal (random) hepatitis, an infectious pathogen is the most likely cause of this syndrome. Liver failure was not identified in any case. Although an extensive epidemiological survey of all reported cases in the Midwest is necessary to rule out common factors among horses that might indicate a specific source, no common thread was recognized in these 13 cases. Horses responded clinically to administration of nonsteroidal anti-inflammatory drugs and did not require antimicrobial treatment. Although it is unknown if affected horses will experience recrudescence or liver failure in the future, this has not been reported to date. Screening of healthy herd mates for increases in liver enzyme activity is warranted, and continued investigation into the etiology and pathophysiology of this syndrome is critical.

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.

Investigation of the Systemic Antibody Response and Antigen Detection Following Intranasal Administration of Two Commercial Equine Herpesvirus-1 Vaccines to Adult Horses

Kennedy Spann; Samantha Barnum, MS; and Nicola Pusterla, DVM, PhD, DACVIM, DAVDC-Equine*

The intranasal administration of two commercial equine herpesvirus-1 (EHV-1) vaccines did not elicit a systemic immune response. Further, vaccine derived EHV-1 could be detected in most intranasally vaccinated horses, potentially impacting diagnostic interpretation of EHV-1 during outbreak situations. Authors' address: Department of Medicine and Epidemiology, School of Veterinary Medicine, University of California – Davis, Davis, CA 95616; e-mail: npusterla@ucdavis.edu. *Corresponding and presenting author. © 2023 AAEP.

1. Introduction

EHV-1 vaccines are often administered intranasally during an emergency such as outbreaks of equine herpesvirus myeloencephalopathy. However, there is currently no data available on the efficacy of such protocols, nor the diagnostic challenge when recently vaccinated horses become clinically infected and nasal secretions are collected to support a diagnosis of EHV-1 infection. Therefore, the objective of this study was to determine if two commercially available EHV-1 vaccines, a killed-adjuvanted (KAV)[a] and a modified-live (MLV)[b] EHV-1 vaccine, could induce a measurable systemic antibody response post-intranasal administration. A second objective was to determine the detection time of EHV-1 in nasal secretions by qPCR following the intranasal administration of the respective EHV-1 vaccines.

2. Materials and Methods

Thirty healthy adult horses, with no recent EHV-1 vaccine administration, were randomly assigned to one of three groups: (i) MLV[b] group, (ii) KAV[a] group, and (iii) unvaccinated control group. While MLV[b] is labeled for the intramuscular administration only, KAV[a] can be given either intramuscularly or intranasally according to the manufacturer. The vaccines and sterile PBS (unvaccinated controls) were administered in the right nostril using an atomizer tip. The right nostril of each study horse was

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swabbed prior to vaccine administration and daily thereafter for 5 consecutive days using 6" rayon-tipped swabs and analyzed for the presence of EHV-1 through previously validated and established qPCR protocols. Additionally, serum samples were collected on the day of vaccine/sterile PBS administration and 30-days later for antibody detection using an anti-EHV-1 Ig and isotope-specific IgG4/7 multiplex assay as previously reported.

3. Results and Discussion

Total Ig and isotype-specific IgG4/7 against EHV-1 measured pre- and 30-days post-vaccination were not different amongst the three study groups. Vaccine-derived EHV-1 was only detected in the two EHV-1 vaccine groups with 9/10 horses in the MLV group and 8/10 horses in the KAV group testing qPCR-positive for EHV-1 for 1 to 3 days. There was no significant difference in number of horses testing qPCR-positive for EHV-1 and absolute quantitation of EHV-1 in nasal secretions by qPCR between the two vaccine groups.

Acknowledgments

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Declaration of Ethics

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

Conflict of Interests

The authors have no conflicts of interest.

Footnotes

[a]Calvenza®, Boehringer Ingelheim Animal Health, St. Joseph, MO 64506-2002.

[b]Rhinomune®, Boehringer Ingelheim Animal Health, St. Joseph, MO 64506-2002.

Investigation of the EHV-1 Genotype (N_{752}, D_{752} and H_{752}) in Swabs Collected from Equids with Respiratory and Neurological Disease and Abortion from the United States (2019-2022)

Nicola Pusterla, DVM, PhD, DACVIM, DAVDC-Equine*; Samantha Barnum, MS; Kaila Lawton; Cara Wademan; Rachel Corbin; and Emir Hodzic, DVM, PhD

While the N_{752} genotype has remained the predominant genotype affecting horses with respiratory disease and abortion, it has also become a leading genotype in cases of equine herpesvirus myeolencephalopathy (EHM), when compared to historical data. The new H_{752} genotype, first reported in the United States in 2021, has remained confined to a cluster of geographically and temporally related outbreaks, and the data showed no emerging spread of H_{752} since it was first reported. While the monitoring of equine herpesvirus-1 (EHV-1) genotypes is important from a diagnostic and epidemiological standpoint, it may also help establish medical interventions and preventive protocols to reduce the risk of severe complications associated with EHV-1 infection. Authors' address: Department of Medicine and Epidemiology, School of Veterinary Medicine, University of California – Davis, Davis, CA 95616; e-mail: npusterla@ucdavis.edu. *Corresponding and presenting author. © 2023 AAEP.

1. Introduction

Contemporary data on EHV-1 genotype (non-neuropathogenic or N_{752}, neuropathogenic or D_{752}, and new variant or H_{752}) in clinically diseased equids is important to determine the frequency of these genotypes and their association with disease expression. While the interplay between viral, host, and environmental factors remains quite elusive in the pathogenesis and disease expression of EHV-1, contemporary studies using diagnostic material are essential to understand which genotypes are circulating in specific horse populations. Therefore, it was the aim of the present study to evaluate the EHV-1 genotype (N_{752}, D_{752} and H_{752}) in swabs collected from horses with respiratory disease, abortion, and neurological disease and submitted to a diagnostic molecular laboratory.

2. Materials and Methods

A total of 297 EHV-1 qPCR-positive swabs collected from 2019 to 2022 from horses with respiratory disease (EHV-1), neurological disease (equine herpesvirus-1 myeloencephalopathy (EHM)), and abortion were tested

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for the three different EHV-1 genotypes (N_{752}, D_{752} and H_{752}) using qPCR allelic discrimination assays.

3. Results and Discussion

All submissions originated from the United States and included 257 EHV-1 cases, 35 EHM cases, and 5 cases of abortion. EHV-1 qPCR-positive cases were predominantly seen during winter and spring. N_{752} was the predominant genotype detected in EHV-1 cases (87.5%), EHM cases (74.3%), and abortions (80%). D_{752} was detected less frequently in EHV-1 cases (9.3%) and EHM cases (25.7%), while H_{752} was only detected in EHV-1 cases (3.1%). H752 EHV-1 qPCR-positive cases were linked to individual outbreaks geographically and temporally related.

Acknowledgments

Funding Source

This study was funded by the Center for Equine Health, School of Veterinary Medicine, University of California, Davis, with additional contributions from public and private donors.

Declaration of Ethics

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

Conflict of Interests

The authors have no conflicts of interest.

Antibody Response to Equine Influenza Virus and Equine Herpesvirus-1 Vaccine in Adult Horses Receiving Intravenous Dexamethasone

Nicole Kreutzfeldt, MRCVS*; and Nicola Pusterla, DVM, PhD, DACVIM, DAVDC-Equine

Dexamethasone did not adversely affect the antibody response to a commercial bivalent equine influenza virus (EIV) and equine herpesvirus (EHV)-1/-4 vaccine in adult horses. Authors' address: University of California–Davis, One Garrod Drive, Davis, CA 95616; e-mail: nicole.kreutzfeldt@gmx.de. *Corresponding and presenting author. © 2023 AAEP.

1. Introduction

The purpose of this study was to investigate the effect of intravenous dexamethasone on the antibody response to an EIV and EHV-1/-4 vaccine in healthy adult horses.

2. Material and Methods

There were 55 healthy adult research horses in a randomized cohort study: healthy control (group 1), vaccination only (EIV/EHV-1/EHV-4 vaccine[a], group 2), vaccination and concurrent single dose of dexamethasone[b] (20 mg, group 3), and vaccination and daily doses of dexamethasone from day 1 to 3 (group 4). SAA levels were measured using a stall-side analyzer on day 1 and 3. Antibody titers against EIV (hemagglutination inhibition assay, Kentucky 2014 antigen) and EHV-1 (multiplex ELISA targeting total immunoglobulin G [IgG] and IgG 4/7) were measured on days 1 and 30.

3. Results

Group 2 showed a significant increase in SAA values 72 hours after vaccination ($P = 0.04$). No statistical difference between pre- and post-vaccination anti-EHV-1 antibody titers ($P > 0.05$) was seen in any group. Anti-EIV antibody titers were significantly increased in groups 2 and 3 ($P = 0.05$ and $P = 0.01$, respectively).

4. Discussion and Conclusion

Dexamethasone reduced the inflammatory response post-vaccination but did not result in decreased anti-EHV or anti-EIV antibody titers. Multiple doses of dexamethasone may dampen the antibody response to an EIV vaccine.

Acknowledgments

Funding Sources

This study was funded by the Center for Equine Health, University of California, Davis, and public and private donors. Merck Animal Health provided the vaccines.

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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.

Footnotes

[a]Prestige 2, Merck Animal Health, Madison, NJ 07940.
[b]Dexamethasone, 2 mg/ml solution, Sparhawk Laboratories, Inc., Lenexa, KS 66215.

A New Real-Time PCR Multiplex Assay for Simultaneously Detecting *Streptococcus equi* subspecies *equi* and *Streptococcus equi* subspecies *zooepidemicus*

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The real-time polymerase chain reaction assay reported in this study accurately detects and differentiates between *Streptococcus equi* subsp. *equi* and *Streptococcus equi* subsp. *zooepidemicus*, including detecting concurrent infection with both subspecies. Presenting author's address: School of Veterinary Medicine & Biomedical Sciences, Texas A&M University, College Station, TX 77845; e-mail: ncohen@cvm.tamu.edu. *Corresponding and presenting author. © 2023 AAEP.

1. Introduction

Strangles is a contagious bacterial disease of horses caused by *Streptococcus equi* subsp. *equi* (SEE).[1] Increasingly, *Streptococcus equi* subsp. *zooepidemicus* (SEZ) is recognized as a cause of respiratory disease in horses.[2] Because of limitations of existing polymerase chain reaction assays, the authors sought to identify novel primers and probes that enable simultaneous detection and differentiation of infection with SEE and SEZ.

2. Materials and Methods

Comparative genomics of strains of SEE and SEZ ($n = 50$ each) identified novel gene targets for SEE and SEZ. Primers and probes for real-time polymerase chain reaction (rtPCR) were designed for these genes and aligned *in silico* with the genomes of strains of SEE ($n = 725$) and SEZ ($n = 343$). Additionally, sensitivity and specificity relative to microbiologic culture were determined using 85 samples submitted to an accredited veterinary medical diagnostic laboratory.

3. Results

The respective primer and probe sets aligned with 99.7% (723/725) of SEE and 97.1% (333/343) of SEZ. Of 85 diagnostic samples, 20 of 21 (95.2%) SEE and

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22 of 23 SEZ (95.6%) culture-positive samples were positive by rtPCR for SEE and SEZ, respectively. Both SEE ($n = 2$) and SEZ ($n = 3$) were identified by rtPCR among 32 culture-negative samples. Results were rtPCR positive for both SEE and SEZ in 21 of 44 (47.7%) culture-positive samples.

4. Discussion

The primers and probe sets reported in this study reliably detect and differentiate between SEE and SEZ and permit detection of concurrent infection with both subspecies.

Acknowledgments

Funding Sources

This work was supported by the Link Equine Research Endowment and a grant from USDA-NIFA through Texas A&M AgriLife Research Formula Animal Health. Dr. Noah Cohen is supported by the Glenn P. Blodgett Chair in Equine Studies at Texas A&M University.

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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2. Waller AS, Wilson H. *Streptococcus zooepidemicus*: Commensal or pathogen? in *Proceedings*. Am Assoc Equine Pract 2021;67: 319–326.

Voluntary Biosurveillance of *Streptococcus equi* subsp. *equi* in Nasal Secretions of 9,409 Equids with Upper Airway Infection in the United States

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Strangles is a very common respiratory infection among horses, presenting with acute onset of fever and respiratory signs. Older horses presenting during winter and spring were more likely to test *S. equi* qPCR-positive, while horses vaccinated against *S. equi* appeared to be protected. Authors' addresses: Department of Medicine and Epidemiology, School of Veterinary Medicine, University of California–Davis, School of Veterinary Medicine, Davis, CA 95616 (Jaramillo-Morales, Barnum, Pusterla); Merck Animal Health, S 1476 Pleasant View Road, Alma, WI 54610 (Vaala, Chappell, Schneider, Craig, Bain, Barnett, Gaughan); e-mail: cjaramillomorales@ucdavis.edu. *Corresponding and presenting author. © 2023 AAEP.

1. Introduction

Streptococcus equi subsp. *equi* (*S. equi*) is the causative agent of strangles, an upper respiratory catarrh associated with an important economic impact to the equine industry; epidemiological aspects of the disease are underreported as well as the vaccination impact on its prevention. The aim of the study was to describe epidemiological aspects, including vaccine status, of horses with acute onset of fever and respiratory signs tested by qPCR for *S. equi*.

2. Materials and Methods

Biological samples and epidemiological information of diseased horses was collected via a voluntary biosurveillance program from 2008-2020. Information pertaining to demographics, location, season, clinical signs, and vaccination status was collected from every index case. Nasal secretions were tested via qPCR for *S. equi* and common respiratory viruses (equine influenza virus, equine herpesvirus-1/-4, equine rhinitis A/B virus). Two hundred and sixty-one equine veterinary practices across the US participated in the study.

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3. Results and Discussion

715 horses tested qPCR-positive for *S. equi*, of which 32% had coinfections with respiratory viruses; there was a statistically significant difference in horses testing qPCR-positive for equine herpes virus-4 ($P = 0.03$), equine influenza virus ($P < 0.001$), and equine rhinitis B virus ($P < 0.001$) and concurrent qPCR-positive status for S. *equi*. The median age for the *S. equi* qPCR-positive horses was 8 ± 4 years. Horses used for competition and ranch/farm use were more likely to test qPCR-positive for *S. equi* ($P = 0.006$). During winter and spring, there was a greater number of horses testing qPCR-positive for *S. equi* compared to summer and fall ($P < 0.001$). There was no statistical difference between sex, history of transport or location for horses testing qPCR-positive and qPCR-negative for *S. equi* ($P > 0.05$). Nasal discharge (89%) fever (83%) and lethargy (75%) were the most commonly reported clinical signs. Horses vaccinated against *S. equi* were less likely to test qPCR-positive ($P = 0.001$).

Acknowledgments

The authors wish to thank the veterinarians participating in this biosurveillance program for their collaboration in enrolling study horses and collecting nasal secretions.

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.

Multi-Centered Field Evaluation of a *Salmonella* spp. Point-of-Care PCR Assay Using Equine Feces and Environmental Samples

Nicola Pusterla, DVM, PhD, DACVIM, DAVDC-Equine*; Pramod Naranatt, PhD; Himani Swadia, MS; Laramie Winfield, DVM; Ashley Hartwig; Samantha Barnum, MS; and Eric Mendonsa

The point-of-care (POC) PCR assay was able to reliably detect *Salmonella* spp. in feces and environmental samples when compared to the gold standard of qPCR. Further, *Salmonella* spp. results were available in less than 24 hours, including sample incubation and enrichment and PCR analysis. Authors' addresses: Department of Medicine and Epidemiology, School of Veterinary Medicine, University of California – Davis, Davis, CA 95616 (Pusterla, Barnum); Fluxergy, 13766 Alton Pkwy, Irvine, CA 92618 (Naranatt, Swadia, Mendonsa); Steinbeck and Peninsula Equine Clinics, 15881 Toro Hills Avenue, Salinas, CA 93908 (Winfield, Hartwig); e-mail: npusterla@ucdavis.edu. *Corresponding and presenting author. © 2023 AAEP.

1. Introduction

Several studies have evaluated the use of qPCR for the detection of *Salmonella* spp. in fecal and environmental samples. The advantages of qPCR are its increased sensitivity, rapid turn-around-time, and cost-effectiveness. However, samples for *Salmonella* spp. testing still require shipment to an external veterinary diagnostic laboratory, delaying time to result availability. The introduction of microfluidic card technology has opened the field for rapid POC molecular assays, including fecal and environmental *Salmonella* spp. testing. The purpose of this study was to evaluate a novel POC PCR test kit[a] for the detection of *Salmonella* spp. in feces and environmental samples.

2. Materials and Methods

The study was performed at two veterinary hospitals. A total of 143 fecal samples and 132 environmental samples were collected for POC PCR *Salmonella* spp. testing[a] as well as qPCR testing. Each sample was inoculated into selenite broth and incubated for 18-24 hours. For the POC PCR assay, 14 µl of selenite broth were mixed with 126 µl of PCR reaction mix and pipetted into a microfluidic test card targeting the invA and ttrC gene of *Salmonella enterica.* For qPCR

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analysis, 200 µl of the selenite broth were processed for DNA purification and *Salmonella* spp. testing targeting the invA gene.

3. Results and Discussion

A total of 15/275 (5.4%) tests gave an indeterminate result for the POC PCR *Salmonella* spp. assay likely due to fecal inhibition. The remaining tests gave either a negative (225 samples) or a positive result (35 samples). The POC PCR assay showed strong agreement of 92.4% with the gold standard of qPCR for the detection of *Salmonella* spp. in all study samples. The overall agreement between the POC PCR *Salmonella* spp. assay and qPCR assay was 88.1% for feces and 97.0% for environmental samples. Strong agreement and short turn-around-time make the POC PCR device the first molecular diagnostic platform allowing detection of *Salmonella* spp. in a hospital setting. The availability of an accurate POC PCR assay for the detection of *Salmonella* spp. will enhance the diagnostic capability of equine veterinarians to timely support a diagnosis of salmonellosis and to also monitor the environment to reduce the risk of nosocomial infections.

Acknowledgments

Funding Source

This study was supported by Fluxergy, Irvine, CA.

Declaration of Ethics

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

Conflict of Interest

Dr. Pusterla has served on the scientific advisory board of Fluxergy since 2023. Dr. Pramod Naranatt, Mrs. Himani Swadia and Mr. Eric Mendonsa work for Fluxergy. Dr. Laramie Winfield, Mrs. Ashley Hartwig and Mrs. Samantha Barnum have no conflicts of interest. There has been no financial compensation in exchange for the evaluation of the POC PCR test kit.

Footnote

[a]Environmental Salmonella Test Kit, Fluxergy, Irvine, CA 92618.

Validation of a Diagnostic Test Utilizing an Artificial Intelligence Deep Learning Algorithm, for Detecting Strongyles and *Parascaris* spp. in Equine Fecal Samples

Cory Penn, DVM

The artificial intelligence system can consistently provide diagnostic accuracy comparable to manual evaluations by skilled parasitologists, thus avoiding variations in analysts and providing consistent results in a timely manner. Author's address: Zoetis, Sylvan Way, Parsippany, NJ 07054; e-mail: cory.penn@zoetis.com. © 2023 AAEP.

1. Introduction

Fecal egg counts are an important diagnostic tool in equine parasite management. Automated digital scanning of fecal sample slides integrated with analysis by an artificial intelligence algorithm is a viable, emerging alternative. The study describes the use and validation of an artificial intelligence system (AIS)[a] in equine parasitology.

2. Methods

Prescreened equine fecal samples (Mini-FLOTAC) were randomly assigned to 1 of 3 study groups. Group 1 samples were manually evaluated by an expert parasitologist using a passive-flotation Modified McMaster test. Group 2 and 3 (AIS) samples utilized filtrate on a slide over which a coverslip was placed with one of two different fecal flotation solutions (sodium nitrate solution [$NaNO_3$] and Sheather's sugar solution). Sensitivity and specificity were calculated for Group 2 and 3 samples by reference test performed manually by an expert parasitologist.

3. Results

Diagnostic sensitivity of the AIS algorithm for strongyles versus the manual reference test was 99.2% with $NaNO_3$ solution and 100.0% with Sheather's sugar solution. Sensitivity for *Parascaris* spp. was 88.9% and 99.9%, respectively, for samples prepared with $NaNO_3$ and Sheather's sugar solutions. Diagnostic specificity for strongyles was 91.4% and 99.9%, respectively, with $NaNO_3$ and Sheather's sugar solutions. Specificity for *Parascaris* spp. was 93.6% and 99.9%, respectively, for samples prepared with $NaNO_3$ and Sheather's sugar solutions.

4. Conclusions

The AIS accurately detected strongyles and *Parascaris* spp. in equine fecal samples equivalent to manual

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evaluations by parasitologists and, as a result, has the potential to avoid variations in analysis, thus providing more consistent results.

Acknowledgments

Funding Sources

This study was funded by Zoetis and performed in conjunction with Texas Tech University.

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 Zoetis.

Footnote

[a]Vetscan Imagyst® Zoetis Inc, 10 Sylvan Way Parsippany, NJ 07054.

Thoroughbred Mares as Reservoir Hosts of Leptospirosis

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Asymptomatic pregnant mares can shed pathogenic *Leptospira* via urine. Authors' addresses: National Veterinary Services Laboratories, Animal and Plant Health Inspection Service (APHIS), U.S. Department of Agriculture (USDA), Ames, IA 50010 (Hamond, LeCount, Anderson, Camp, Hicks, Stuber, Morningstar, and Schlater); Maxwell H. Gluck Equine Research Center, Department of Veterinary Science, University of Kentucky, Lexington, KY 40503 (Adam); Infectious Bacterial Diseases Research Unit, Agricultural Research Service, USDA, Ames, IA 50010 (Nally); e-mail: camila.hamond@usda.gov. *Corresponding and presenting author. © 2023 AAEP.

1. Introduction

Equine leptospirosis can result in abortion, stillbirth, neonatal death, placentitis, and uveitis. Horses may act as asymptomatic reservoir hosts of infection. In this study, PCR and culture was used to assess urinary shedding of pathogenic *Leptospira* from asymptomatic mares.

2. Materials and Methods

Serum and urine from thirty-seven asymptomatic Thoroughbred mares on a single farm were tested by the microscopic agglutination test (MAT) and a PCR specific for pathogenic *Leptospira*, respectively. A second urine sample was collected from positive mares for repeat PCR and culture. A positive culture was genotyped by whole genome sequencing and serotyped with reference antisera.

3. Results

Of 37 equine sera tested by MAT, 35/37 (94.6%) were seropositive (titer ≥1:100). Three urine samples, designated H1, H8, and H9, were positive by PCR. Of these, two (H8 and H9) were PCR positive in a repeat sample, and one (H9) was culture positive. The recovered isolate, designated strain H9, was typed as *L. kirschneri* serogroup Australis.

4. Discussion

In this study, urinary shedding of pathogenic *Leptospira* in asymptomatic mares was demonstrated by PCR and culture, demonstrating that horses can act as reservoir hosts of leptospirosis. An isolate excreted in urine from an asymptomatic mare was typed as *L. kirschneri* serogroup Australis. Detection of active shedding requires PCR and/or culture of

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urine; a mid-stream free-catch urine sample from a cleaned vulva should be chilled and processed for PCR as soon as possible, while recovery of cultures requires specialized media.

Acknowledgments

Funding Sources

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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.

How to Recognize Common and Uncommon Clinical Presentations, Physical/In-Hand Musculoskeletal and Ridden Exam Findings That Point to the Equine Neck as the Source of the Issue

Elizabeth J. Davidson, DVM, DACVS, DACVSMR

Horses with cervical spine abnormalities exhibit a variety of abnormal clinical signs. Common complaints are neck stiffness, abnormal head and neck carriage, and resistance to rein tension. Infrequent abnormalities include rearing, forelimb lameness, cross-cantering, and disjointed gaits. Comprehensive clinical assessments such as ridden gait evaluation and other maneuvers that might exacerbate abnormalities due to cervical spine conditions enhance diagnosis. Author's address: University of Pennsylvania, Department of Clinical Studies, New Bolton Center, Kennett Square, PA 19348; e-mail: ejdavid@vet.upenn.edu. © 2023 AAEP.

1. Introduction

Neck-related problems appear to be increasing in incidence in the performance horse and are particularly incriminated in the Warmblood sport horse. The most common clinical presentations are generalized neck stiffness, lack of flexibility during bending manipulations, abnormal head carriage, and resistance to rein tension. Riders may complain of unwillingness to work on the bit, inability to maintain a "frame," or head tilting or tossing. The astute owner may notice asymmetrical cervical musculature but more commonly will be concerned about poor topline muscle development despite regular ridden exercise.

Uncommon yet important histories include an episode of neck trauma such as a fall, collision, forward rotational fall, or backward fall after rearing up.[1] A cervical spine lesion should be considered in horses with unilateral forelimb lameness that cannot be localized to the limb. Any patchy sweating area in the cervical spine region may reflect local nerve damage. Riders may describe that the horse feels weak or disjointed, that it lacks hindlimb impulsion, or that there is a lack of connection between fore and hindlimb cadence. Other ridden complaints include occasional or consistent toe drag, general laziness, and unwillingness to work. Dangerous behaviors such as rearing, adamant refusal to walk forward, or abrupt stops during ridden exercise can also be noted. While it is important to ascertain if the horse has these abnormal clinical manifestations, it is equally important to

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recognize that these historical abnormalities are not specific for cervical spine conditions and that a variety of other conditions can be the underlying cause. Infrequently, horses exhibit idiopathic hopping-like forelimb lameness when ridden.[2] Some affected horses exhibit transient episodes of marked neck pain, stiffness, and lowered head carriage ("neck stuck"). Albeit rare, horses with radiculopathy may stand with a root signature posture characterized by holding a forelimb in a semiflexed position bearing weight only on the toe, neck extended or slightly held to one side, and cervical muscle spasm.

Given the variety of clinical presentations, many of which are ill-defined, vague, inconsistent, and shared by many other non-neck conditions in the horse, diagnosis of cervical spine abnormality is challenging. Further complicating the diagnostic workup, radiographic evaluation frequently reveals bony abnormalities, especially in the caudal neck of middle to older aged horses with and without primary issues referable to the neck.[3] Serology and other testing can also be equivocal. Therefore, authentic diagnosis of a cervical spine disorder is reliant not on one abnormal assessment but based on clinical examination combined with complementary imaging and other testing. The first step in the diagnostic workup is a thorough clinical examination, including maneuvers that might exacerbate abnormalities due to cervical spine issues. This presentation will describe specific strategies that can increase the suspicion of an underlying neck condition as the source of poor performance in the athletic horse during the initial physical, musculoskeletal in-hand, and ridden gait evaluation.

2. Clinical Examination Highlighting Specific Assessments for Suspected Neck Issues

Physical Examination

Physical examination starts with observation while the horse is loosely held with the neck in a neutral position. Any tendency for the horse to preferentially tilt or turn its head should be noted. Visual assessment of the cervical muscular development or atrophy including generalized muscle symmetry or asymmetry when comparing left side to right side and the cranial versus caudal aspect of each side should also be assessed. Areas of muscle atrophy suggest disuse due to either pain or neurological dysfunction. To some extent, conformation will affect the position, shape, and functionality of the neck. Ewe-neck conformation where the ventral cervical neck muscles are overdeveloped is commonly observed in horses that prefer to exercise with an extended head/neck position. Long- and/or low-neck conformation relative to the rest of the axial skeleton may also be a contributing factor to this conformation. Any patchy sweating area, especially with associated hypoesthesia or focal muscle atrophy, may reflect cervical nerve root damage.

Digital palpation of the neck enhances the detection of heat, pain, swelling, or muscle tension. Starting at the poll and gradually progressing toward the shoulder, the poll, the general region of the cervical vertebral bodies, and the overlying muscle mass can be assessed. Unilateral or sectional (cranial, mid, caudal neck) abnormalities may provide additional clues to underlying neck pathology. Palpating right and left sides of the neck simultaneously may help discern asymmetries, especially with subtle abnormalities.

Neck flexibility can be rudimentarily assessed with "carrot stretches." A carrot or other enticing food is used to encourage the horse to flex its neck to the right and the left, caudally to the withers and the hock and hip. Food between the front legs and above the bridge of the nose, neck extension, and flexion in the forward direction can also be assessed. Horses with neck pain may be unwilling or unable to bend their neck, preferentially turning the entire body toward the food. Other horses may prefer to "cheat" via more ventral instead of lateral bending of the neck. Manual manipulation of the neck is performed by some clinicians; however, the author finds this test difficult to perform with consistency, and findings can be nonspecific since many horses with and without neck issues resist this type of manipulation. Similar to limb flexion testing, attempts to apply pressure to or stress one cervical articular process joint or a focal neck region without also applying stress to other structures is difficult or impossible to perform. Kinematic analysis of mobilization exercises in the neck reveals that cervical spine lateral bending results in movement of all cervical spine regions (C1-C7) and also movement of the thoracolumbar vertebral column.[4] Flexion of the left side of the neck also results in corresponding extension of the right side, and therefore resistance during bending may be due to painful left-sided flexion or right-sided extension of the neck.

In-Hand Gait Examination

As with any horse presented for poor performance, a thorough traditional gait (lameness) examination should be performed. For horses with suspected neck conditions, walking and trotting in-hand is performed with a purposefully loose shank so that the horse's preferred head and neck carriage can be assessed. Walking in a figure eight pattern may also be helpful. Some horses with stiff necks may be unable or unwilling to bend their neck and body as they navigate the curvature of the circles, exhibited by a stiff body posture from the poll to the tail. Walking in smaller circles may help to differentiate between whole-body or back stiffness versus neck stiffness. Horses with normal necks and sore backs may bend through the neck while maintaining rigidity through the thoracolumbar region.

During the in-hand gait evaluation, it is also important to recognize and investigate limb lameness. Lameness remains the primary cause for poor performance in athletic horses. Despite the high prevalence,

lameness is not always recognized by the horse owner,[5] and therefore a lameness examination should always be included in the veterinary assessment of these horses, especially those with ill-defined or vague gait abnormalities. Most of the time, lameness is due to limb pain; however, there are limited but increasing reports of forelimb lameness attributed to primary neck pain.[1,6,7] Additionally, an idiopathic hopping-type forelimb lameness syndrome in the ridden horse has also been described with an association with cervical nerve root pain in a small number of affected horses.[2]

In-Hand Longeing Exercise

Changes in head and neck position and movement while longeing may also indicate an underlying neck abnormality. Tipping the head to one side, head tossing, and preferential extended head and neck position may be associated with cervical spine pain. Other affected horses may prefer to travel with their head and neck held to the outside or inside of the circle. These abnormalities can be observed at the walk, trot, and/or canter, in one or both directions, and are highly variable in occurrence, duration, frequency, and severity. Continuing the longeing exercise for a longer time may result in increased frequency of the abnormal dynamic head and neck movements, which in turn can serve as a consistent "baseline" upon which ensuing diagnostics can be performed.

Longeing with Tack

Since many clinical presentations of horses with suspected cervical spine disorders are exhibited when the horse is ridden, it can be difficult to separate one or all components in the act of riding (the rider, horse, and/or tack) or if there are particular movements or postures created during riding that trigger the abnormal clinical presentations. One differentiating tactic includes longeing exercise with head tack. Observations of head and neck movement while longeing the horse equipped with a bridle, with and without a bit, with different bits, and with various nose band tension can be beneficial. Longeing exercise with different headpiece configurations such as padded, anatomical, or other configurations designed to minimize poll pressure can also be insightful. Induced abnormal clinical signs under various head tack applications may be due to a primary dental or poll issue versus a neck problem. Longeing with and without side reins to induce various degrees of enforced head and neck flexion is indicated if clinical signs are associated with certain head and neck positions. Unilateral side rein tension and long lining may also be valuable. These in-hand maneuvers are particularly helpful when abnormal clinical signs include dangerous ridden behaviors such as rearing, aggressive head tossing, or severe tripping caused by underlying pain during neck flexion as they eliminate the necessity for a rider. Induction of abnormalities following application of head tack can also be helpful to separate neck pain from thoracolumbar or sacroiliac pain since many of the presenting abnormal clinical signs are shared by a variety of topline problems.

Ridden Examination

For many horses with neck issues, abnormalities are most or only apparent when ridden where certain movements, sport-specific gaits, or changes of pace such as canter-to-trot transitions can be reliably reproduced. For horses with neck pain, applying specific and varying degrees of rein tension by the rider, for example, with contact (cervical spine flexion) versus riding on a long rein (cervical spine extension), may aid in the diagnosis. As previously discussed, head and neck flexion can be replicated by longeing with side reins; however, in some horses, this maneuver may not explicitly recreate the circumstances that incite clinical abnormalities. In a study comparing rein tension during unridden and ridden tests, rein tension force was higher with a rider versus longeing, and abnormal behaviors were more frequent when riding than not riding.[8] For some horses, ridden gait examination may be necessary. In other horses, underlying neck issues may not be specifically linked to specific head and neck positions but are induced by the act of riding. For example, horses with cervical nerve root pain may only exhibit forelimb lameness, idiopathic hopping-type forelimb lameness gait, or root signature posture when ridden. Other ridden gait abnormalities due to proprioception deficits such as tripping, disjointed gaits, and cross-cantering may also be present only when or exacerbated while riding.

Certain abnormal equine behaviors initially coined "equine pain face"[9] and more recently referred to as the Ridden Horse Pain Ethogram include numerous head and neck positions and movements amongst a variety of other abnormal behaviors and gaits.[10] Studies have revealed a correlation between these abnormalities and underlying musculoskeletal pain.[10,11] However, Ridden Horse Pain Ethogram head and neck abnormalities may not be specific for pain in the cervical spine since abnormal head and neck behaviors were significantly decreased after diagnostic analgesia of the limbs, sacroiliac region, or back.[11] For the rider, unwanted or abnormal behavioral responses to rein tension are frequently believed to be mouth or neck abnormalities. In some horses, this is indeed the situation; however, this is not true for all horses. For some, this is merely a sign of discomfort in a site yet to be determined.

Neurological Examination

If neck dysfunction is suspected during the assessment, especially if there is evidence of any neurological deficit, a neurological examination should be performed. Thorough neurological examination is considered best practice; however, a detailed description of a comprehensive neurological evaluation is beyond the scope of this presentation. For horses with suspected cervical spine issues, neurological

assessment of posture and gait are paramount. Neurological gait abnormalities such as paresis (weakness) and/or ataxia (proprioception abnormalities) can be subtle in early or dynamic cervical spine conditions. Evaluation of gait while walking in straight lines during tail-pull maneuvers, walking with and without head elevation, walking up and down hills, and walking in small, tight circles enhances recognition of neurological deficits, especially in the early diseased horse. Observations of abnormal limb movement and/or placement during these maneuvers such as hypermetria, hypometria, circumduction, or pivoting on a limb or limbs provide additional clues of potential underlying neurological deficits. Less commonly, exercising abnormalities such as cross-cantering, disunited or disjointed gaits, toe dragging, and tripping may also be noted. Bear in mind that many abnormal neurological gait characteristics are also commonly observed in horses with primary orthopedic pain. At the author's institution, examinations are frequently performed by both a sports medicine/lameness specialist and a neurology specialist, which can further heighten suspicion of the neck and sometimes help differentiate between or include underlying conditions in both cervical spine systems. In other horses, worsening or continuation of the subtle neurological deficits following resolution of lameness further increases suspicion of a cervical spinal cord abnormality.

Challenges and Next Steps

Although there is similarity in the collective abnormal clinical features of horses with neck pain, there is considerable variability in the type and severity of clinical signs in an individual horse. Equally important, many of these abnormal clinical signs are shared by a multitude of non-neck musculoskeletal pain sites and dysfunction. Additional challenges during the initial assessment include a mismatch or misinterpretation by riders regarding the neck as the bona fide underlying source of pain. For example, in the horse that presents for "heavy in the bridle" or "heavy on one rein," neck pain is a common rider concern. Yet these ridden behaviors are more frequently associated with limb lameness and resolution of the "heavy in the hand" feeling after diagnostic analgesia of the lame limb(s) refutes an owner-perceived neck issue. Hindlimb toe drag can be noted in horses with cervical cord compression but is also observed in horses with bilateral hindlimb lameness conditions such as hind proximal suspensory desmitis, sacroiliac joint pain, and distal tarsitis. Rearing, refusal to walk forward, unwillingness to work, and general laziness can also be exhibited in horses with back, sacroiliac, or other musculoskeletal sites of pain. While a thorough clinical examination remains best practice to enhance the clinician's suspicion of an underlying cervical spine condition, it is often only the beginning of the diagnostic pathway. For most horses, complementary and additional testing directed toward cervical spine abnormalities is required to definitive diagnosis.

In horses with combined lameness and abnormal behaviors, diagnostic analgesia is very helpful in differentiating between primary limb lameness versus pain originating from the neck. Resolution of both the lameness and the abnormal head/neck behaviors confirms limb lameness as primary. Resolution of lameness but continued abnormal behaviors is equally valuable; some horses may have more than one musculoskeletal pain site, limb lameness, and neck pain. In other horses, continued abnormal ridden behaviors after diagnostic analgesia in the back and/or the sacroiliac region help to differentiate other axial skeleton pain sites versus neck pain. During the clinical examination, ruling out can be just as important as ruling in neck pain and/or dysfunction as the potential underlying cause of the abnormal clinical abnormalities. Subsequent testing such as serology and imaging can also yield false positive and false negative results; therefore, having done due diligence via a thorough comprehensive clinical assessment increases the likelihood of the horse actually having an underlying cervical spine abnormality. Without a doubt, evaluations in these poor-performing horses with suspected neck conditions can be time-consuming, exhausting, and expensive but are well worth the effort since they keep the clinician on an effective diagnostic path.

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 and no financial interests associated with this paper.

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How to Refer a Neurologic Case

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Horses with neurologic disease present diagnostic and therapeutic challenges to practitioners, particularly in ambulatory settings. Optimizing the initial field evaluation and setting appropriate expectations with all involved parties will improve client satisfaction and increase the likelihood of obtaining an accurate diagnosis, allowing targeted treatment or management. Author's address: Department of Clinical Studies, New Bolton Center, University of Pennsylvania School of Veterinary Medicine, Kennett Square, PA 19348; e-mail: amyjohn@vet.upenn.edu. © 2023 AAEP.

1. Introduction

Many horses develop signs that might indicate neurologic disease during their lifetime. Neck problems involving the vertebral column are particularly common, including cervical osteoarthropathies, cervical vertebral stenotic myelopathy, and intervertebral foraminal stenosis. All involved individuals (owners, trainers, barn managers, referring veterinarians, and receiving veterinarians) benefit most when they are aligned regarding the goals and expectations for the visit. Advanced communication of these goals and expectations between all involved parties will improve the experience for the client and increase the likelihood of arriving at an accurate diagnosis in the most expedient fashion.

2. Initial Evaluation by the Referring Practitioner

These proceedings describe important points to consider during evaluation of a horse that might have a neurologic disease related to the cervical spinal cord, with particular focus on those that might have structural abnormalities of the cervical vertebral column. These cases include horses with spinal cord compression (cervical vertebral stenotic myelopathy, CVSM) and horses with nerve root or spinal nerve compression (intervertebral foraminal stenosis). A guiding tenet of neurology is that clinical signs are related to lesion location and not underlying disease. Therefore, diagnostic evaluation is geared toward determining whether the horse's signs are due to a structural problem within the neck or whether the horse has a different underlying disease process. The most common neurologic problems that mimic CVSM include neurodegenerative disease, known as equine neuroaxonal dystrophy/equine degenerative myeloencephalopathy (eNAD/EDM), and infectious myelitis, most commonly due to *Sarcocystis neurona* (equine protozoal myeloencephalitis, EPM).

Essential tasks for the referring practitioner are as follows. First, the veterinarian needs to understand and document the concerns regarding the horse through discussion and clinical examination. Then, the veterinarian should discuss what diagnostic testing should be performed prior to referral and what is best performed at the referral center. If uncertain about the best course of action, the referring veterinarian should reach out to the receiving veterinarian

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to discuss a plan. Concurrently or subsequently, the referring veterinarian should provide pertinent information and results to the receiving clinician and explicitly discuss expectations about the goals of the visit and the anticipated diagnostic pathway. Any specific situational or insurance concerns should be conveyed to minimize misunderstandings and dissatisfaction. There is no "right" or "wrong" answer about how much testing should be performed prior to referral. For some cases, it might be appropriate to refer the case after a phone call or conversation with the client. For others, the client wants to exhaust all possible diagnostic testing at the farm prior to undertaking a trip to a referral center. The financial pros and cons should be considered; for many horses, early referral is more cost-effective in the long run due to the expense of performing treatment trials, repeating diagnostic tests, and failing to identify the underlying cause of the problem in an expedient manner.

Diagnostic evaluations of horses with neurologic signs usually include a combination of anamnesis, clinical examination, blood testing, cerebrospinal fluid (CSF) analysis, and imaging studies. These components might be performed by the referring veterinarian, the receiving veterinarian, or both. Important considerations are discussed below.

Anamnesis

Historical information can provide important clues regarding the underlying etiology and guide diagnostic recommendations. Horses with CVSM or eNAD/EDM might have many years' worth of signs (chronic history of tripping or underperformance, for example), whereas horses with EPM tend to have more recent and progressive signs. Owners frequently perceive horses with CVSM to have neck pain or stiffness, whereas horses with EPM are comfortable unless comorbidities exist. Horses with eNAD/EDM are likely to have erratic or unpredictable bad behavior or an overall change in behavior and temperament. Additional useful information includes response to therapeutic interventions, if performed: Does the horse improve when treated with phenylbutazone, and does the ataxia improve after a month of antiprotozoal treatment?

Clinical Examination

Clinical examination is discussed elsewhere in this session.

Blood Testing

Serology is often submitted to investigate whether the patient has been exposed to infectious causes of neurologic disease. Interpretation of these tests will be discussed elsewhere in this session. Knowing whether the horse has or has not been exposed to the causative agents of EPM (*Sarcocystis neurona* and *Neospora hughesi*) might alter the diagnostic pathway, and for this reason the results might be helpful in setting up the appointment. However, veterinarians should ensure that owners understand that positive serologic results indicate exposure to the organism but do not confirm disease and that subsequent CSF analysis will be recommended. Ideally, a copy of the serology is provided in advance or at the time of the appointment.

Vitamin E is an essential antioxidant and micronutrient. Deficiencies have been associated with several neurologic and muscular conditions, including eNAD/EDM, equine motor neuron disease, and vitamin E responsive myopathy. Many practitioners recommend vitamin E supplementation after neurologic disease has been identified. Ideally, a blood sample should be analyzed for vitamin E concentration prior to initiation of supplementation so that deficiencies are recognized as a low serum vitamin E concentration might influence the differential list.

CSF Analysis

Some practitioners are comfortable collecting CSF in the field. If CSF is available, ensure that cytology is performed in addition to desired infectious disease testing because knowledge of cell counts, protein concentration, and cytology will aid in interpretation of infectious disease test results. Additionally, any excess CSF should be saved and stored in a freezer rather than discarded. Ideally, serum harvested at the same time as CSF collection should be saved as well. These CSF and serum samples can be stored in no-additive tubes and frozen at −20°C or −80°C. Storing samples allows later submission of additional tests should the first set of results not yield a diagnosis.

Imaging Studies

Practitioners have varying comfort levels in obtaining cervical imaging in the field. Regardless of practitioner skill, radiographic images obtained with a hand-held machine in the field are unlikely to approach the quality of images obtained with a larger overhead system at a referral center, particularly of the caudal cervical vertebral column. In some cases, survey cervical radiographs obtained in the field can guide the referral appointment by suggesting either myelography and/or computed tomography (CT) as the next appropriate imaging modality. In other cases, the quality of field radiographs obtained does not permit adequate interpretation, and the owner must pay to have them repeated at the referral center. The potential need to repeat studies should be discussed with the client. Ultrasonography of the neck can provide useful information regarding the presence of abnormalities such as synovitis or osteophytosis of the articular process joints but does not allow adequate assessment of canal or foraminal stenosis.

3. Case Referral

Ideally, the referring practitioner and receiving clinician connect prior to the visit via text, phone, or e-mail to establish expectations and a diagnostic plan. For some cases, the plan might be limited to performance of a neurologic exam to confirm clinical

status, with no diagnostic testing desired. For others, all parties might desire the most comprehensive workup possible, potentially consisting of CT-myelography and extensive cerebrospinal fluid analysis. Sometimes, the diagnostic pathway is uncertain, with more invasive or expensive testing predicated on the results of initial diagnostic test results. In the author's opinion, it is better to plan for the most extensive evaluation the client might desire and then cancel unnecessary procedures, rather than attempt to add procedures during the visit, since it might be challenging or impossible to perform additional desired diagnostic tests due to scheduling or logistical reasons.

Choosing the appropriate diagnostic pathway and referral center requires knowledge of the information that can be gleaned from each procedure and the capabilities of the referral center. For example, standard survey radiography can provide information about vertebral canal stenosis and presence of osteoarthritis, but it cannot confirm spinal cord or nerve root compression. Cervical myelography provides excellent information regarding spinal cord compression that occurs in a dorsoventral direction or in flexed or extended neck positions but can miss lateral or dorsolateral spinal cord compression. CT-myelography allows detection of lateral and dorsolateral compression but usually does not permit evaluation in flexed and extended neck positions. Standing CT (without myelography) can give excellent information regarding osteoarthritis and foraminal stenosis but is not ideal for assessing spinal cord compression. Therefore, if the goal is to determine whether the horse has spinal cord compression, a standing CT (without myelography) is not the recommended diagnostic pathway. Instead, the ideal pathway would be a cervical myelogram (with flexed and extended views) followed by CT-myelography. Conversely, if the goal is to determine whether a horse's neck pain and thoracic limb lameness is due to osteoarthritis and foraminal stenosis, a standing CT might provide all necessary information while avoiding the risks of general anesthesia and intrathecal contrast administration.

As aforementioned, knowing which questions need to be answered (Cord compression? Foraminal stenosis? Infectious disease status?) will help guide the appointment. Additional considerations include those related to the patient's status, client's wishes, financial resources, and insurance expectations. Some horses are too ataxic or too anxious to tolerate a standing CT. Some clients are very concerned about CSF centesis or general anesthesia, whereas others desire to pursue every potential diagnostic test. Advanced imaging adds considerable cost and might not be warranted in every situation. Ask yourself and/or the client, "Will the information obtained from a myelogram (or other diagnostic test) change the decision-making process or options for the horse? Does the client need to have the information to be comfortable moving forward? Is the procedure necessary to satisfy insurance criteria?" If the answer to all these questions is "no," the procedure is likely unnecessary.

4. Discussion

Most clinicians at referral centers are happy to discuss cases with referring veterinarians. Establishing a relationship with local specialists allows practitioners to familiarize themselves with the diagnostic capabilities and estimated costs at the referral center. These relationships are mutually beneficial, allowing the practitioners to support their clientele fully, while providing caseload to the referral centers. Good relationships require communication in advance of the visit so that both parties understand the goals of the visit and the likely diagnostic pathway. This allows the referring veterinarian to prepare their client for the visit, establishing expectations for what will happen and how much it will cost. Mentally prepared clients are more likely to be satisfied with their visits, which will improve relationships in every direction! Additionally, and most importantly, this type of communication benefits the horse as it streamlines the examination to those procedures that are most useful to answer the clinical questions, thus minimizing additional stress and expense.

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.

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How to Take High-Quality Radiographs of the Equine Cervical Vertebral Column, Troubleshoot Common Issues Encountered in the Field, and Refine Interpretation

Kathryn W. Bills, VMD, DACVR, DACVR-EDI

This article will help practitioners improve their cervical vertebral column radiography skills and refine their ability to recognize pathology associated with horses presenting with neurologic disease, poor performance, and neck pain. Author's address: New Bolton Center, University of Pennsylvania, 382 West Street Road, Kennett Square, PA 19348; e-mail: kwulster@vet.upenn.edu. © 2023 AAEP.

1. Introduction

Neck pathology is increasingly recognized as a cause of lameness, neurologic dysfunction, and poor performance in the equine athlete.[1–3] Compared to radiographs of the distal limb, high-quality radiographs of the cervical vertebral column are more difficult to acquire in the field routinely. Suboptimal radiographs have a downstream effect on the accuracy of radiographic interpretation, including failure of lesion identification (several causes) and over-reading error (e.g., overestimation of the degree of articular process osteoarthrosis). This paper aims to provide best practices for acquiring radiographs of the cervical vertebral column in the field, mitigation strategies when images are suboptimal, and guidance for clinical correlation and risk assessment.

2. Radiograph Acquisition

Equipment

80kVp and 90kVp portable generators can be used to acquire diagnostic images of the equine cervical vertebral column. 100kVp generators are also available but are considerably heavier at approximately twice the weight of a 90kVp generator, which creates logistical difficulties during acquisition.

Patient Positioning

High-quality radiographs of the cervical vertebral column start with proper patient positioning. Sedation should be considered to minimize patient movement as the exposures for the caudal cervical vertebral column typically require prolonged time settings, given the lack of high mA capability of portable generators. The horse should stand squarely with the head held in a neutral position by the handler in the sagittal plane with the head perpendicular to the ground as viewed from in front of the horse (e.g., without and left or rightward deviation of the muzzle). Flexion, often induced by the handler, typically manifests radiographically with mid-cervical kyphosis, particularly at C3-C4. One can also cause a false appearance of subluxation at C6-C7 and C7-T1 (Fig. 1).

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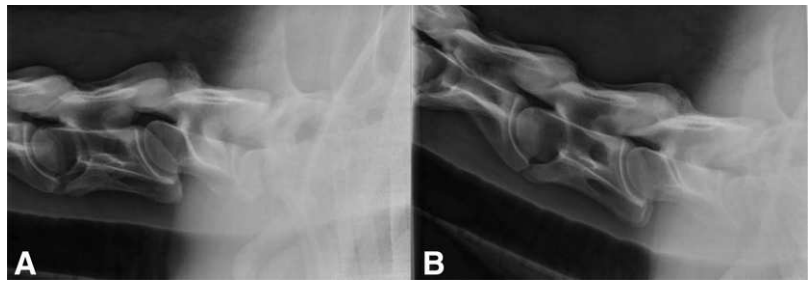


Fig. 1. A 4-year-old Warmblood gelding presented for intermittent severe left forelimb lameness that did not improve in the field with median/ulnar diagnostic analgesia. No neurologic deficits were present on clinical examination. Radiographs of the horse's elbow, shoulder, and cervical spine were acquired. The elbow was radiographically normal. Positioning with a neutral to slightly flexed head position was associated with inducible C6-C7 subluxation (A), while neutral to slight extension improved the alignment of C6-C7 (B). A developmental lesion (osteochondrosis) was identified in the glenoid and was considered the most likely cause of lameness following improvement with intra-articular scapulohumeral diagnostic analgesia.

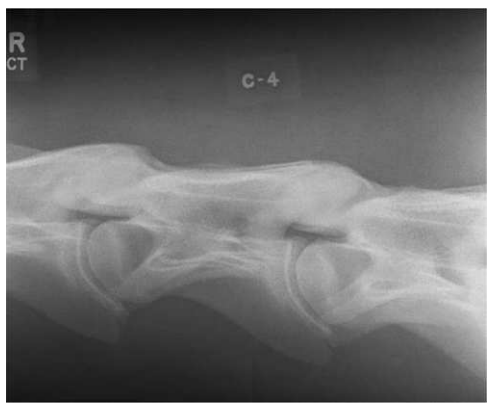


Fig. 2. Example of a fiducial marker in the mid-cervical region dorsal to vertebrae of similar morphology (C3-C4-C5).

Fiducial Markers

Fiducial marker placement helps determine the location being evaluated for vertebrae with similar morphology (C3-C4-C5) (Fig. 2). Markers are particularly useful in horses with abnormal vertebral morphology, such as unilateral or bilateral homologous transposition or absence of the C6 transverse process ventral lamina.[4,5]

Plate Positioning, Lateral-Lateral Radiographic Projections

With the patient properly positioned, holding the plate perpendicular to the ground instead of parallel to the angle of the cervical vertebral column allows the vertebral column to be projected on the hypotenuse of the plate, allowing more anatomy to be included in a single image. Standard right-to-left or left-to-right lateral projections should be acquired from the occiput to cranial T1 to include the entire cervical vertebral column. This typically requires 5 to 6 projections to image all regions. Beam divergence primarily affects articular processes on the periphery of the image, so if there is suspicion of enlargement, additional images may need to be repeated with altered centering (Fig. 3). Some references recommend taking both right-to-left and left-to-right lateral-lateral images, but the benefits of doing so, in the author's opinion, are met by taking oblique projections, which have additional benefits discussed below. With proper technique, C6 to C7 can be routinely imaged even in large horses. However, adequate exposure of C7 to T1 in the field with a portable generator is somewhat dependent on the patient's size, conformation, and muscling. Most commonly, one will only be able to appreciate a general sense of articular process size, vertebral canal width relative to the vertebral body, ventral lamina morphology, and possibly intervertebral disc space width instead of high-quality detail of this site. As such, lesions such as articular process osseous fragments and osteolysis are easily missed at this site.

Mitigation of underexposure can be achieved with collimation. Decreasing scatter can significantly improve

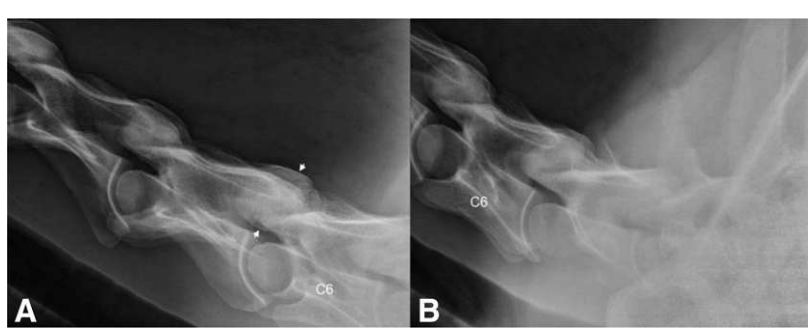


Fig. 3. Lateral radiographs of the mid to caudal cervical spine with altered centering. A, centered on C5 with a false appearance of C5-C6 articular process enlargement compared to B, with the radiograph centered on the C6-C7 articular process joint.

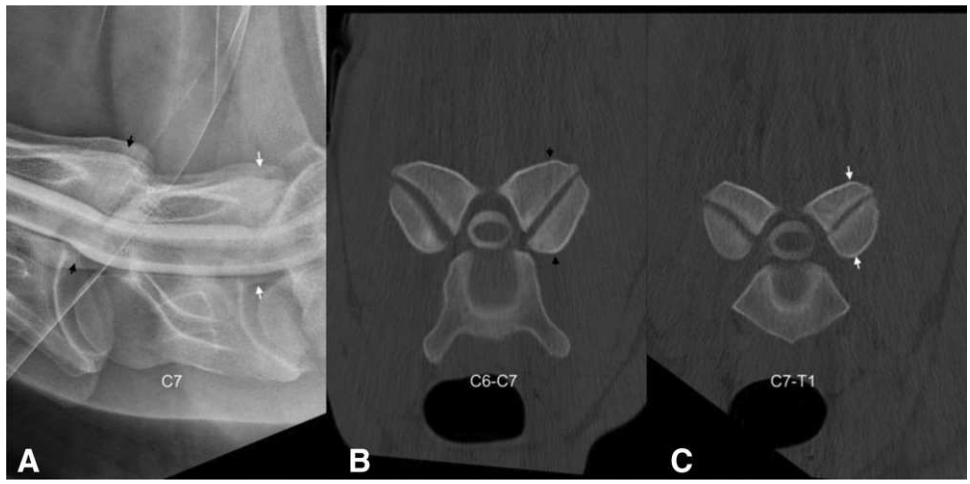


Fig. 4. A, Cervical vertebral myelography centered at C7. B, Transverse plane CT myelogram centered at the C6-C7 APJ; and C, Transverse plane CT myelogram centered at C7-T1 APJs all of the same horse. Note the similar size of the C6-C7 (black arrowheads) and C7-T1 (white arrowheads) articular processes on the radiographs with partial obscuration of the intervertebral foramen compared to the CT size discrepancy between C6-C7 (black arrowheads) in B and C7-T1 (white arrowheads) in C with significantly smaller C7-T1 articular processes.

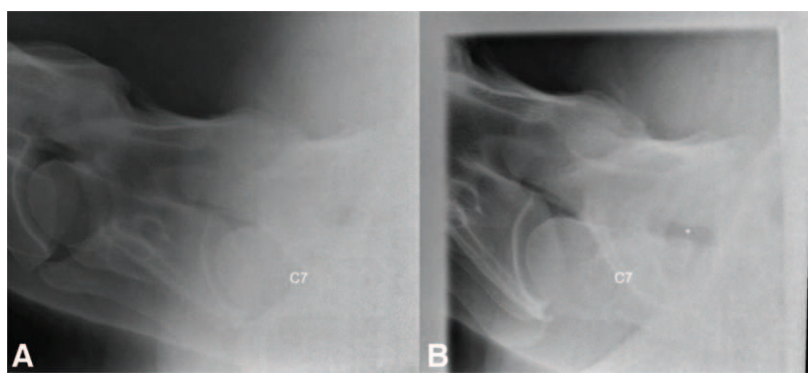


Fig. 5. Uncollimated (A) and collimated (B) radiographs of the same region of the caudal cervical vertebral column. Note the improved visualization of the C6-C7 articular processes, C7 vertebral body, and intervertebral foramen (*) in B.

the quality of bone definition and improve contrast resolution (Fig. 5). It is the author's opinion that C7-T1 articular processes also tend to have a false appearance of enlargement on lateral radiographs when compared to computed tomography (CT) of the same horse (Fig. 4). This is likely due to the more axial location of the C7-T1 articular processes relative to C6-C7 and the subsequent magnification of the former.

3. Determining Lateral-Lateral Radiograph Adequacy

The end goal of lateral radiographs is to evaluate the relative width of the vertebral canal subjectively and more objectively via measurements of mean sagittal ratios, evaluate vertebral column alignment, and identify articular process enlargement or other pathologies, such as osseous fragmentation and any associated obscuration of the intervertebral foramina. This is best achieved by superimposing the articular processes. Many references cite that superimposition of the ventral lamina should be used to determine if cervical radiographs are appropriately "straight," as this typically also leads to superimposition of the articular processes. However, this is not always the case, and adjustments must be made individually to correct for this (Fig. 6). Non-superimposed articular processes can lead to partial obscuration of the intervertebral foramina and a false impression of left/right articular process asymmetry. Additionally, because one joint is inherently closer to the plate, there is often an impression of slight size asymmetry even with normal articular processes.[4]

Oblique Projection Acquisition

There is no current standard for when oblique projections should be acquired of the cervical vertebral column. Still, in the author's opinion, there is little downside from a clinical perspective except for personnel radiation exposure, which is marginal if ALARA conditions are satisfied. If obtained, both right ventral to left dorsal (RV-LD) oblique and left ventral to right dorsal (LV-RD) oblique projections are recommended along the length of the cervical vertebral column. Oblique projections allow for discrimination between

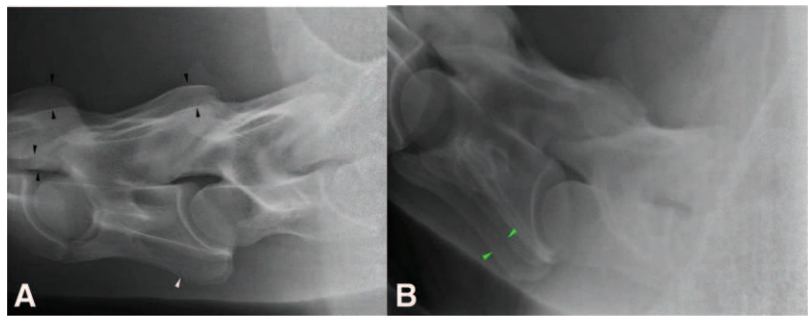


Fig. 6. Collimated right to left lateral radiograph of the caudal cervical vertebral column with a 90kVp portable generator in two different horses. Note the superimposition of the C6 ventral lamina in A (white arrow head) but the lack of superimposition of the C5-C6 and C6-C7 articular processes (black arrowheads) compared to B, appropriate superimposition of the C6-C7 articular processes while the ventral lamina of C6 are not superimposed (green arrowheads).

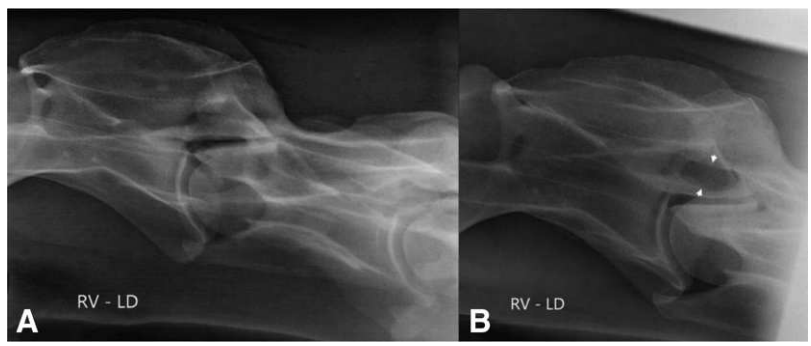


Fig. 7. ~15 degree (A) vs ~30 degree (B) right ventral to left dorsal oblique projections of the C2-C3 articular processes. Note the improved conspicuity of the right intervertebral foramen and ventral margin of the right cranial C3 articular process in B (white arrowheads).

unilateral and bilateral disease, interrogation of osseous fragment location, and assistance in determining the degree of articular process osteoarthrosis by comparing left and right sides and adjacent vertebrae. In the author's experience, some practitioners take oblique projections from only one side (e.g., only the RV-LD oblique), but it is vital to acquire them from both sides. The author prefers ventral to dorsal oblique projections to minimize magnification of the articular processes, but it is of greater importance to take the oblique projections the same way so the size of the articular processes can be directly compared.[6] For instance, it would be preferable to take paired RD-LV and LD-RV projections instead of paired RD-LV and RV-LD projections. Different angles are used for the oblique projections depending on the region of the neck being imaged, with a shallower angle (~20–30 degrees) utilized for C2-C3 and a steeper angle (~45–55 degrees) used for the caudal articular process joints (APJs).[4] If a horse has symmetrical anatomy, the angle between RV-LD and LV-RD projections will be the same, but given the preponderance of articular process joint asymmetry, angle adjustments need to be made in real-time.

4. Determining Oblique Projection Adequacy

Oblique projections are deemed adequate when the intervertebral foramen width is maximized (Fig. 7).[6] This allows for the evaluation of general articular process size compared to adjacent articular processes, caudodorsal articular process osseous fragments, ventral cranial articular process osteoproliferation, and the degree of obscuration of the intervertebral foramen of the dorsally projected joint. In the same projection, the ventrally projected articular processes can be evaluated for general size compared to adjacent articular processes, cranioventral articular process osseous fragments, and to a lesser extent, trabecular sclerosis. The ventrally projected portion of the vertebral body and lamina can also be compared to adjacent vertebrae to characterize ventral lamina transposition. Though this finding currently has indeterminate significance, if necessary for complete characterization, morphologic variation of the caudal cervical ventral lamina is often better characterized with a shallower oblique angle than the angle used to evaluate the articular processes and intervertebral foramina.[4,5] In the author's experience, when correcting the oblique projection angle, steeper projections are typically required. Similar to lateral-lateral projections, oblique projection image quality is also significantly improved with collimation (Fig. 8).

Ventral Dorsal and Dorsoventral Projections

Ventrodorsal (VD) or dorsoventral (DV) radiographs are typically only diagnostic in the cranial to mid-cervical spine and present some additional radiation safety risks. In the author's opinion, the same information can often be gained using oblique radiographic

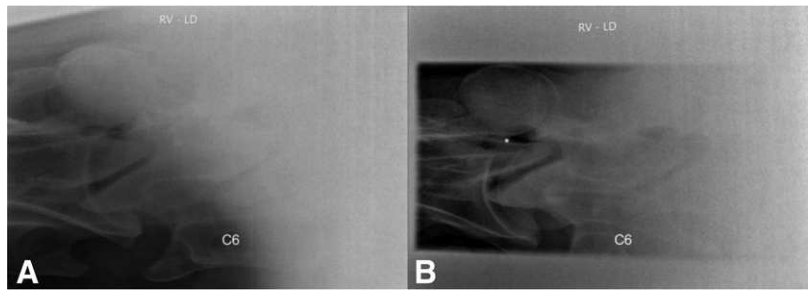


Fig. 8. Uncollimated (A) and collimated (B) right ventral to left dorsal oblique radiographs of the same region of the caudal cervical vertebral column. Note the improved visualization of the C5-C6 articular process bone detail and intervertebral foramen in B (*).

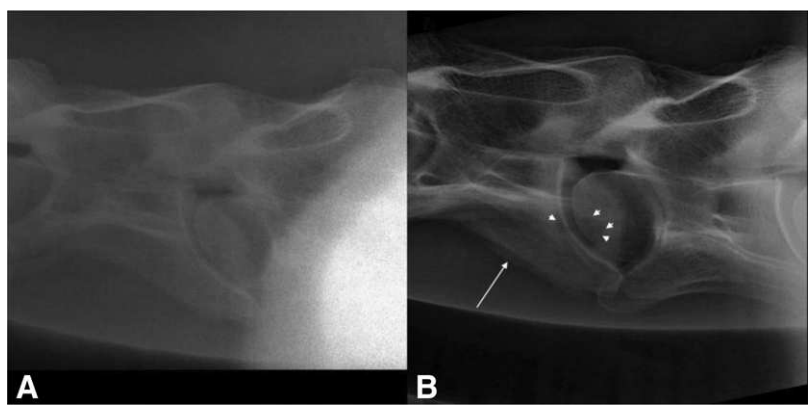


Fig. 9. A, Well-positioned and adequately exposed lateral radiograph of the caudal cervical spine in an 8-year-old Thoroughbred gelding that presented with acute severe neck pain taken with a portable x-ray generator. B, lateral radiograph of the same region taken with a high-voltage generator. Note the ill-defined osteolysis superimposed with the caudal C5 vertebral body (white arrowheads), surrounding trabecular sclerosis, and ill-defined caudoventral lamina periosteal reaction (white arrow).

projections instead of ventrodorsal/dorsoventral views. However, particularly in trauma cases, a VD/DV projection is beneficial and best highlights transverse process fractures that can be overlooked on the lateral projection.

5. Interpretation

A guide to improved radiographic interpretation of cervical vertebral column pathology is beyond the scope of this article but will be discussed as it pertains to missed diagnoses resulting from suboptimal acquisition techniques.

6. Failure of Lesion Identification

Missing radiographic lesions on equine cervical vertebral column radiographs is related to quantum mottle ("grainy-ness") due to underexposure, motion, positioning, and lack of inclusion of the field of interest – or a combination. Osteolysis is seen most commonly with discospondylitis (or other infection) or neoplasia. Even when included in the field of interest, subtle lysis is rarely identified even in hindsight, typically due to underexposure (Fig. 9). This can be partially mitigated with collimation, but a suspicious region must still be identified to focus the beam.

7. Occiput and Cranial Cervical Spine

The occiput is best visualized by loosely placing the ears under the headstall of the halter or using white tape to gently pully the ears rostrally. Common pathology of the occiput includes nuchal ligament and semispinalis capitis enthesopathy, as well as avulsion fragments which can be easily missed or not visualized if the ear base is superimposed (Fig. 10).[7] The clinical significance of these lesions is variable, with many warmbloods presenting with occiput enthesopathy without clinical signs.[1]

8. Caudal Cervical Spine

If the main clinical question is to determine if there is a degree of osteoarthrosis sufficient to explain an "unblockable" unilateral forelimb lameness (e.g., nerve root signature, C6-T2 neurolocalization), it is important that the C6 to C7 and C7 to T1 articulations be imaged with both lateral and oblique projections and that the owner is aware that lack of identification of caudal cervical pathology with a portable generator does not rule pathology of this region out as a cause of reported clinical signs. Collimation and steeper oblique projections are the most easily implemented mitigation strategies that can make a significant difference in image quality and, by extension, one's ability to make a definitive diagnosis.

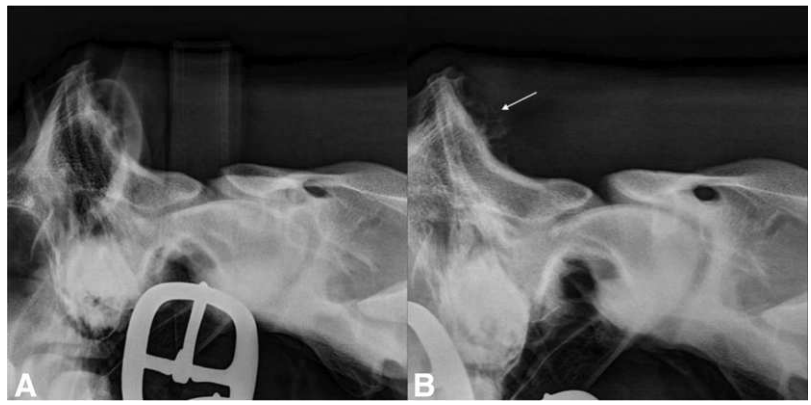


Fig. 10. Lateral radiograph of the occiput of the same horse with the halter headstall and ears superimposed with the occiput (A) vs an image more clearly showing the abnormal occiput enthesis (B; white arrow).

9. Diagnosis and Next Steps

In all cases, no matter the disease process considered most likely, one should put the patient in one of four categories:

1) The radiographs are moderate to severely abnormal (with consideration of the patient's signalment) and are most likely to explain the clinical signs.
   a. How does age come into consideration? For example, a young horse with moderate osteoarthrosis has a higher likelihood of clinical signs associated with radiographic abnormalities compared to an aged horse with the same degree osteoarthrosis.
2) The radiographs are normal or mildly abnormal, in which case osseous pathology of the cervical vertebral column is unlikely to be the cause of clinical signs.
   a. This does not necessarily rule out disease secondary to soft tissue pathology (e.g., joint capsular thickening, synoviocoele, epidural cyst, or hematoma causing spinal cord compression) but it is less common that this occurs independent of osseous pathology.[8]
3) Abnormalities are identified but the findings are equivocal as the cause of clinical signs.
   a. For instance, identifying moderate osteoarthrosis of C5 to C6 and C6 to C7 in an aged warmblood may or may not be associated with spinal cord compression and requires more invasive testing to rule this out, such as cerebrospinal fluid sampling and CT myelography.[9]
4) A cause for clinical signs is not apparent but could have been missed due to unavoidable shortcomings associated with cervical vertebral radiography in the field.
   a. For instance, a horse has severe unilateral "unblockable" forelimb lameness, and there is moderate symmetrical osteoarthrosis of C6 to C7 articular processes but C7 to T1 cannot be clearly evaluated.

After this determination, the veterinarian will best be able to guide the owner toward the most appropriate next steps, whether this is with definitive treatment, empirical treatment, further testing in the field, or referral for further workup.

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.

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How to Use Diagnostic Testing for Neurological Conditions in the Field

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Blood tests and, less commonly, cerebrospinal fluid tests are utilized to narrow the differential list for horses with neurologic disease prior to treatment or referral. Appropriate test selection, accurate interpretation of results, and knowledge of test limitations will improve diagnostic accuracy while reducing overall cost. Author's address: Department of Clinical Studies, New Bolton Center, University of Pennsylvania School of Veterinary Medicine, Kennett Square, PA 19348; e-mail: amyjohn@vet.upenn.edu. © 2023 AAEP.

1. Introduction

Diagnosing horses with neurologic disease is challenging in any situation, but particularly in the field, where facilities and equipment are limited. Nonetheless, ambulatory veterinarians are often faced with a horse suspected to have neurologic disease, manifested either by obvious signs of neurologic dysfunction or by enigmatic gait deficits or poor performance. The most common noninfectious spinal cord diseases of horses are cervical vertebral stenotic myelopathy (CVSM) and equine neuroaxonal dystrophy/equine degenerative myeloencephalopathy (eNAD/EDM). The most common infectious spinal cord disease is equine protozoal myeloencephalitis (EPM), with Lyme neuroborreliosis less frequently diagnosed. Horses that are negative for CVSM and EPM often have a final diagnosis of EDM/eNAD, which can only be definitively diagnosed postmortem. However, less commonly diagnosed conditions such as traumatic spinal cord injury and central nervous system lymphoma should also be considered.

When faced with an ataxic horse in a hospital setting, the author's general diagnostic plan is as follows. Prior to admission, the likelihood of a viral disease such as equine herpesvirus myeloencephalopathy, West Nile virus myeloencephalitis, or rabies is considered. If equine herpesvirus myeloencephalopathy is high on the list, the horse is isolated, and samples (whole blood and nasal swabs) are submitted for equine herpesvirus 1 polymerase chain reaction (PCR) testing prior to further workup. Rabies suspects are treated with caution and workup is limited to prevent exposure or harm to personnel. In all other cases, a complete neurologic evaluation is performed. Most ataxic horses in the author's practice show signs consistent with cervical spinal cord disease, and the majority are not suspected to have viral disease. When that is the case, cervical radiography is performed as the first diagnostic test. If radiographs reveal evidence for CVSM, myelography or possibly computed tomography myelography is often recommended. Spinal fluid is routinely collected during myelography and can be assessed cytologically as well as

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submitted for EPM testing. If radiographs are normal, equivocal, or mildly abnormal, standing cerebrospinal fluid (CSF) collection is offered. Using sedation and either a lumbosacral or ultrasound-guided C1-C2 approach, CSF can be obtained. CSF and blood samples can be submitted for CSF cytology and EPM testing, plus Lyme antibody testing and phosphorylated neurofilament heavy (pNF-H) assay if desired. If EPM results are positive, treatment is initiated. If EPM results are negative, myelography is again considered.

The diagnostic algorithm described above works well in a referral setting, but what should the ambulatory veterinarian do? A frank discussion with the client regarding diagnostic limitations in the field and costs/benefits/risks of referral versus care on the farm is recommended. Cervical radiographs performed with a portable machine can be diagnostic but, due to equipment limitations, are often of lower quality than those performed with an overhead system at a referral hospital. Serology for infectious diseases (EPM and Lyme) often has a high false positive rate (and a low positive predictive value) in the absence of paired CSF testing. Treatment trials are expensive, and it is not uncommon for an owner to spend thousands of dollars to treat diseases that the horse does not have. Initial workup at a referral center might lead to a lower total cost than months of treatment trials on the farm. Sometimes referral is simply not an option, and for those horses, the veterinarian must make decisions based on careful neurologic examination, regional disease prevalence, and available test results. This presentation will discuss the most utilized blood and CSF tests and interpretation of results, as well as benefits and drawbacks to their use.

2. EPM Testing

Antemortem diagnosis of EPM remains challenging and is always presumptive.[1] Many normal horses are exposed to the causative protozoa and develop antibodies in the absence of clinical disease. Therefore, performing serology will only reveal whether the horse has been exposed to *S. neurona* or *N. hughesi* and does not indicate the current disease status of the central nervous system (CNS). To achieve the best possible diagnosis in the live horse, three criteria must be met: presence of neurologic disease, exclusion of other likely causes, and confirmation of specific antibodies in the CSF, serum, or both. The commonly used diagnostic tests for EPM assess whether the horse has antibodies against the protozoa in serum, CSF, or both. EPM PCR testing to identify antigens (protozoal DNA) in CSF has been advocated recently as a potentially useful adjunctive diagnostic technique.

General principles for interpretation are as follows:

- A positive serum result indicates exposure to the organism but does not confirm CNS infection, regardless of the magnitude of the titer.
- A negative serum test usually indicates that the horse has not been exposed to the organism. Rarely, a recently infected horse might show clinical signs prior to seroconversion, in which case repeated testing in 10 to 14 days should be positive. However, negative serum results typically exclude EPM from consideration.
- If paired serum testing is performed to look for seroconversion, both samples should be tested on the same plate (same day) to allow direct comparison.
- A positive CSF test is more likely to correlate with an EPM diagnosis than a positive serum test. However, "false" positives commonly occur due to natural transfer of antibodies or blood contamination. Horses with low CSF titers are less likely to have EPM than horses with high CSF titers.
- A negative CSF test usually means EPM is not the cause of disease. Rarely, as mentioned above, a recently infected horse will show clinical signs prior to developing a measurable antibody level in CSF; retesting 10 to 14 days later should be positive.
- The best way to diagnose EPM with antibody assays is to submit both serum and CSF for quantitative testing and calculation of a serum: CSF titer ratio (or specific antibody index), which allows detection of intrathecal antibody production.
- The sensitivity and specificity of PCR testing have not been adequately described. Negative PCR results do not exclude the possibility of EPM. Positive PCR results might indicate active infection, even in the presence of negative immunodiagnostic results, but specificity is uncertain and false positive results have been observed.[2,3]

The author's current approach is to submit paired CSF and blood samples for *S. neurona* surface antigen 2/4/3 enzyme-linked immunosorbent assay (or *Neospora* enzyme-linked immunosorbent assay) serum:CSF titer ratio, which allows identification of intrathecal antibody production and correlates best with active CNS disease.

3. Lyme Disease Testing

Antemortem diagnosis of neurologic Lyme disease (Lyme neuroborreliosis or LNB) is best achieved by fulfilling several criteria, which include potential *B. burgdorferi* exposure, presence of neurologic signs, diagnostic testing to rule out other potential diseases, documentation of abnormal CSF, and identification of the organism or immunologic evidence of infection.[4] CSF cytological analysis is strongly recommended for horses with suspected LNB; results are often

abnormal with neutrophilic or lymphocytic pleocytosis and increased total protein.

General principles of interpretation for Lyme test results are like those for EPM testing, but Lyme diagnosis is even more challenging. A positive test usually indicates past or present infection with *B. burgdorferi*, although vaccination can also cause positive results for some tests. Regardless of test utilized, clinical Lyme disease cannot be confirmed, and there is no gold standard test. Horses living in an endemic area are frequently seropositive, so positive results will have a low positive predictive value of disease. None of the tests prove causation of clinical signs or predict whether disease is likely to develop in the future. There is no known correlation between magnitude of titer and likelihood of disease. It is unclear how well tests that predict stage of infection perform with horses that have had repeated exposures. Several additional caveats should be mentioned:

- Knowledge of vaccination history can aid in interpretation of results; canine vaccines used in horses might induce antibody production against outer surface protein A ± C, depending on the product.
- In theory, documentation of intrathecal antibody production is recommended for the diagnosis of LNB, but in practice it becomes difficult. Unlike with EPM, there is no established optimal cutoff for LNB using a serum:CSF antibody ratio. Horses with LNB frequently have abnormal CSF cytology and hence might have an abnormal blood-brain barrier, confounding results. Sample dilution can complicate interpretation of results (the Lyme multiplex assay tests serum at a dilution of 1:400, whereas CSF is run undiluted).
- The Lyme multiplex assay shows poor discriminatory ability for LNB.[5] Retrospective analysis of Lyme multiplex values for neurologic horses with postmortem diagnoses shows similar results for horses with and without LNB. Horses with LNB can have negative multiplex results, and horses without LNB can have positive multiplex results (on serum and CSF).
- PCR testing for *B. burgdorferi* can be performed on CSF, as can more advanced molecular techniques such as genomic hybrid capture assay.[6,7] A positive result is highly suggestive of LNB, but a negative result does not exclude the disease; the sensitivity of these techniques is unknown.

Most of the time, Lyme disease is not the explanation! For horses with cervical spinal cord localization and no evidence of meningitis, Lyme disease is virtually never the final diagnosis.

4. Neurodegenerative Disease

Neurodegenerative disease (eNAD/EDM) is always a tentative diagnosis in the living horse and should only be considered after documenting clinical signs consistent with the disease and excluding other possible diseases like CVSM and EPM through appropriate diagnostic testing. A biomarker test for neurodegenerative disease, pNF-H, is commercially available. However, the sensitivity of this test for eNAD/EDM is low (about 12%), and many confirmed cases have normal (negative) results.[8]

- pNF-H is a biomarker test, reflecting degeneration of neurons (particularly axons) and release of structural proteins into spinal fluid and blood. It is not a genetic test and is not specific for eNAD/EDM.
- pNF-H results that are within the normal reference interval do not exclude neurologic disease, regardless of whether serum or CSF is tested. A horse cannot be "cleared" of neurologic disease or neurodegenerative disease based on normal pNF-H results.
- pNF-H results that are above the normal reference interval are supportive of neurologic disease if the horse has neurologic signs. Based on limited evidence, neurodegenerative diseases such as eNAD/EDM and equine motor neuron disease appear more likely than other neurologic diseases to cause increased pNF-H in serum.[8,9] However, the specificity of increased serum pNF-H is not 100%! Many different conditions, including EPM, CVSM, and eNAD/EDM, can cause increased pNF-H in CSF.
- Not enough information is known about the performance of this test in neurologically normal horses to interpret increased pNF-H in a normal horse. Therefore, it is strongly recommended to avoid submitting samples from normal horses.

5. CSF Analysis

Some practitioners are comfortable collecting CSF in the field, whereas others are not. Horse and facility factors might also influence the practitioner's enthusiasm for performing CSF centesis. If CSF is collected, a sample should be submitted for cytology (cell counts, protein concentration, and cytological analysis) in addition to specific infectious disease and biomarker analyses. The most common diseases (CVSM, eNAD/EDM, and EPM) typically do not cause substantial changes in cell counts or cytology, with normal or mildly increased protein concentrations. The presence of meningitis, abnormal cells, or a markedly increased protein concentration should alert the practitioner to the possibility of a less common disease condition.

6. Discussion

In summary, antibody and biomarker assays performed on serum can provide adjunctive information

to the clinical examination but do not confirm a diagnosis. Adding information gained from CSF tests will increase diagnostic certainty. Negative EPM serum or CSF test results are useful in excluding EPM from consideration except in horses with very recent development of signs. Positive EPM serum tests show that EPM is a possibility but do not confirm disease, regardless of how high the titer is. Performing EPM serum:CSF titer ratios will markedly increase diagnostic accuracy. Lyme antibody test results are largely irrelevant for horses with spinal ataxia unless the horse has signs or CSF cytology consistent with meningitis. The biomarker pNF-H provides limited information and is frequently normal in neurologic horses and those with neurodegenerative disease. It should not be used to diagnose a specific disease condition, although increased serum pNF-H is observed most in horses with neurodegenerative disorders. Knowing the utility and limitations of diagnostic testing will help veterinarians to utilize client funds most effectively and improve accuracy of diagnosis.

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.

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How to Inject Cervical Articular Process Joints in the Field with Intra-Articular Medication

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Horses with neck pain may benefit from intra-articular cervical articular process joint therapy. Using accurate ultrasound-guided technique optimizes success and decreases the likelihood of injection complications. Author's address: University of Pennsylvania, Department of Clinical Studies, New Bolton Center, Kennett Square, PA 19348; e-mail: ejdavid@vet.upenn.edu. © 2023 AAEP.

1. Introduction

Intra-articular (IA) cervical articular process joint (CAPJ) treatment is commonly performed in performance horses with suspected neck conditions, and affected horses benefit from IA CAPJ therapy.[1–5] Several ultrasound-guided techniques have been described in the literature,[2–6] and this procedure can be readily performed in the field. Compared to the cranial CAPJs, caudal CAPJs are more difficult to image due to the deep anatomical location and increased prevalence of osteophyte formation at these sites. Best practices include good working knowledge of the ultrasonographic appearance of the CAPJs and adherence to medication regulations in the competition horse.

2. Technique

Ultrasonographic Identification of the CAPJ

The general location of an individual CAPJ is identified by counting cervical vertebrae starting behind the base of the ear and moving caudally toward the shoulder. In general, the cervical vertebrae are approximately one hand width in length, with space between each hand as an estimated site of individual CAPJ injection. The skin is prepared with a copious amount of alcohol, and clipping is usually unnecessary. The CAPJs can be identified using a multifrequency (6–10 MHz) linear or convex transducer with displayed depth ranging from 6 to 10 cm depending on the location and muscling. At the author's institution, a multifrequency (1.8–6.2 MHz) macroconvex ultrasound transducer[a] is used. The transducer is oriented perpendicular to the long axis of the cervical spine with the CAPJ identified cranial and dorsal to the transverse process of the caudal vertebrae of the joint. The CAPJ is visualized as an anechoic gap between hyperechoic crescent-shaped osseous contours of the associated cranial and caudal cervical articular processes. To ensure correct identification of an individual CAPJ, first identify the CAPJ between the second and third cervical vertebrae (C2-C3), and then move caudally identifying one CAPJ at a time. The C6-C7

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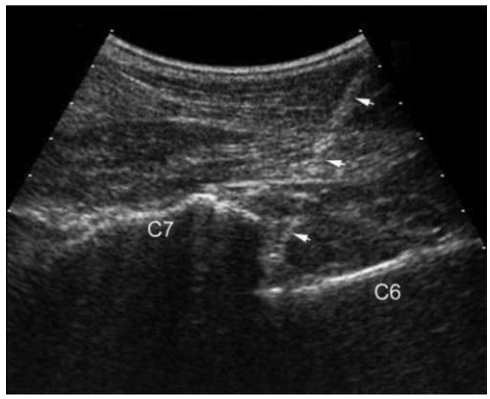


Fig. 1. Ultrasound image of a right C6-C7 CAPJ injection. The spinal needle (arrows) is hyperechoic and directed toward the CAPJ space.

CAPJ is situated just cranial to the supraspinatus muscle. Placing a skin marker dorsal to the selected CAPJ location facilitates quick identification for the CAPJ injection procedure.

Patient Preparation

The horse is typically sedated with intravenous xylazine hydrochloride (0.2–0.4 mg/kg)[b] or detomidine HCL (0.004–0.008 mg/kg).[c] The horse's neck is positioned in a neutral position maintaining a straight or slightly flexed-away posture. The injection site is aseptically prepared with chlorhexidine scrub solution followed by alcohol. The ultrasound probe is aseptically covered with a sterile surgical glove and a small amount of sterile acoustic gel between the transducer and the sterile cover. Both the injecting hand and the ultrasound hand are covered with sterile surgical gloves. Adjustments to the ultrasound image quality may be necessary after scrubbing and/or transducer cover application and should be performed prior to putting on surgical gloves for the CAPJ injection.

Injection of the CAPJ

The affected CAPJ is again located using ultrasonographic guidance. A copious amount of alcohol on the skin facilitates image acquisition. The transducer is slowly rotated clockwise for the right side and counterclockwise for the left side until it is oriented parallel to the long axis of the neck, maintaining the CAPJ within the center of the ultrasound image. Once rotated, the osseous contours of the cranial and caudal cervical articular processes have a characteristic "S-shaped" curvilinear echogenic appearance, also referred to as the "chair" sign (Fig. 1).[4] The CAPJ space is identified as the anechoic gap between the two cervical articular processes. A 9 cm × 20 g spinal needle is inserted through the skin approximately 2 cm cranial to the transducer and advanced in a caudal and axial (toward midline) direction, matching the angle of the spinal needle with the CAPJ and transducer. Spinal needle insertion can be accomplished with a needle guide attached to the transducer or using a free-hand technique. The author prefers the free-hand technique. The needle is advanced slowly ensuring continual visualization of the needle as it penetrates through the musculature and advances toward the CAPJ space. A properly positioned needle casts a hyperechoic reverberation and shadowing from the skin edge to the joint (Fig 1). For most horses, longer spinal needles are not necessary, especially when using a small footprint transducer. Once seated within the CAPJ, the stylet is removed, and synovial fluid is aspirated. In some CAPJs, joint fluid is not recovered. The therapeutic medication of choice is then injected. The spinal needle is removed and the CAPJ injection technique is repeated at additional sites as needed. In most horses, paired right and left CAPJs are injected.

Intra-Articular Therapy

Therapeutic medications for IA CAPJ injections vary among clinicians,[1–5] and there is only one published report regarding posttreatment efficacy.[1] Selected IA therapies primarily include corticosteroids such as methylprednisolone acetate, triamcinolone acetonide, or isoflupredone acetate. Some clinicians will also combine hyaluronic acid or amikacin sulphate with the IA corticosteroids. Less commonly, pitcher plant extract[1d] autologous protein solution, and autologous conditioned serum[3] have been used as IA CAPJ therapy. The author prefers IA methylprednisolone acetate ranging from 20 to 40 mg per CAPJ.

3. Challenges and Helpful Hints

- The vertebral artery courses along the ventral aspect of the CAPJs. Color flow Doppler imaging at the CAPJ site facilitates the identification of an injection path that avoids this artery.
- In horses with significant CAPJ pathology, the anechoic joint space can be obscured due to periarticular osteoproliferation. Slight movement of the transducer, usually in a dorsal or ventral direction, can assist in identifying a congruent articular margin to facilitate injection. Prior radiographic evaluation of the cervical spine can enhance the recognition of CAPJ arthropathy and facilitate accurate IA CAPJ therapy. However, in some horses, periarticular osteoproliferation is only identified during ultrasonographic assessment.
- Avoid spinal needle insertion along the ventral aspect of the CAPJ as this might result in inadvertent penetration of the subarachnoid space. If accidentally entered, cerebrospinal fluid may freely flow from the needle. Do not inject medication into the subarachnoid space.
- As with any joint injection, inflammatory or infectious synovitis is a possible postinjection complication. Elevated rectal temperature and/or

neck swelling, stiffness, or soreness should be evaluated immediately and treated appropriately.

4. Postinjection Protocol

Treatment with postinjection anti-inflammatory can be done at the discretion of the attending veterinarian. The author prefers administering intravenous phenylbutazone (4 mg/kg) immediately after CAPJ therapy. Horses are confined to a stall for 24 hours, followed by return to regular management for an additional 2 days. Return to ridden exercise can begin as early as 3 days after injections. For severely affected horses, return to athletics can be delayed for 1+ week(s) after injections. Ridden exercise is slowly introduced over several days to weeks, depending on the severity of clinical signs. Tack walking on a long, loose rein followed by gradual trotting and cantering exercise is recommended. The rider should refrain from maneuvers such as collection, lateral movements, or excessive neck bending for the initial 1 to 2 weeks of ridden exercise.

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 and no financial interests associated with this paper.

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[a]Aplio i8CX1, Canon, Tustin, CA 92780.
[b]Rompun®, Bayer, Shawnee Mission, KS 66201.
[c]Dormosedan®, Zoetis, Parsippany, NJ 07054.
[d]Sarapin®, High Chemical Company, Levittown, PA 19056.

How to Incorporate Physiotherapeutic Modalities for Rehabilitation of the Neurologic Horse

Sherry A. Johnson, DVM, MS, PhD, DACVSMR

Rehabilitation of the neurologic horse represents a unique challenge for the equine practitioner. Improving postural stability and balance control through improving strength of the spinal stabilizer muscle multifidus is one of the most promising rehabilitative targets. Author's address: Equine Sports Medicine and Rehabilitation, 8386 FM 455E Pilot Point, TX 76258; e-mail: sherryjdvm@gmail.com. © 2023 AAEP.

1. Introduction

Human sports medicine clinicians have fully embraced the vital role physical therapy and rehabilitation play in the longevity of successful athletic careers, but equine sports medicine practitioners have been slower to identify and incorporate rehabilitative approaches maximally beneficial for specific diagnoses. Barriers to this progress include lack of universal recommendations regarding the timing, frequency, and specific indications of modalities in conjunction with widely varied therapeutic approaches. Overarching neurologic rehabilitation goals to decrease pain, improve flexibility, increase strength, and restore maximal neuromuscular control are believed to result in recoveries with less convalescence, less morbidity, and ultimately improved function. The most progressive rehabilitation programs utilize regular, longitudinal patient assessments followed by appropriate adaptation of protocols with both injury-specific (local tissue) and whole-body considerations.[1] Specific rehabilitation approaches for the neurologic horse must also consider the safety of the owner, trainer, and associated personnel in the handling of ataxic horses, for which subsequent risks and precautions must be thoroughly assessed.

The objective of this outline is to discuss various physical modalities, therapeutic exercises, and strategies being currently used to rehabilitate the neurologic horse, with further information including a generalized rehabilitation program available within the author's recently published chapter.[1] Appropriate incorporation of any modality or therapeutic exercise into a successful rehabilitation program relies first and foremost on an as accurate as possible diagnosis, acknowledging that advanced imaging may not be possible in all scenarios due to financial or logistical constraints. Additionally, as laboratory testing approaches continue to expand the ability to rule in or out differential diagnoses less invasively,[2] the practicing clinician is in a constant state of diagnostic evolution in determining the neuroanatomic source of

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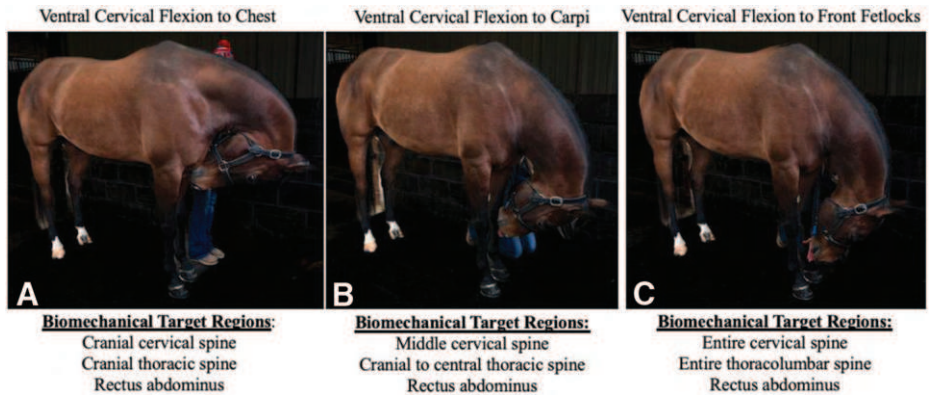


Fig. 1. Ventral cervical flexion exercises performed at three different levels: chest (A), carpi (B), and front fetlocks (C). Corresponding anatomic regions targeted with each exercise listed respectively for each level based on research performed by Clayton et al (2010) that found the largest angular changes to occur within the cranial and caudal cervical regions (<10 degree change within the middle cervical spine). Incorporation of these exercises must align with the rehabilitative goals of improving cervical range of motion, augmenting core stability, and stretching the thoracolumbar region. Photos courtesy of Equine Sports Medicine & Rehabilitation, Whitesboro, TX.

clinical signs. Despite recent diagnostic advancements, however, universal recommendations regarding the timing, frequency, and specific indications of many of the below-described modalities are still lacking. As further research is able to define specific parameters, significant advancements within the neurologic rehabilitation field can be expected.

2. Physiotherapeutic Strategies to Improve Postural Stability and Balance Acuity

Strength training, improving proprioception, and augmenting balance control following neurologic injury remain central focuses of human physical therapy programs, and while standardized investigations have yet to focus on equine applications, there are several mechanisms through which neuromuscular control can be targeted to aid the equine clinician in neurologic rehabilitation outcome. Improving postural stability and balance control through improving strength, size, and symmetry of the spinal stabilizer muscle multifidus remains one of the most promising targets for the equine clinician.[3,4] This muscle can be targeted through the use of physiotherapeutic exercises,[3] various forms of perturbation,[4] and even whole-body vibration.[5]

Therapeutic Exercises

Pursuant to the neurologic equine patient, several core strengthening exercises and their role in activating deep, stabilizing epaxial musculature to subsequently improve postural motor control and alter kinematics have been investigated.[3,4,6] Both baited and passive exercises offer opportunities to facilitate stretching during dynamic phases and strengthening during static phases of the exercise. Institution of dynamic mobilization exercises over a 3-month time period were shown to increase both size and symmetry of the multifidus muscle assessed via longitudinal ultrasonographic evaluation.[3] A recent investigation demonstrated a positive association between postural stability and multifidus muscle hypertrophy in lame horses undergoing individualized rehabilitation programs.[4] While blanket recommendations regarding prescription of the below listed exercises is not advised, the stretches listed below offer means through which various regions of the cervical and thoracolumbar spine may be targeted when appropriate (Figs. 1 and 2).

In the author's experience, these dynamic exercises are most effectively instituted as part of an individualized program then modified according to clinical improvement or lack thereof. Depending on neuroanatomic localization of the lesion, targeting various regions of the cervical spine is possible based on level of dynamic bending.[6,7] As the patient improves in flexibility and ability to complete various physiotherapeutic exercises the clinician can then begin to increase level of difficulty by altering static postural (stance) position (limb protracted vs retracted, for example), or combining these exercises with other physical therapy aides (resistance bands and/or balance pads, for example). Suitability for these exercises must be assessed carefully in terms of a patient's ability to safely and comfortably perform them in light of the specific neurologic diagnosis. It is also the author's opinion that more physiologic benefit is achieved when fewer repetition of these types of stretches can be correctly performed in contrast to agitation with increased repetitions using incorrect form, so care must be taken to ensure the exercises are performed in as pain-free state as possible.

Significant muscle hypertonicity and spasming contributing to avoidance of these exercises may be alleviated by first applying heat therapy to the cervical or thoracolumbar regions for 15-30 minutes via warm compresses or commercially available systems (infrared solariums, for example). Heat therapy may also be combined with massage using a variety of commercially available human self-massage tools that in the author's experience are suitable for equine use due to

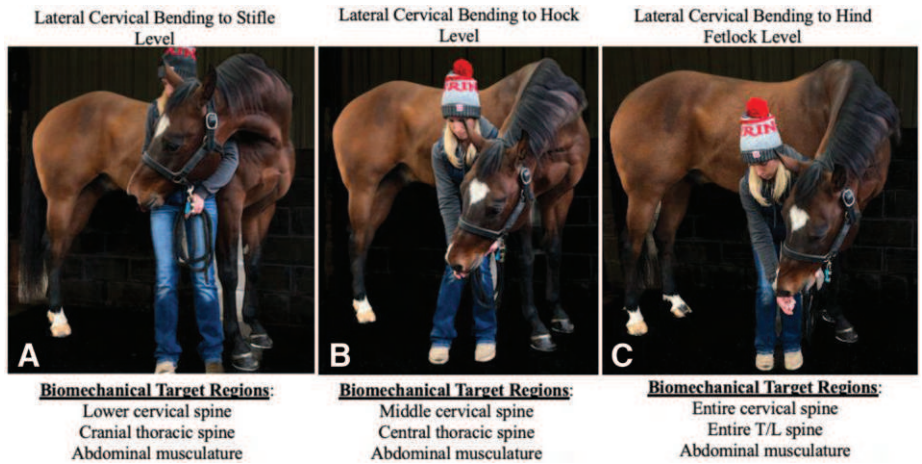


Fig. 2. Lateral cervical bending exercises performed at three different levels: stifle (A), hock (B), and hind fetlocks (C). Corresponding anatomic regions targeted with each exercise listed respectively for each level based on research performed by Clayton et al (2012) that evaluated lateral cervical bending at the levels of girth, hip or tarsus for which they noted activation through the multifidus and longus colli muscles. They also noted that the further caudally horses were bending, the more the caudal cervical and thoracolumbar regions were activated. Incorporation of these exercises must align with the rehabilitative goals of improving cervical range of motion, augmenting core stability and increasing lateral spinal motion. Photos courtesy of Equine Sports Medicine & Rehabilitation, Whitesboro, TX.

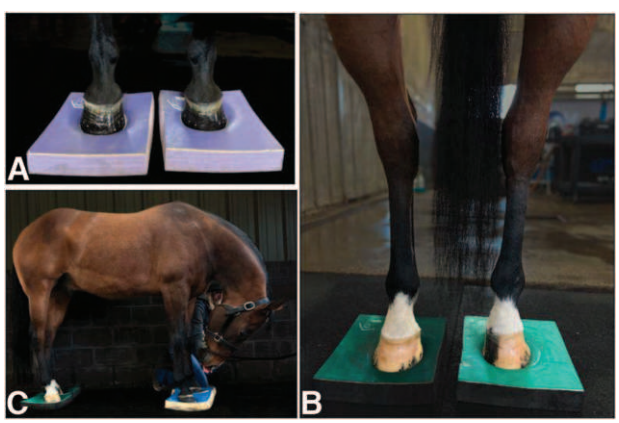


Fig. 3. Balance pad use in horses referred for professional rehabilitation: A, Bilateral forelimb application while standing on medium density (purple) Sure Foot balance pads; B, Bilateral hindlimb application while standing on firm density (green) balance pads[a]; C, Bilateral forelimb application with blue pads (soft) and bilateral hindlimb green (firm) pad application while performing ventral cervical flexion to the level of the fetlock to further challenge balance acuity. Photos courtesy of Equine Sports Medicine & Rehabilitation, Whitesboro, TX.

various pressure and intensity settings that can be adjusted as needed. In the author's experience, this warm-up period can help increase soft tissue extensibility, improve pain, and increase flexibility that may ultimately result in improved function.

Forms of Balance Perturbation

Perturbation training specifically has not yet been studied in horses, but it is well accepted that postural stability is integral in maintaining equine balance, protecting the spinal column, and allowing more accurate reactions to destabilizing forces.[4] Improving postural stability in neurologic horses, therefore, represents a key rehabilitative target to improve both static and dynamic function. A variety of physical therapy aides can be utilized by the practitioner in veterinary-guided rehabilitative management of the neurologic horse, including recently developed foam pad systems (Fig. 3).[a] The pads are commercially available in varying levels of firmness and can be utilized for forelimb, hindlimb, or multi-limb. The goal with use of these pads as part of a neurologic rehabilitation program is to challenge and/or exacerbate postural weakness in order to stimulate and ultimately improve neuromuscular function. As recently described,[1] depending on the severity of neurologic dysfunction, the author typically begins with forelimb, firm-pad application on a smooth, non-slick surface to ensure safety for both horse and handler. Once the horse acclimates both physically and behaviorally to forelimb, firm-pad application, the author typically then gradually incorporates more soft pads, and eventual hindlimb and/or all four-limb application. Once balance pad is mastered in standard application fashion (on a flat, non-slick surface), the clinician can then begin to incorporate further challenges to the neurologic system by introducing manual perturbation or combining pad application with core exercises (Fig. 3).

The author also finds the pads to be a worthwhile diagnostic tool due to the fact that subtle neurologic deficits may go undetected during the normal, dynamic exam, but be exacerbated with a balance challenge. It often is unclear whether subtle body swaying while on the pads indicates true neurologic dysfunction, core weakness, or a combination of both, but the author believes global function can be improved through titrated re-training exercises, even in neurologically normal horses. The clinician must be fully mindful of concurrent orthopedic injuries for

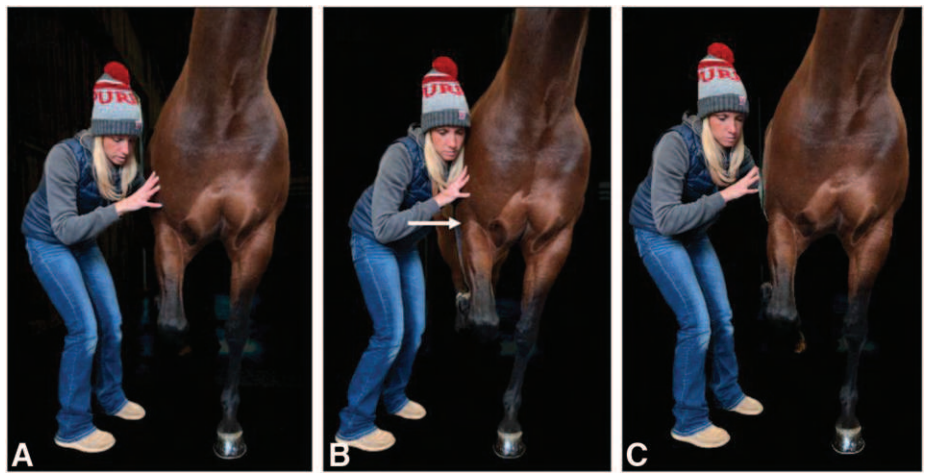


Fig. 4. Manual right forelimb perturbation pre-pressure application (A), during pressure application for 3–5 seconds (white arrow, B) and upon gradual release during balance recuperation (C). Such exercises represent an avenue through which the clinician can dynamically stimulate neuromuscular feedback in the neurologic horse. Photos courtesy of Equine Sports Medicine & Rehabilitation, Whitesboro, TX.



Fig. 5. Incorporation of various forms of resistance band systems that are commercially available including hind end and bellyband system[b] (A) and full body wrap[c] (B). Multi-modal incorporation of resistance band work can be accomplished by combining its use with ground pole exercises (C) or other various forms of exercise prescription. Photos courtesy of Equine Sports Medicine & Rehabilitation, Whitesboro, TX.

strategic pad use so as not to exacerbate existing injuries through soft-pad use.

Manual perturbation exercises also represent an avenue through which the clinician can stimulate neuromuscular feedback in the neurologic horse. Obvious safety considerations must be thoroughly evaluated, but if deemed physically stable enough, perturbation challenges can be introduced by lifting a forelimb or hindlimb and gently applying steady pressure for 3–5 seconds towards the weight-bearing limb, followed by gradual pressure release (Fig. 4) and subsequent balance recuperation. Surface changes and/or incline/decline work can also be introduced as horses progress through a rehabilitative program and can eventually incorporate a variety of proprioceptive stimulation tools such as ground poles, tactile stimulators or resistance bands.

Proprioceptive Stimulation & Strengthening Tools

The use of various strength training aids within the equine rehabilitation setting has been of recent interest, including the use of a system of elastic resistance bands, full body wraps and Pessoa lines.[8–10] Commercially available elastic resistance band systems[11,b] are thought to stimulate core abdominal muscles with the abdominal band and engage hindlimb musculature with the hindquarter band (Fig. 5). Its use in horses at a trot was recently investigated and found to reduce mediolateral and rotational movement throughout the thoracolumbar region.[9] Further studies investigating more long-term use and potential mechanistic pathways will help refine its use in the neurologic rehabilitation setting. Also pertinent to rehabilitation of the axial skeleton are the use of training lines. Pessoa training aids were demonstrated to increase both lumbosacral angles and thoracolumbar dorsoventral excursion when used in horses being lunged at a jog,[10] but care must be utilized when prescribing their use in neurologic horses with concurrent cervical pain. Also recently available to the clinician is a commercially available full-body resistance band wrap[c] that the author has used in select neurologic cases (Fig. 5B). Formal studies are lacking on this tool specifically, but it is the author's impression that the full body wrap provides tactile stimulation in a stabilizing manner that can be utilized during controlled exercise sessions, self-exercise (turnout), or as part of a multi-modal, cross-training rehabilitative program (in combination with ground poles, tactile stimulators, core stretches, etc.). With its continued use and



Fig. 6. As described in Johnson,[1] incorporation of various forms of tactile stimulators can be used for the forelimb or hindlimb within the neurologic rehabilitative setting including bell boots (A), homemade tactile stimulators (B) or custom-made 700 g pastern weights with the option to attach tactile stimulators (C, Mark Williams/Scott McClure). Photos courtesy of Equine Sports Medicine & Rehabilitation, Whitesboro, TX, and DRS Photography.

protocol refinement, further recommendations can be expected.

Specific to equine neurologic dysfunction, other physical therapy aides such as ground poles and tactile stimulators offer clinicians passive means of engaging neuromotor control during activities in daily rehabilitation or training. Ground poles when arranged at various distances, heights, and configurations can encourage increases in thoracolumbar excursion, active range of joint motion, and limb suspension.[12] Swing and stance phase kinematics while going over ground poles have been previously investigated,[12,13] with several interesting findings related to their incorporation into neurologic rehabilitation. Ground pole exposure was noted specifically to increase forelimb braking, increase activity of forelimb adductors, and activate flexor muscles.[12,13] Their gradual integration into neurologic rehabilitation programs can aide the clinician in augmenting controlled proprioceptive challenges, activating specific muscle groups, and increasing activity of muscles responsible for downward speed transitions (braking). Hill work and incorporating backing exercises into hill work can also be used to simultaneously improve muscular strength and challenge proprioceptive acuity. Incorporating various physiotherapeutic tools (resistance bands, ground poles at various heights, distances and configurations, surface changes, etc.) into programs as horses progress in strength and neuromotor control allows the clinician the ability to provide "cross-training" opportunities in a variety of creative capacities as owner safety, and patient compliance will allow.

The effects of tactile stimulators on biomechanical stimulation have also been previously investigated.[14,15] When nine sound horses were evaluated with or without 55 g weighted tactile stimulators on the hind pasterns, higher foot flight arcs, reduced hind stance duration, and increased concentric activity of tarsal musculature was appreciated.[14] In subsequent investigation this same research group evaluated four types of tactile stimulators including a strap, tactile stimulators only, a 700 g limb weight only, and a 700 g limb weight with tactile stimulators.[15] Authors noted that the highest foot flight arc was appreciated with the 700 g weight with tactile stimulator. Lowest hoof flight arcs were observed with no stimulation or loose straps only.[15] Incorporation of various forms of tactile stimulators can be utilized for forelimb or hindlimb use within the neurologic rehabilitative setting including bell boots, homemade tactile stimulators, or custom-made 700 g pastern weights (Fig. 6). In the author's experience, applying bell boots or other tactile stimulators in varied capacities (forelimb vs hindlimb application and at various stages during an exercise session) can help provide dynamic proprioceptive stimulus to avoid the plateau of response/stimulus that often occurs with habitual application.

3. Aquatic Therapy

In the rehabilitation setting, the proposed benefits of aquatic exercise include buoyancy, viscosity, and resistance that promote global improvements in muscular timing, strength and neuromotor control.[16] Several options to employ aquatic therapy for the equine athlete are currently available including above ground underwater treadmills, in-ground underwater treadmills, and swimming pools (circular or straight).[11] Investigations into the benefits of aquatic therapy for the equine patient have thus far reported subsequent physiologic responses,[17–19] biomechanical effects,[20] beneficial role in mitigating carpal osteoarthritis,[21] and improvements in postural sway.[16]

The safety and suitability of exposing neurologic horses to aquatic work must be carefully considered in light of equipment available, rehabilitative goal,



Fig. 7. Underwater treadmill therapy during all phases of the session including entry (A), walk phase (B) and ramp exit (C) in a linear, in-ground, high-water depth system.[d] The neurologic horse's ability to safely navigate dampened incline and decline surfaces must be carefully considered prior to aquatic prescription in this particular unit. Photos courtesy of Equine Sports Medicine & Rehabilitation, Whitesboro, TX and Kirstie Marie Photography, Pilot Point, TX.

and severity of neurologic dysfunction secondary to specific diagnosis. The benefits of improving postural sway as a means of increasing global strength and stability through underwater treadmill exercise are well documented,[16] but severe neurologic dysfunction may prohibit the clinician from safely exposing select cases to this rehabilitative therapy. In the author's experience, the decision to incorporate aquatic work can be aided through the use of safety benchmark assessments such as: 1) grade of ataxia at a walk on firm, flat footing; 2) grade of ataxia while performing incline/decline exercise; and 3) exacerbation of ataxia while lightly sedated. Should the assigned ataxic grade be >2 according to the modified ataxia-grading scale of 0 to 4[22] for any condition, it is the author's experience that aquatic exercise should be avoided until neurologic improvement can be achieved. In cases where a ramp must be navigated in and/or out of the underwater treadmill (Fig 7), the neurologic horse's ability to safely perform incline and decline work on a dry, flat surface should be assessed prior to commencement of aquatic exercise involving ramp entry and/or exit. Additionally, clinicians should be mindful that the lower cervical region is put into significant (temporary) extension during decline ramp entry into a high water depth in-ground linear underwater treadmill unit (Fig. 7), so if neurologic signs or cervical pain appear to be significantly worsened on dry, flat ground with elevated head and/or neck carriage, this clinical exacerbation may prohibit this specific form of aquatic exercise and require use of an underwater treadmill unit capable of adjusting water depth appropriately. When underwater treadmill work can be safely incorporated, gradual increases in exposure time and water depth can be considered to achieve rehabilitative goals of improving neuromotor strength, timing, control, and overall stability in the neurologic horse. Concurrent orthopedic morbidities must also be considered in terms of water depth, time, and frequency of exposure to aquatic exercise.

4. Whole Body Vibration

Of recent interest has been the use of low-amplitude, low-frequency mechanical vibration therapy. Although empirically prescribed, perceived benefits reported by owners and horsemen include general relaxation and overall well-being. Acute hematologic and clinical effects of horses undergoing vibration therapy have been recently described, noting no adverse effects following vibration sessions.[23] Within the neurologic rehabilitative setting, there has been recent interest in the effects of prolonged vibration therapy on the cross-sectional area and symmetry of the multifidus muscle.[5] A significant increase in multifidus muscle cross-sectional size and symmetry was found following 60 days of twice daily, 30 minute whole body vibration sessions.[5] Known for its role in spinal stabilization and postural muscle acuity as previously discussed, development of the multifidus muscle is thought to have potential as an osteoarthritis deterrent[24–26] and axial skeleton stabilizer,[4] making it a potential therapeutic target for neurologic rehabilitation programs. With further experimentation expected, insight into more specific protocol applications and incorporation can be expected.

5. Conclusion

Rehabilitation of the neurologic horse continues to represent a unique challenge for the equine practitioner. Improving postural stability and balance control through improving strength of the spinal stabilizer muscle multifidus remains one of the most promising rehabilitative targets. This muscle can be targeted through the use of physiotherapeutic exercises, various forms of perturbation, and even whole body vibration. Neuroanatomic localization and diagnosis specificity enable the practitioner to determine suitability for such rehabilitative tasks, and with the advent of evolving strategies and commercially available equipment, the bandwidth for professionally guided programs is continuously being developed and are expected to improve traditional outcomes.

Acknowledgments

Declaration of Ethics

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

Conflict of Interest

Dr. Sherry A. Johnson is a senior partner and managing rehabilitation veterinarian at Equine Sports Medicine and Rehabilitation (Pilot Point/Whitesboro, TX and Scottsdale, AZ).

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[c]Eagle ProSix Bark River, MI 49807.
[d]HydroHorse Inc., Merrill, OR 97633.

Where to Begin: Complicated Lameness or Poor Performance Cases?

Jodie Daglish, BVSc, MS, DACVSMR, MRCVS

Complicated lameness cases represent a diagnostic challenge that require an open-minded approach to assessment of the patient through thorough and attentive clinical examination. Clinical findings must then be carefully assimilated with diagnostic analgesia approaches and the use of diagnostic imaging, including advanced techniques to reach a satisfactory and clinically contributory conclusion. Author's address: Newmarket Equine Hospital Referrals, Cambridge Road, Newmarket, Suffolk, CB8 0FG, UK; e-mail: Jodie.daglish@neh.uk.com. © 2023 AAEP.

1. Introduction

Complicated lameness cases may represent a varied spectrum of problems, from genuine subtle but athletically limiting single-limb lameness, to confounding multilimb mild to severe lameness, to "axial skeleton lameness," and to generic "poor performance" presentations. Given that mild lameness is associated with poor interobserver assessment[1,2] and that the development of scales to grade subtle musculoskeletal pain is still in its infancy,[3,4] it is accepted that complicated lameness is a diagnostic challenge and may require advanced techniques to reach a conclusion. Extensive debate was generated by the question of redefining lameness with respect to the spectrum of gait asymmetry and the delineation of lameness outside of this.[5–8] The type and value of the case will dictate the extent that the evaluation can reach. In the United Kingdom, pet insurance allows a degree of flexibility where budget would otherwise restrict available options. Readily available technology means that clients themselves can perform rudimentary gait analysis including review of substandard competitive performances. This means the use of advancing technology in veterinary practice is used with increasing frequency[2] and that clients are accepting of these additional available tools. For the practitioner, how should these cases be approached, and when should these tools be employed alongside traditional lameness evaluation techniques? During his Plenary opening lecture at the 2017 annual congress of the British Equine Veterinary Association, Professor Derek Knottenbelt stated that "technology won't replace vets. . .but vets who use technology logically and carefully will replace those who don't."[9]

2. Clinical Presentation

When an aberrant gait is observed at walk, trot, or canter, the practitioner must establish if it is:

- Associated with an active disease process
- Due to muscular (pain) compensation secondary to a short-lived focus of pain elsewhere

NOTES

- A biomechanical anomaly secondary to permanent structural change.[10]

Gait asymmetry or irregularities may present in one or multiple gaits and may be observed in only very specific circumstances. These characteristics may assist the practitioner in directing the diagnostic pathway more specifically but also rely on clear communication between practitioner and caretaker.

3. History Taking

Questions posed to owners should include information from the time of purchase, including the following:

- Duration of current ownership and relative time to onset of presenting issue
- Level of experience of a previous rider compared to current
- Changes in level and frequency of work, including a reduction in frequency of training, even if short term only
- Changes in tack and equipment routinely used
- Changes in access to turnout and management routine
- Visible changes in appearance of the feet, topline, and hind quarter muscling
- Historical musculoskeletal issues and treatments required/performed.

Questions pertinent to the current history will include the following:

- Time of onset of presenting signs relative to
  - Increased level of work
  - Increased frequency of traveling or competition
  - Changes in equipment or tack used
  - Changes in diet or fecal production
  - Timing of a mare's seasons
- Noted abnormalities in behavior at this time, such as
  - Sensitivity to grooming
  - Difficulty picking up or maintaining limbs in flexion for the farrier
  - Biting or kicking while girthed up
  - Becoming cold backed or broncing/bucking when mounted
  - Dull, depressed, anxious, or agitated demeanor
- Changes in attitude to work, for example
  - Reluctance to go forward
  - Rearing, bucking, or kicking out under saddle
  - Knocking poles down with increased frequency
  - Stopping at jumping efforts or refusing to start
  - Difficulties maintaining the canter, including through transitions
  - Increased frequency of spooking
  - Inability to complete a higher level of exercise intensity, e.g., breaking out of the canter to trot or losing a forward-moving gallop.

4. Clinical Examination

Palpation Findings

The approach should be systematic and cover the whole horse:

- At rest what posture does the horse elect?
- Does the horse's conformation predispose them to issues? Examples include thoracolumbar lordosis, straight hocks, or angular or flexural limb deformity.
- Evaluate for muscle symmetry and development. It is not uncommon to find specific lack of muscular development in association with abnormal skeletal structures.
- Are bony landmarks symmetric? Especially in the pelvis, this may produce functional restrictions in gait.[11]
- Inspect quality of horn, foot balance, shoeing style, and symmetry of feet.
- Identify increased or asymmetric sites of synovial distension in the lower limbs.
- Is there thickening, loss of definition, or sensitivity on palpation of the soft tissues of the lower limbs?
- Is range of motion of the joints in the lower limbs appropriate for patient age and signalment, and are they symmetric between limbs?
- Protraction, retraction, and movement of the thoracic limb over the body wall and hindlimb in pelvic tilt[11] are also useful gauges of chronic restriction or guarding.
- Regarding the cervical spine,[12] palpate the soft tissues from the poll to withers; are there trigger points? Pressure applied directly over the articular process joints will indicate focal pain that often correlates to arthropathy—mild to marked variations. Inspect available lateral flexion and symmetry of movement. Is ventral flexion smooth or protected?
- Regarding the thoracolumbar spine,[13] evaluate pain on pressure applied to spinous processes individually, to the ligamentous structures overlying the bony processes and palpation of the epaxial muscles. Are these sensitive, restricted, guarded, or normal? Is the response repeatable? Is there available lateral flexion,

dorsal excursion, and ventral excursion of each region of the spine?
- The pelvis evaluation[11,14] can be started from the ground with response to tuber sacrale compression, tuber coxae push, caudal tail traction, and/or lumbosacral tuck and hindlimb circumductions. These may all elicit ballistic or guarded responses that each reflect abnormalities. Evaluate from above with chiropractic knowledge—is lumbosacral junction flexion/extension normal? Do the sacroiliac joints move in a normal fashion? Are there asymmetries in the overlying soft tissues?

Dynamic Examination

- Lameness grading in the traditional sense is subjective. Several scales exist, but often each veterinarian has their own criteria and their own application of the grading scale based on personal clinical experience. The AAEP lameness grading scale is perhaps the simplest and therefore easily repeatable; however, for veterinarians dealing with subtle presenting lameness or performance issues, this scale is oversimplified. Descriptions pertaining to the stride characteristics such as cranial and caudal phase of the stride, fetlock extension, abduction or adduction of the limb, toe drag, and weight shifting can help to characterize an assigned lameness grade and should be noted at baseline for each circumstance the horse is evaluated. Multiple limb lameness is confounding, and a predominant lameness should always be sought. Care should be taken not to allow severe lameness to influence the appearance of lameness in an ipsilateral forelimb or contralateral hindlimb through gait compensation. Similarly, bilateral mild lameness may mask the appearance of lameness, particularly in a horse presented for the first time; how does it move relative to its normal "baseline?" Does it move as expected for its signalment, training, and performance level to date?
- The horse should be evaluated at all gaits where possible. This is performed more easily in the sport horse rather than racehorse, but lameness minimally visible at trot may manifest dramatically at canter as aberrant behaviors or gait characteristics. These may include difficulty achieving the upward transition and/or maintaining the canter on the correct lead, bunny hopping or broncing, lack of disassociation of the hindlimbs, and reduced thoracolumbosacral spinal motion.
- Flexion tests are an essential part of lameness evaluation, with information to be gained from the response of the animal to flexing the region of the limb tested, amount of flexion achieved, the duration of flexion that is tolerated, and the response to increased weight bearing on the stance limb. Consequential lameness following the flexion test may be assessed as increased or decreased, graded positive or negative, or given a numerical grade (e.g., response severity 0 to 5). Change in gait characteristic may be important and should be documented, as should contralateral limb response. Be specific; distal limb versus proximal limb, stifle versus hock, extension of the lumbosacral junction, suspensory tests, lifting of the forelimb with lateral flexion of the cervical spine, adduction of the hindlimb, or pelvic tilt may each induce different responses.
- Poor performance evaluation should comprise the following list according to safety and demonstration of presenting clinical signs:
  - Walk in a straight line on firm ground so foot placement can be assessed. Turn on a small circle in both directions.
  - Trot on a straight line (hard and/or soft surface).
  - Trot on a circle on soft and hard surfaces.
  - Canter on a circle on soft ground (essential for axial skeleton assessment).
  - For ridden assessment, have the rider demonstrate where the horse feels abnormal, plus walk, trot, and canter on each rein; collected and loose rein work. Inclines and declines may provide further information.
    - If the rider is unwilling to ride for the purpose of evaluation, is it safe to have a technician do so? Or can videos of prior examples of the behavior be reviewed?
  - Consider repeating the examination in tack without rider and/or with the rider bareback (if safe to do so).
  - Conduct neurological assessment.
  - Conduct separated flexion tests of the distal limbs, stifles, and full limbs.

Additional Methods to Reach a Diagnosis

Measures described above have been used historically to assess pain in the horse. This has inherent bias according to the practitioner's area of interest, expertise, level of relevant experience, and severity of the presenting lameness.[2] Issues surrounding these approaches include inconsistency between observers,

difficulties in documentation of the pain grade, or lack of appropriate tests for specific regions of the body. Practitioners may wish to supplement their evaluation with consideration of the following techniques.

5. Objective Measurements

- *Composite pain scores* are based on observations made at rest and assess facial expressions and behavioral traits. Facial expressions most frequently associated with pain at rest were low and/or asymmetrical ear positioning, an angled appearance of the eyes, a withdrawn or tense stare, mediolaterally dilated nostrils, and tension in the jaw, chin, lips, and certain facial muscles.[15] Consistency of results utilizing pain scales has shown excellent interobserver repeatability, but the majority of these scales have been conducted in more "severe" induced lameness or visceral pain states[16] and therefore may not represent the typical clinical scenario for complicated lameness. Scales utilized for assessment of induced orthopedic pain are the Horse Grimace Scale, Equine Utrecht University Scale of Facial Assessment of Pain, Equine Pain Scale, and Composite Pain Scale. These have each been developed with slightly different focuses:
  - The Horse Grimace Scale and Equine Utrecht University Scale of Facial Assessment of Pain are evaluated with respect to moderate to severe induced orthopedic pain with a focus on facial expressions.
  - The Equine Pain Scale is studied in the assessment of general pain using facial expression and position and postural changes.
  - The Composite Pain Scale is studied with reference to postsurgical orthopedic pain utilizing physiological parameters and body behaviors.

In a recent study employing all four scales for the evaluation of orthopedic pain with induced (mild to moderate) unilateral lameness, posture-related behaviors (posture, position in the stall, head position, degree of interaction and focus) were identified to have the strongest association with movement asymmetry. Facial expression was less consistently associated with movement asymmetry and demonstrated greater interobserver variability.[17] Practitioners should note that the results of this study were linked with unilateral limb lameness and therefore ask if these findings can be considered suitably validated for multilimb lameness or axial skeleton pain. Practitioners may note subtle examples of the reported pain indicators within the examination, and it would appear appropriate to practice pain scale observations, perhaps in a modified fashion, bearing in mind that validation of a single scale for lower grades of lameness has not been performed. The author does not routinely employ these scales but does take (descriptive) note of facial characteristics, posture, behavior, and position in the stable during initial and subsequent (where possible) moments of observation. Interestingly, and subjectively only, the author has noted changes in demeanor, level of interaction, and facial expression in hospitalized patients in days following intra-articular medication.

- *The Ridden Horse Pain Ethogram (RHpE)* has been recently developed[3,4] and comprises 24 behaviors commonly observed in horses presenting for lameness that can be abolished with diagnostic analgesia. Of these, most are 10 times more likely to be observed in the lame horse compared to a nonlame horse, including but not limited to the following:
  - Head tilted or tilting repeatedly
  - Head position changing regularly (tossed or twisted from side to side)
  - Eyelids closed or half closed for 2 to 5 seconds
  - Tongue exposed
  - Tail swishing large movements
  - Spontaneous changes of gait
  - Sudden change of direction against the rider's cues
  - Stumbling or tripping repeatedly

The RHpE infers pain at much more subtle levels of lameness than other reported pain scales and is therefore more appropriate for complicated lameness or poor performance scenarios. Altered facial and behavioral expressions during ridden work comprise the documented 24 features. When 8 or more of these behaviors are observed, musculoskeletal pain is likely. The RHpE relies on acute and detailed observation that is repeatable. Video recordings may be helpful to assist the practitioner between evaluations. Repeat assessment may be made following diagnostic analgesia to determine response. The features described may improve or resolve with diagnostic analgesia, allowing for positive inference regarding the site(s) of interest.

- *Qualitative gait analysis (QGA) technology* has been developed for clinical use and validated for lameness examinations using body-mounted inertial sensors alongside an accelerometer to document movement symmetry.[18,19] Agreement between experienced practitioners and body-mounted inertial sensor systems used for QGA is moderate[20] but increases to good in more substantial lameness. Multiple QGA systems now exist and are readily accepted in clinical practice[2] for detection of sagittal plane asymmetry

parameters to confer lameness. Despite increasingly widespread availability, there remains variation in how practitioners perceive and thus employ QGA systems. Advocates are more likely to own a system. In a recent survey[2] of clinical use of QGA systems, approximately 60% of respondents were more than 10 years graduated, 50% used the system in 0% to 25% of their caseload, and a similar number worked in both clinic and ambulatory settings. QGA has been reported for use in straightforward lameness evaluation most predominantly but may be utilized in cases presenting for axial skeleton pain to determine primary or secondary origin of pain. QGA are optimized for symmetric gaits and are not currently applicable at canter. Practitioners typically utilize QGA in mild to moderate lameness, where lameness is multilimb in origin, to document degree of gait asymmetry for clientele (confirmation or dissuasion) and to objectively document response to diagnostic analgesia, eliminating treatment bias.[21] It remains to be seen if QGA will become a routine inclusion in prepurchase evaluations for most practitioners.

- *Kinetics* is the study of forces acting on a body, e.g., how forces generate motion in gait production. Kinetic analysis may be utilized to establish changes in weight bearing between limbs through evaluation of differences in forces generated during loading. This has been employed readily in human and small animal fields where force plates or mats may be easily repositioned and manipulated. Despite this and excepting the instrumented treadmill at the University of Zurich, equine force plate data are reliant on multiple passes over a short, instrumented walkway, typically achieving one to two strides per pass. Currently, force plate data have been utilized to identify lameness and changes in postural sway and for evidence of ataxia in equine patients.[22–24] An instrumented horseshoe has also been previously evaluated as a novel means of kinetic analysis.[25] These techniques have many inherent difficulties in execution, which precludes the routine use of daily clinical kinetic gait analysis in equine patients.
- *Kinematics* is the study of movement of a body and is used to generate information on motion characteristics of the limb or trunk through the stride phases to establish range and duration of motion of each joint or region. At a crude level, this is performed on a smart phone with "slo-mo" playback of videos taken at baseline and subsequent lameness examination. This may assist visual resolution and acuity of the practitioner at a basic level, including side-by-side review of multiple evaluations, relying on good repeatability of the assessment. Advanced examples of kinematic analysis may be performed in dedicated motion capture gait laboratories, where sophisticated camera systems are used to track motion of reflective markers mounted on the body at predetermined landmarks. Measurements have been reported for activities at all gaits, including walking in water and during jumping. Data derived from such analysis include displacement of segments, joint angles and derivatives, velocity, and acceleration. There is large room for error, and numerous sampling passes are required for data capture. High-quality analysis based on these systems is therefore confined to the research setting where a controlled and repeatable environment can be assumed, followed by processing of the huge amount of data generated.[26]
- *Wearable technology* is an exciting and expanding field that may represent future methods of pain assessment, particularly in challenging cases. Originating as an extension of the use of QGA sensor systems, a smart phone was employed to determine if postural sway could be accurately recorded.[27] This demonstrated that body-mounted sensors could be investigated for use in assessment of postural stability in horses. Egan[28a] reviewed the use and potential for application of wearable technology for identification of changes in gait and consideration of bilateral pain. This group evaluated the possibility of a single, stable, worn inertial measurement unit to establish changes in activity at rest and to correlate to induced lameness. The idea is drawn from the use of longitudinal monitoring in human athletes for the early detection of injury or illness for translation to the equine field.

6. Survey Imaging Techniques

Nuclear scintigraphy has been extensively documented in equine practice for identification of (stress) fractures in the racehorse and identification of disease processes in the sports horse. Application of this modality for general survey imaging of the sports horse has been suggested to be less sensitive and specific than previously suggested in the literature with respect to milder lameness or poor performance.[29] The study relied on diagnostic analgesia and expert opinion as the gold standard for drawing these conclusions. Ultimately, nuclear scintigraphic evaluation must be performed in conjunction with a thorough clinical examination, diagnostic analgesia to confirm relevance of findings, and imaging to determine

specific diagnoses. Acquisition of images in isolation is inappropriate. The modality relies on administration of a radioactive pharmaceutical, which consequently has legal responsibilities for practice and the technicians performing the scan. The radioactive isotope of choice in the general referral population is Technetium 99, which has a short half-life and can therefore allow rapid release of the patient back onto the "clinic floor" usually 24 hours following administration. Nuclear scintigraphy is a sensitive but not specific tool for diagnosis, allowing an overview of the patient for detection of sites of increased bony metabolism, which should correspond with sites of osseous abnormalities on subsequent radiographic and ultrasonographic evaluation. The technique is associated with a high number of false positives, and therefore practitioners must be confident in the "normal" scintigraphic picture for the age, type, and use of the horse under evaluation. Nuclear scintigraphy is typically desirable when lameness is severe and likely attributable to an unidentified or poorly delineated fracture, usually of the proximal limb, and is used frequently in racehorse practice. In complicated lameness cases, nuclear scintigraphy may be employed where:

- Lameness remains unchanged despite complete diagnostic analgesia of the targeted limb.
- Diagnostic analgesia and the patient are incompatible.
- Inconsistent lameness is present.
- The degree of lameness present is not able to be assimilated with the severity of behavioral signs observed.
- Multiple sites of pain are identified and known relative importance is desirable to the owner.

Lumbosacral Junction and Sacroiliac Region

Increased or abnormal patterns of radiopharmaceutical uptake (IRU) have been reported in association with clinical signs of sacroiliac region pain and/or with a positive response to diagnostic analgesia of this region.[30] Scintigraphic findings of the lumbosacral junction had moderate to good agreement with corresponding transrectal ultrasonographic evaluation findings.[31,32] Given the small window of evaluation available on ultrasonographic assessment, scintigraphy may allow a greater level of confidence in ascribing clinical relevance to findings in this region. Similarly, a lack of IRU in the face of clinically localizing signs may support the concept of muscular compensation secondary to hindlimb lameness.

Pelvis

Asymmetry in pelvic bony and femoral bony protuberances may be palpable on clinical examination but can be classified in terms of chronicity with scintigraphic evaluation; this may allow more accurate rehabilitation timelines to be established or for a more definitive guide for likely persistence of biomechanical/functional gait abnormalities.

Cervical Spine

Hopping-type lameness originating from the cervicothoracic junction may be associated with increased radiopharmaceutical uptake at Ce5-Ce6, Ce6-Ce7, or Ce7-T1 articular process joints or at the Ce6, Ce7, or T1 vertebral bodies when there is accompanying osseous abnormalities; however, false negatives may occur where nerve compromise alone is identified.[33,34] Story et al.[34] established that spinal cord anomalies, including dorsal root ganglion degeneration, may be evident in horses that develop aberrant and sometimes violent behavior under saddle without any diagnostic imaging abnormalities being evident. Increased radiopharmaceutical uptake may be observed at these sites without a distinctive hopping-type lameness being present. Primary cervical spine pain, altered behavior such as difficulty achieving the contact, and lameness without the reported hopping appearance may also occur. Due to the anatomical variation in size of the caudal articular process joints relative to those cranial, particularly in Warmblood horses, it should not be assumed that progressive enlargement of the pharmaceutical uptake footprint on scintigraphic studies is clinically relevant. The author considers moderate to marked IRU, asymmetric IRU, or distinctive change in shape of the joint more clinically relevant. Scintigraphic IRU in the cervical articular process joints has been identified to correlate well with clinical signs while correlating poorly with radiographic assessment.[35] In this study, an absorption coefficient value was measured and confirmed that a value of 1.243 was able to separate clinically normal from clinically abnormal Warmblood horses used for dressage and show jumping at the Ce6-Ce7 articular process joint. Sensitivity decreased but specificity increased with increasing age of horses.[35] To date, there have been no studies correlating cross-sectional (computed tomographic) findings with nuclear scintigraphic findings. Nuclear scintigraphy may assist in determining sites of active bone metabolism in cases at sites of articular process joint arthropathy or osteoarthritis; however, the practitioner should correlate IRU with localizing clinical signs, diagnostic analgesia, or response to treatment of the affected joints to confirm relative importance.

The Ribs

Fractures of the ribs were reported in 73 horses following clinical presentation of forelimb lameness, poor performance, resistance to ridden work, or a known trauma.[36] In these cases, 18/47 recorded palpation examinations identified the site of interest versus 100% sensitivity on scintigraphic evaluation.

Thoracolumbar Spine

Thoracolumbar spine abnormalities have been documented, allowing correlation of metabolic activity of spinous process apices to clinically active thoracic

region pain.[37] Sixty-five percent of horses with both radiographic and scintigraphic evidence of impinging spinous processes demonstrated localizing signs of pain identified within the thoracolumbar spine. Moderate to marked IRU was more likely to be observed in cases with primary thoracolumbar spine pain.[37] The author has identified that in some clinical cases, multiple sites of spinous process impingement may be identified on radiographs but demonstrate increased metabolic activity at only one or two sites, allowing more targeted treatment interventions to be performed. Elsewhere in the spine, thoracolumbar articular process joint arthropathy has been documented in associated IRU patterns,[38] whereby clinically affected patients had moderate to intense IRU relative to clinically normal horses. Radiographic correlation with scintigraphic findings was greatest where IRU was intense. Spondylosis of the thoracic spine has also been identified and documented with scintigraphic studies.[39] Although it is an uncommon diagnosis (3.4% of horses with back pain), only 33% of spondylosis lesions identified on radiographs were associated with IRU.

Stifle

Scintigraphic evaluation of the stifle is reported to be reasonably specific but highly insensitive for detecting lameness originating from the stifle.[40] As with other sites, additional orthogonal images may be acquired; however, in the reported study, this did not improve diagnostic sensitivity.

Distal Limbs

Evaluation of sites within the distal limb have also been documented and have demonstrated variations in IRU with respect to subsequent imaging modality findings when mild to moderate lameness is present. This emphasizes the need to ensure appropriate clinical relevance is placed on nuclear scintigraphic findings. Follow-up diagnostic analgesia and imaging techniques must be performed to fully elucidate the characteristics of the active disease process within the patient. The front feet are a site where IRU of the distal phalanx and collateral cartilages correlate well with subsequent magnetic resonance imaging findings.[41] It is worth noting here that most studies evaluating distal limb scintigraphic patterns are longstanding and therefore potentially outdated based on improvements in scintigraphic equipment and available software. Accuracy of scintigraphic profiles within the distal limbs of horses with complicated lameness may therefore be warranted.

7. Further Imaging Modalities

Magnetic resonance imaging (MRI) of the foot, fetlock, and proximal metacarpal/tarsal region is now employed readily in cases where a radiographic or ultrasonographic diagnosis is not able to be reached despite a positive diagnostic analgesia result. Low field systems and improved image acquisition mean that good-quality images are routinely able to be achieved in the standing sedated horse. Imaging of the stifle under general anesthesia is available in a smaller number of facilities and is considered a feasible "next step" should alternative options fail to reach a satisfactory diagnostic outcome.[42] Sensitivity and specificity has been documented to be high with MRI in the foot,[43] fetlock,[44] digital flexor tendon sheath,[45] and proximal metacarpus/tarsus.[46] Thus, identification of subtle/early disease processes is possible, potentially providing the practitioner with the ability to curtail or slow the progression of the disease state and prevent a more substantial injury from occurring. MRI is undoubtedly a valuable tool and provides practitioners with a substantially greater level of confidence in their diagnosis, often providing better quantification of risk of ongoing training and competition. In more severe cases of lameness, MRI may provide additional details of multifactorial disease processes where ultrasonographic and radiographic evaluation findings do not assimilate with the severity of lameness, or where standard treatment has failed to elicit expected improvements and may assist the practitioner in the evaluation of complex lameness cases where a diagnosis remains elusive.

Computed tomography (CT) has advanced in recent years to provide cross-sectional imaging of the stifle and neck in addition to cone beam imaging of the head.[47] There has also been exciting developments in the availability of systems able to acquire standing distal limb images.[48,49] Similar to MRI, CT imaging is not considered a first-line imaging modality but should be employed where an adequate diagnosis has not been reached with conventional first line modalities. Cases that are complex and present a diagnostic challenge may find that CT or contrast enhanced CT provides additional details regarding tissue properties, delineates the extent of the disease process, and assists in identification of soft tissue compromise, particularly within the caudal cervical spine where spinal cord or spinal nerve root impingement is suspected.[50] This has been demonstrated in several clinical case series[51,52] and has assisted in both therapeutic planning and prognostication, particularly when osseous proliferation occurs axial to the articular process joint or where effacement of the intervertebral foramen is present. In conjunction with a terminal study involving clinical cases showing intractable dangerous behavior, soft tissue lesions including intervertebral disc protrusion and epidural and subarchnoid hemorrhages have been identified and confirmed with histopathology.[34] In cases of complex lameness or poor performance associated with "axial lameness," cross-sectional imaging with detailed osseous and soft tissue windowing is likely the only premortem modality available to reach a comprehensive diagnosis relating to the caudal cervical spine and cervicothoracic junction.

8. Summary

When establishing a system for complicated lameness, assessment should be systematic and thorough. Generate a problem list considering limb-related issues, axial skeleton issues, and potential medical

issues identified. Apply relative weighting according to severity of clinical examination findings, degree of overt lameness, and behavioral anomalies. Do the signs add up? Does it make sense with the history? Is something missing or have subtle/quiet findings been given enough credit? Sometimes the primary issue is obvious, and at other times the problem is found with additional layers of diagnostic tests. Consider subtle lameness and poor performance as a jigsaw puzzle—there are many parts making up the whole. Interpret findings considering what the owner has presented the horse to you for. Remember that treatment will not be effective for the presenting signs if it is not targeting the correct diagnosis.

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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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Diagnostic Analgesia for Lameness: It Isn't Just a Simple Stick

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Diagnostic analgesia is complex and often not straightforward. It is important to continue to follow simple guidelines, pay attention to the time when re-evaluating lameness after individual blocks and to know what literature has revealed about perineural and intrasynovial blocks. Author's address: Colorado State University, 300 West Drake Road, Fort Collins, CO 80523; e-mail: kaseabaugh@yahoo.com. © 2023 AAEP.

Diagnostic analgesia is not quite as simple as may have been suggested in veterinary school. It was likely oversimplified but not deliberately, as much has been discovered about diagnostic analgesia in the last decade. In recent years, multiple studies have been performed that reveal more information about diagnostic analgesia. In many ways, however, this has greatly complicated lameness diagnosis.

This session will discuss what the literature has revealed about diagnostic analgesia in the horse. The session will highlight what should be expected from each block and what other structures could potentially be blocked.

1. Simple Guidelines

It is important to start with a few simple guidelines:

Stick to the Basics

Equine practitioners should continue to be systematic and consistent with their lameness evaluations. Simply jumping to imaging can create more questions, especially with MRI. When blocking a lameness for the first time, start low on the limb.

Keep It Simple

Blocking protocols should be systematic and simple. Avoid changing blocking protocol for every horse.

Don't Overthink It

If a horse blocks to a palmar digital nerve block, look at the foot first. Trust that the block has done what it was supposed to do. If there are no significant findings in the region that is suspected, then it is important to broaden the region of interest. When having to look elsewhere, look proximal.

2. Timing is Important

Research has shown that diffusion of anesthetic is a major factor when performing perineural blocks. Diffusion of intra-articular anesthesia to surrounding structures is also a factor. This has influenced the author's lameness examination more than anything. It has also complicated the lameness examination. This is based on the fact that local anesthetics will diffuse proximally over time.[1,2] This suggests that if a

NOTES

horse is 50% improved at 5 minutes and 70% improved at 10 minutes, the increased improvement in the lameness may be due to the movement of the anesthetic proximally on the leg, and that should be taken into consideration when moving to diagnostic imaging. Ideally, nerve blocks should be evaluated at 5 minutes and again at 10–12 minutes post block. The duration of local anesthesia can be influenced by other factors. The duration of action of any anesthetic will be decreased in a limb that is inflamed. Conversely, the addition of epinephrine can extend the duration of action of lidocaine.[3,4] Also, if the anesthetic was not placed directly into the neurovascular bundle, the block may take more time to have an effect or not work at all.[5] This can become very significant when performing sequential blocks in rapid succession.

The role of diffusion and time is even more important following intra-articular anesthesia. For this reason, these blocks should always be evaluated at consistent time intervals. Intra-articular blocks may also not last as long. Though not proven scientifically, it is the author's opinion to think of intra-articular anesthesia in the following manner:

- Significant improvement at 5 minutes—synovitis is the predominant source of pain.
- Significant improvement at 10 minutes—capsulitis and/or intra-thecal soft tissues is the predominant source of pain.
- Significant improvement at 15 minutes—neighboring extra-articular soft tissue structures are the predominant source of pain.
- Significant improvement at 20-30 minutes—the local anesthetic has diffused to block neighboring extra-articular nerves and anything distal to the joint could be the source of pain.

Specific blocks will be discussed by regions where localizing a lameness is aimed.

3. The Foot

Approximately 40% of lameness will originate from the foot,[6] but the foot is a very complicated region. Distal to the metacarpo-/metatarsophalangeal joint there are two joints, one bursa, one tendon sheath, three tendons, and multiple ligaments. There are a lot of potential areas for problems, all of which can be localized with one block, and sometimes it is almost impossible to isolate the lameness further.

Palmar/Plantar Digital Nerve Block (PDNB)

The expectation of a PDNB is that it will block the heel and sole region of the foot. This includes the dorsal sole.[7] Technique is important because if placed low, at the level, or below the ungual cartilages, it is unlikely to block distal interphalangeal joint and proximal interphalangeal joint in its entirety.[8] A PDNB will block distal interphalangeal joint synovitis but is unlikely to get subchondral bone pain in distal P2.[9]

Just as with many blocks, proximal diffusion is likely and more proximal sources of lameness are a potential. There have been reports of lesions identified in the metacarpo-/metatarsophalangeal joint following lameness resolution with a PDNB.[10] A compression bandage placed around the pastern region can reduce the proximal diffusion of radiodense contrast medium after a PDN,[11] and this could help to improve the precision of a PDNB.

Basisesamoid Nerve Block (BNB)

The BNB is more proximal on the limb than the PDNB and targets the dorsal branches of the palmar/plantar digital nerve as they cross the first phalanx. The expectation is that a BNB will anesthetize the dorsal aspect of the hoof, distal interphalangeal joint, and proximal interphalangeal joint. Nagy et al. reported significant proximal diffusion of radiodense contrast medium in the first 10 minutes following block placement.[1] This supports the suggestion of watching the horse move 5 minutes after a BNB.

Due to proximal diffusion, the metacarpo-/metatarsophalangeal joint and distal suspensory branches should be considered as potential sources of lameness following a BNB.[12]

Abaxial Nerve Block (ANB)

In the author's opinion, the ANB should be considered the same as a basisesamoid nerve block. Diffusion should be expected. It is expected that the ANB will block the entire foot. Just as with the BNB, the metacarpo-/metatarsophalangeal joint and distal suspensory branches are potential sources of lameness following an ANB.

Distal Interphalangeal Joint Block (DIPJB)

There are multiple approaches to the DIPJB.[9,13] It is expected that the DIPJB will block the DIP joint proper. It is also known to block the navicular bursa within 5 minutes.[14] It is recommended to use a 6 mL volume of anesthetic to minimize extra-articular diffusion of anesthetic.[15] Due to diffusion of the anesthetic, there is potential for a DIPJB to block solar pain due to the close proximity of the palmar/plantar digital nerves to the palmar/plantar pouch of the joint.[15,16] The use of 10 mL of anesthetic did result in greater anesthesia of the palmar/plantar digital nerves as evidenced by blocking the toe and heel aspects of the sole.[15]

Navicular Bursa Block (NBB)

There are also multiple approaches described for blocking the navicular bursa. The distal palmar approach to the "navicular position" is recommended.[17] It is expected to block the navicular bursa and adjacent soft tissue structures. An NBB will not block the distal interphalangeal joint by 10 minutes.[18] The NBB has the potential to block solar pain.[16] It could be argued that a NBB is not necessary, that appropriate clinical examination and perineural anesthesia will provide the same conclusion. There will be occasions, however, when an NBB may be necessary to separate the clinical significance of advanced imaging findings.

The Metacarpo-/Metatarsophalangeal Region

The metacarpo-/metatarsophalangeal region includes the metacarpo-/metatarsophalangeal joint, digital flexor tendon sheath, deep digital flexor tendon, superficial digital flexor tendon, sesamoidean ligaments, and suspensory ligament branches. The metacarpo-/metatarsophalangeal region is most directly blocked by a low four-point nerve block or an intra-synovial block. As mentioned above, however, this region can also potentially be blocked by an abaxial, basisesamoid, and palmar digital nerve block.

Low Four-Point Nerve Block (LFPB)

The LFPB targets the medial and lateral palmar/plantar metacarpal (tarsal) nerves and palmar/plantar nerves (4 in total). Due to potential inadvertent placement of the block into the digital flexor tendon sheath or the metacarpo-/metotarsophalangeal joint,[19] aseptic skin preparation is advised. There is significant proximal diffusion with time,[2] but the anesthetic is unlikely to diffuse past mid metacarpal region.[2,19] The importance of the LFPB is that it is expected to block the metacarpo-/metatarsophalangeal region. This is different than the PDNB, BNB, and ANB as these blocks only have the potential to block the metocarpo-/metotarso phalangeal region.

Metacarpo-/Metatarsophalangeal Joint Block

The metacarpo-/metatarsophalangeal joint pouch surrounds the suspensory ligament branches. Some suspensory branch tears actually communicate with the metacarpo-/metatarsophalangeal joint pouch. Therefore, a metacarpo-/metatarsophalangeal joint block should be expected to block the joint and distal suspensory ligament branches. The metacarpo-/metatarsophalangeal joint block can also potentially block injuries to the proximal aspects of the sesamoidean ligaments.[20] Be cautious of extravasation if using a lateral approach as the lateral palmar/plantar nerve is in close proximity and potentially could result in anesthesia of the lateral aspect of the distal limb.

Digital Flexor Tendon Sheath Block

Anesthesia of the digital flexor tendon sheath should be expected to block the synovial lining and any injuries of the digital flexor tendon sheath, including any injuries of the deep digital flexor tendon, superficial flexor tendon, manica flexoria, and distal digital annular ligament. Similar to the metacarpo-/metatarsophalangeal joint block, anesthetic in the digital flexor tendon sheath can potentially block the sesamoidean ligaments.[20] Many approaches to the digital flexor tendon sheath are in close proximity to the neurovascular bundle, and extravasation can potentially block neighboring nerves.

The Proximal Metacarpus

The proximal metacarpus can be blocked with a high four-point, local diffusion block or an isolated block of the lateral palmar nerve as it crosses the medial aspect of the accessory carpal bone. There are four approaches to blocking the lateral palmar nerve at the level of accessory carpal bone.[21] Inadvertent injection into the carpometacarpal joint and carpal sheath is a possibility based on the technique.[21] Local anesthesia of the lateral palmar nerve along the medial aspect of the accessory carpal bone has the lowest incidence of inadvertent synovial penetration[21] but will result in diffusion of anesthetic along the entire palmar aspect of the carpus.[21] The advantage to this approach is that it is well tolerated by the horse and only requires a single needle stick. It also does not interfere with ultrasound scanning. The author prefers blocking the lateral palmar nerve to localize lameness of the proximal metacarpus. Both the high four-point and a local diffusion block will result in fluid and gas at the origin of the suspensory ligament which will interfere with ultrasound scanning.

The Proximal Metatarsus

The proximal metatarsus can be blocked with a high four-point, local diffusion block or an isolated block of the deep branch of the lateral plantar nerve (DBLPN). Local anesthesia of the DBLPN is performed by injection axial to the lateral metatarsal bone (MTIV), 15 mm distal to the head of the MTIV.[22] Even with absolute precision, anesthesia of the DBLPN can result in subsequent anesthesia of the lateral plantar nerve.[23] Additionally, inadvertent injection into the tarsometatarsal joint (6-25%) and tarsal sheath (16-37.5%) can occur.[24,25] It is the author's preference to block the DBLPN when isolating the proximal suspensory region. The presence of fluid and gas will make ultrasound difficult following the block. It should be noted that the anesthesia of the DBLPN can block structures other than the proximal suspensory ligament. Barrett et al. reported that 47% of limbs that responded to analgesia of the proximal suspensory ligament had more severe lesions in the distal tarsus.[26]

The Stifle

Local anesthesia of the stifle is also commonly performed. The stifle joint consists of 3 three compartments: the medial femorotibial joint, the lateral femorotibial joint, and femoropatellar joint. During diagnostic analgesia each compartment can be blocked individually or a single stick technique has been described to inject all three compartments from a single craniolateral injection site.[27] Blocking all three compartments may be necessary for a thorough lameness evaluation as Toth et al. demonstrated that instillation of anesthesia into the compartment that has the pathology will improve the lameness more than if the anesthesia is placed in one of the other compartments, meaning diffusion between compartments cannot be relied upon for significant improvement in the lameness.[28] Incidentally, Radtke et al. did find that intra-articular anesthesia of the equine stifle can improve foot lameness,[29] which in fact would rely upon diffusion of anesthetic out of the stifle joint to peripheral nerves. Only 1/3 of horses showed improvement in the foot lameness, and the improvement was only up to

50 percent,[29] but this information should be considered during diagnostic analgesia of the stifle.

4. Conclusion

The abundance of scientific literature regarding diagnostic analgesia poses more questions than answers. Despite the challenges, lameness localization is still very important. Diagnostic analgesia is not straightforward but is necessary for lameness diagnosis and persistence is important. Remember to keep it simple, use small volumes for better accuracy for perineural blocks, and watch at consistent timepoints. Lastly, repeating the exam on a different day with a slightly different approach is not wrong but in fact often necessary.

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.

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How to Diagnose Muscle Diseases That Impact Performance

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1. Introduction

Acute muscle pain, chronic muscle pain, and mechanical restriction of limb movement can all contribute to lameness and poor performance. The diagnostic challenge lies first in identifying which muscles are impaired, second in differentiating primary muscle pain from a secondary response to an orthopedic disorder, and third in finding the root cause. The fundamentals of the diagnostic plan are a careful history assessment and a thorough hands-on physical examination.

2. History

The list of potential causes of poor performance is narrowed by signalment and history. The owner's videos and history are particularly important because many muscle disorders are intermittent in nature, and clinical signs may not be apparent at the time of veterinary examination. Duration and frequency of clinical signs and characterization of possible eliciting factors including tack, exercise schedule, diet, current medications and supplements, and concurrent disease or lameness should be documented to identify potential causes as well as triggering environmental stimuli that must be managed to prevent recurrence.

3. Physical Examination

Inspection of the horse at a distance for symmetry of muscle mass from all sides should be performed with the horse standing exactly square. Subsequently, palpation of the entire muscle mass of the horse while comparing left and right sides will provide valuable information regarding muscle tone, myofascial trigger points, heat, pain, swelling, subtle muscle atrophy, and fasciculations. Running a blunt instrument over the lumbar and gluteal muscles to evoke extension (swayback) followed by flexion (hogback) will determine if guarding typical of primary vertebral or sacroiliac disorders is present. Any signs of neurologic disease (weakness, ataxia, atrophy) should lead to a detailed neurologic examination. It is ideal to obtain a resting blood sample for pre-exercise serum muscle enzyme analysis prior to gait evaluation. The gait evaluation is essential to identify the extent to which muscle pain impacts movement. A lameness examination is necessary to determine if muscle pain is secondary to a primary orthopaedic lameness. If the origin of pain is not yet identified, evaluation of tack for fit and a ridden evaluation may be necessary to fully investigate muscle pain and loss of performance.

4. Serum Creatine Kinase and Aspartate Transaminase Activities

When determining the cause of a muscle disorder, it is essential to determine if significant myofiber degeneration is present. This is because it has a significant impact on the approach to treatment. Elevated serum creatine kinase (CK) and aspartate transaminase (AST) activities from several thousand to hundreds of

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thousands of units per liter are pathognomonic for rhabdomyolysis. If CK activity is normal at rest, a second sample should be obtained 4 to 6 hours after a 15-minute exercise test when CK activity peaks to rule out subclinical rhabdomyolysis. Normally, exercise rarely results in an increase in CK, and a doubling from pre-exercise values is considered an indicator of subclinical rhabdomyolysis. Extreme fatiguing exercise (e.g., endurance rides or the cross-country phase of a 3-day event) may result in CK activities to transiently be 10,000 U/L, but usually less than 5,000 U/L.[1] AST activity peaks 12 to 24 hours after an insult and returns to baseline 2 to 3 weeks later. Elevations in AST are a useful indicator of an episode of rhabdomyolysis within the past few weeks.

5. Differential Diagnoses

Muscular causes of lameness/poor performance in horses can be classified into four broad categories: weakness, mechanical lameness, acute muscle pain, and chronic muscle pain (Fig. 1).

6. Weakness

The force generated by a muscle is determined by the cross-sectional area being recruited. Topline and gluteal atrophy is apparent when the tuber sacrale protrudes slightly and can contribute to a decline in performance by reducing the power generated. In performance horses, this type of atrophy is usually gradual and often goes unnoticed by the owner. If comparisons are made to previous photographs and horses in a similar state of training, the lack of appropriate muscle mass becomes obvious.

Diagnostic Approach

A full neurologic exam should be performed in horses with poor muscle mass to determine if weakness, proprioceptive deficits, or ataxia are present. If asymmetric atrophy is present, an anatomy text should be consulted to trace the nerve supplying the atrophied muscle from the affected muscle to its exit from the spinal cord via the intervertebral foramina. This area is then targeted for diagnostic imaging. Symmetric atrophy also dictates that a full neurologic exam be performed with careful assessment of strength on tail pull. The tail pull is performed on both sides when the hoof on that side is weight bearing. After two strides, a healthy, fit horse should be able to resist being pulled to one side. A muscle biopsy of the atrophied muscle may indicate whether the atrophy is of neurogenic or myogenic origin. For generalized atrophy, serum vitamin E concentration should be measured.[2] Because vitamin E is easily oxidized, the sample should be protected from light (wrap in tin foil or place in a glove) and kept chilled, with serum removed as

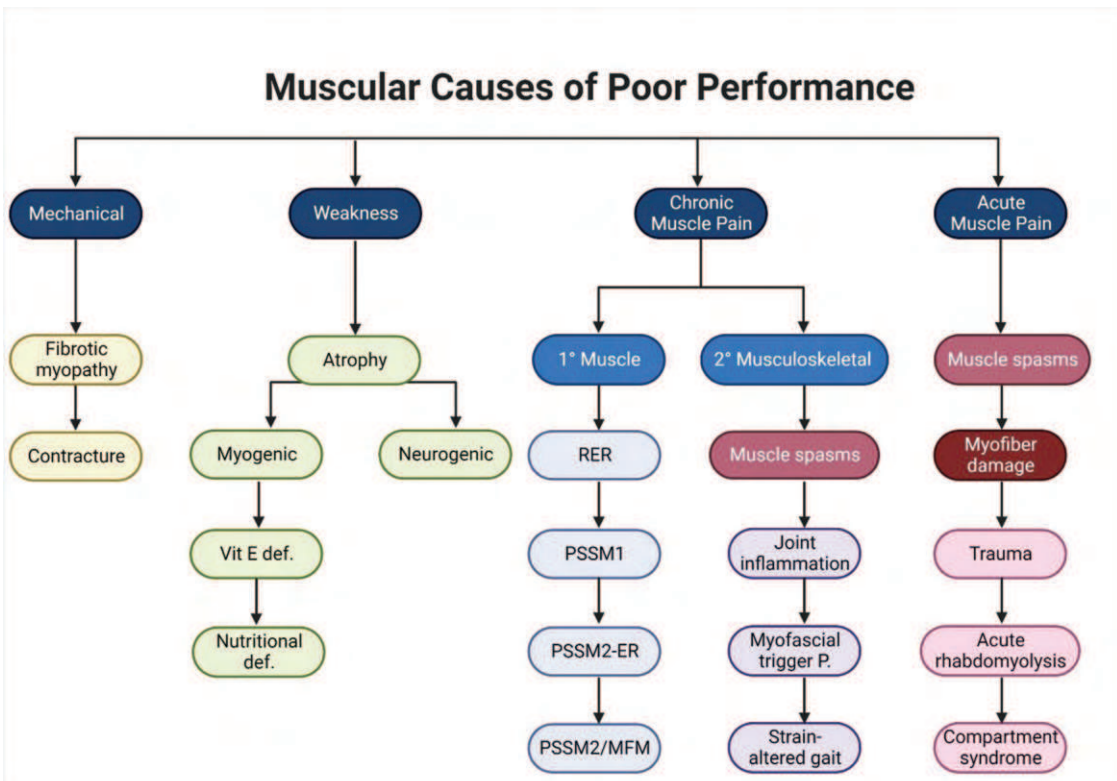


Fig. 1. Potential muscular causes of lameness/poor performance are listed under four overarching categories: mechanical lameness, muscle weakness, acute muscle pain, and chronic muscle. Vit, vitamin; def., deficiency; RER, recurrent exertional rhabdomyolysis; PSSM1, type 1 polysaccharide storage myopathy; PSSM2-ER, type 2 PSSM exertional rhabdomyolysis; MFM, myofibrillar myopathy; P., points.

soon as possible. Because a normal serum vitamin E concentration does not rule out past deficiencies, a biopsy of the sacrocaudalis dorsalis medialis muscle should be considered. Vitamin E responsive myopathy and equine motor neuron disease show characteristic histopathology in the sacrocaudalis dorsalis medialis muscle.[3,4] In Quarter Horse-related breeds with symmetric atrophy, a genetic test for myosin heavy chain myopathy (*MYH1* mutation) is indicated.[5] Sarcopenia is the loss of muscle mass that commonly occurs with aging. In older horses with muscle atrophy, it is important to ensure that pituitary pars intermedia dysfunction, systemic diseases, dental disease, or nutritional deficiencies are not contributing to muscle atrophy. A nutritional consultation may help to ensure that highly digestible proteins with an appropriate balance of amino acids are being consumed.

7. Mechanical Lameness

Fibrotic Myopathy

The weakest point within a muscle is the myotendinous junction, and thus this region is most susceptible to strain and tearing. Following a tear, complete healing requires that damaged muscle segments find each other and realign so that myoblasts can eventually migrate into the space and rejoin damaged segments. If the muscle ends are separated by contracture of the muscle belly or excessive hemorrhage, fibroblast proliferation occurs in the space, resulting in a fibrotic myopathy or, in extreme cases, ossification. The fibrous connective tissue impairs the muscle's ability to lengthen and contract normally, resulting in a mechanical lameness that restricts the full range of motion.[6,7]

Diagnostic Approach

Fibrotic myopathy occurs most commonly with the semimembranosus/tendinosus muscle but can occur in other muscles.[6] On physical examination, a divot may be apparent near the Achilles tendon, and a firm band of connective tissue may be palpable dorsal to the divot. Manual manipulation may reveal a mechanical restriction of the full range of joint motion, and a gait analysis reveals a goose stepping where the anterior swing phase is shortened and the hoof is retracted prior to placement on the ground. Ultrasonography is key to identifying a region of fibrosis or ossification. Fibrous tissue appears as hyperechoic regions, and mineralization causes shadowing artifacts. A similar goose-stepping gait may be present if the semimembranosus or tendinosis muscles have spasms without fibrosis. In such cases, the typical gait is present but ultrasonography is normal.

Shivers and stringhalt are two neurologic disorders that can contribute to abnormal gaits. More information on these disorders is available in recent reviews.[8,9]

8. Acute Muscle Pain

Muscle pain originates from nociceptors that wrap around arterioles within the body of the muscle and, when activated, relay the sensation of pain to the central nervous system.[10,11] Specific mechanisms that activate nociceptors include the following:

1. release of muscle fiber ATP
2. acidification of the local environment
3. sensitization of nociceptors by the release/synthesis of inflammatory cytokines prostaglandin E_2 and kinin peptides[10]

Clinical signs of acute muscle pain include increased muscle tone, sensitivity to palpation, painful knots within the muscle, heat, swelling, and guarding against movement of the joints in that area.

Muscle pain can arise from mechanical overloading (exercise in excess of training, cast in abnormal position) that triggers tension receptors in skeletal muscle and does not result in an increase in serum CK or rhabdomyolysis that increases serum CK activity. When damage occurs to the muscle fibers, the sarcolemma is disrupted and ATP is released. A small focal rise in ATP activates nociceptors, and inflammatory cytokines may then be released or synthesized, which further sensitizes nociceptors. Another mechanism causing acute muscle pain is muscle spasms that lead to focal areas of ischemia and localized lactic acidosis, which also activates nociceptors. With muscle spasms, there is no muscle degeneration; the sarcolemma remains intact and serum CK and AST are normal.

Diagnostic Approach

Physical examination with palpation and gait evaluation are used to localize the affected muscle(s). The extent of the muscle damage is assessed by measuring serum CK and AST activities. In experienced hands, thermography may be of value in localizing affected muscles.[12] Diagnostic ultrasonography is a valuable tool to assess the extent of focal muscle trauma.[13] Careful comparisons must be made between similar sites in contralateral limb muscles, in both transverse and longitudinal images, because the typical striated echogenic pattern varies according to the muscle group. The appearance of muscle is also sensitive to the way the horse is standing and whether the muscle is under tension, so it is important that the horse is standing squarely and bearing weight evenly if possible. The depth of the muscle belly should be compared between the affected and unaffected limb to identify swelling. Acute muscle fiber disruption appears as relatively hypoechoic areas bordered by jagged edges of hypercontracted muscle with increased echogenicity. If hemorrhage occurred, a loculated hematoma may be evident, which will slowly be replaced by hypoechoic granulation tissue. Tears in the muscle fascia may be identified following blunt trauma. Over time, muscle repair shows a progressive increase in echogenicity.

9. Chronic Muscle Pain

Muscle pain lowers the excitability of the α-motor neurons innervating the painful muscle, creating muscle spasms, which in turn create more pain and induce further spasms in a vicious cycle.[10] Over time, constant activation of muscle nociceptors increases the excitability of sensory neurons in the spinal cord. This sensitization manifests itself clinically as allodynia, where stimuli that normally do not cause pain are perceived as painful, and hyperalgesia, where stimuli that are normally painful cause more severe pain than before.[10,11] Chronic muscle pain also results in structural remodeling in the central nervous system, resulting in pain persisting over the long term.[10] Because the functional and structural changes in the central nervous system need time to regress, chronic muscle pain is difficult to treat.

Myofascial trigger points are another manifestation of muscle pain and appear as palpable, punctate firm areas in the muscle tissue that are painful on movement and palpation.[14] They usually occur from sustained repetitive activities or muscle trauma and develop near motor end plates. They represent contraction of a small number of sarcomeres in individual muscle fibers that compress neighboring capillaries, cause local ischemia, and activate nociceptors.[10] Muscles with myofascial trigger points often also have pain at the origin or insertion of the affected muscle and potentially referred pain. In humans, the referred symptoms often lead patients to localize their pain incorrectly, making defining the origin of trigger points even more challenging in horses.

Diagnostic Approach

The objective of a thorough physical examination in horses with chronic muscle pain is to determine if it is secondary to a primary orthopedic disorder or if it is due to a primary myopathy. Vertebral lesions, sacroiliac disease, and other orthopedic lesions alter a horse's gait and muscle recruitment patterns, leading to strain, spasms, and trigger points.[15] Because lameness is common in performance horses, they may have both a primary muscle pain and an orthopedic lameness.

10. Primary Myopathies Impacting Performance

There are two principal categories of primary myopathies: those that cause pain from muscle degeneration with elevated serum CK and AST activities (exertional rhabdomyolysis) and those that cause pain from spasms and tension without damaging the sarcolemma and increasing serum CK and AST (exertional myopathy).[16] Causes of exertional rhabdomyolysis (ER) include sporadic ER from exercise in excess of training, recurrent exertional rhabdomyolysis (RER), type 1 polysaccharide storage myopathy (PSSM1), type 2 PSSM in Quarter Horse-related breeds (PSSM2-ER), and malignant hyperthermia in Quarter Horse-related breeds.[16] In Arabian horses, a form of myofibrillar myopathy (MFM) can cause high serum CK activity and pain at the end of endurance rides or following several weeks of rest.[17,18] Exertional myopathy, without elevations in CK and AST, in Warmblood horses has been called PSSM2 or, now more accurately, MFM.[19]

Diagnostic Approach

1. *Muscle enzymes:* Determination of serum CK and AST activities is essential to diagnose ER. Significant elevations in CK at rest are pathognomonic for rhabdomyolysis. Elevations in AST are often indicative of a previous episode of rhabdomyolysis if there are no elevations in liver enzymes or hemolysis.
2. *Exercise challenge*: An exercise challenge can be helpful in detecting subclinical ER in horses that have normal serum CK activity. Blood samples should be taken before exercise and about 4 to 6 hours after 15 minutes of trotting exercise to capture peak changes in CK activity. If signs of stiffness develop during exercise, exercise should be concluded. A normal response is less than a 2-fold increase from basal CK activity.
3. *Genetic tests:* For Quarter Horse-related breeds with elevated CK or AST activities, genetic testing for PSSM1, myosin heavy chain myopathy, and malignant hyperthermia are indicated.[20,21] PSSM1 genetic testing is also indicated in most horse breeds with exertional rhabdomyolysis except Arabians, Thoroughbreds, and Standardbreds, which are not afflicted with PSSM1.[22] The commercial genetic tests for PSSM2 and MFM do not accurately identify these myopathies based on current research, and therefore the author does not recommend their use.[23,24]
4. *Treatment trial:* Owners may elect to assess whether a diet and management plan for RER, PSSM, or MFM impacts clinical signs rather than pursue invasive diagnostic tests. In general, if a myopathy can be impacted by a change in diet, clinical signs will improve within 4 weeks of instituting a diet trial. This should be done after other causes of poor performance such as gastric ulcers, lameness, behavior, etc. are ruled out. In Warmbloods under 8 years of age, a treatment trial for MFM may be a good approach because the pathognomonic aggregates of desmin may not develop until $\geq$ 8 years of age.[19] A treatment approach has recently been described in another AAEP proceeding.[25]
5. *Muscle biopsy:* If genetic tests are positive for PSSM1, there is no further indication to perform a muscle biopsy. Muscle biopsy is informative for muscle disorders such as PSSM1, PSSM2, and MFM that have consistent histopathology. Muscle biopsies from horses with sporadic ER and RER or muscle spasm are often normal. The sensitivity and specificity of muscle histopathology is such that it should

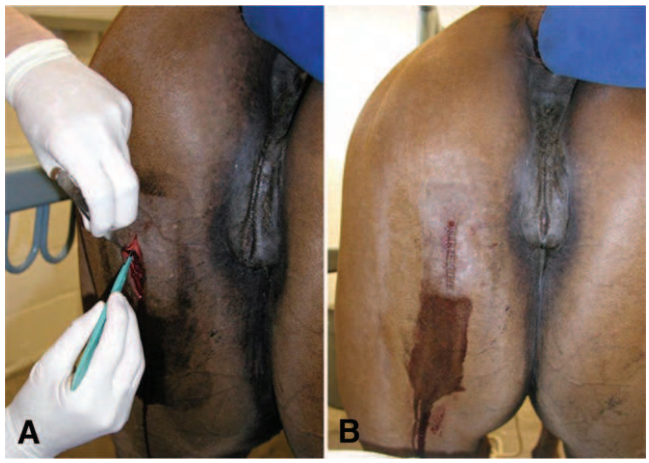


Fig. 2. A, The site of the semimembranosus muscle biopsy. An incision is made through the skin and fascia, the fascia is undermined on each side, and a 2-cm-wide, 2-cm-long, 1-cm-deep section of muscle is removed without removing the fascia. B, Closure of the fascia and subcutaneous tissue prior to suturing the skin ensures a scar will not be evident.

not be used to make breeding or purchasing decisions.

Selection of a muscle is important. For exertional rhabdomyolysis and exertional myopathies, open biopsies of the semimembranosus muscle or 6-mm diameter needle biopsies of the gluteus medius muscle are recommended. A sample that provides a 2-cm square of tissue in a cross-section is required to provide enough muscle fibers to identify the small number of scattered fibers with characteristic changes. The site for semimembranosus muscle biopsies is approximately 8 cm distal to the tuber ischii, and for the middle gluteal muscle, it is 8 cm along a line from the top of the tuber coxa to the tail head (Fig. 2A). The biopsy procedure does not impact the horse's future performance, and when the fascia and subcutaneous tissue are closed in addition to the skin, scarring is not evident (Fig. 2B). A biopsy of the sacrocaudalis dorsalis medialis muscle just above the tail head is required to assess horses with generalized muscle atrophy.

Research laboratories prefer submission of fresh muscle tissue that is frozen in methylbutane using a specific and finicky technique in the laboratory. This allows a multitude of stains to be performed and isolation of DNA, which facilitates discovery of new diseases. This approach is labor intensive and expensive, and shipped samples are prone to artifacts. Formalin-fixed samples are less susceptible to artifact formation if left to sit in room-temperature air for 5 minutes before placing in formalin and do not require chilling or overnight shipment. Formalin-fixed samples can be used to diagnose known myopathies using several immunohistochemical stains.

11. Conclusion

Both the art and the science of veterinary medicine are required to investigate poor performance in horses. Potential muscular causes of lameness/poor performance can often be categorized as muscle weakness, mechanical lameness, acute muscle pain, and chronic muscle pain. The diagnostic approach begins with a careful history assessment and physical, lameness, and neurologic examinations to rule out primary neurologic or orthopedic disorders. Finding the root cause of a primary myopathy may require assessment of serum muscle enzymes and vitamin E, an exercise challenge test, imaging techniques, genetic testing, and muscle biopsy.

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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 receives royalties from the PSSM1 genetic test. The author directs the Valberg Neuromuscular Diagnostic Laboratory and receives financial remuneration for interpreting muscle biopsies. The author has research and consulting collaborations with Kentucky Equine Research, Versailles, KY and receives royalties from products that were developed based on this research such as RE-LEVE and MFM Pellet.

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Neurologic Diseases That Cause Lameness or Poor Performance: Focus on Diagnosis

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Horses fail to meet performance expectations for many reasons, including neurologic disease, lameness, and systemic disease. Neurologic disease can mimic other problems, and some horses might have multiple problems affecting performance. Careful observation and clinical examination, along with appropriate diagnostic testing and interpretation, are the keys to accurate diagnosis. Author's address: Department of Clinical Studies, New Bolton Center, University of Pennsylvania School of Veterinary Medicine, Kennett Square, PA 19348; e-mail: amyjohn@vet.upenn.edu. © 2023 AAEP.

1. Introduction

Neurologic deficits can be misconstrued as lameness, vision problems, pain from gastric ulcers, or many other potential diagnoses. One frequent challenge is differentiating mild neurologic disease from multilimb or complicated lameness. For the purposes of these proceedings, "lame" will describe an abnormal gait due to abnormal structure or function of the musculoskeletal system, and "neurologic" will describe an abnormal gait due to abnormal structure or function of the nervous system. Differentiating between lameness and neurologic disease can be quite frustrating, particularly when a horse has an abnormal gait due to a combination of both problems. A systematic approach to these cases, although time-intensive, will reduce costs to the owner and improve diagnostic accuracy in the long run. The starting point should always be the clinical examination, NOT blood testing. Neither serology for Lyme and equine protozoal myeloencephalitis (EPM) nor phosphorylated neurofilament heavy (pNF-H) biomarker results can differentiate between neurologic and orthopedic disease—only the diligent practitioner can!

Developing a logical diagnostic framework for horses with abnormal gaits that includes both orthopedic and neurologic assessment is essential. The author tends to start with neurologic evaluation and then performs an additional orthopedic examination if warranted, but most clinicians work in the reverse order! The practitioner should learn to recognize clinical clues that point towards either neurologic or orthopedic disease. An understanding of which neurologic diseases frequently mimic orthopedic disease will help guide the diagnostic pathway.

2. Clinical Examination

The clinical history obtained at the beginning of the exam might provide some important clues to the source of the problem. In addition to a description of

NOTES

the horse's signs, the duration of the problem, its progression, the effect of interventions, and perception of whether the horse is painful should be established. With the notable exception of some cervical vertebral problems, neurologic disease often does not cause pain. Certain painful orthopedic conditions (such as a foot abscess) can cause a non-weight bearing lameness that is very similar to a horse with a radial or femoral neuropathy, but the horse with the neuropathy generally will be more willing to attempt to use the limb, whereas the horse with the painful lameness will be more reluctant to move. Often the client will know whether the horse improves with non-steroidal anti-inflammatory drugs (NSAIDs), time off work, or exercise, and this information might or might not lend support to an orthopedic cause.

As aforementioned, the author starts with the neurologic evaluation. There are many different ways to perform a neurologic examination, and several excellent references are available.[1–3] In general, an equine neurologic exam can be divided into 4 parts: (1) evaluation of mental status and behavior; (2) cranial nerve exam; (3) evaluation of posture, spinal reflexes and musculature while the horse is standing; and (4) evaluation of gait, posture, and postural reflexes while the horse is moving. This session will focus on gait analysis.

Every clinician develops a system for neurologic gait evaluation. The author's normal routine is as follows: walk the horse in a straight line, trot the horse in a straight line, walk the horse in serpentine, walk the horse with the head elevated, walk the horse while pulling the tail in each direction, spin the horse in tight circles, walk the horse backwards, walk the horse on uneven ground (up and down hill, with the head and neck in both neutral and extended positions, or back and forth over curb or cavaletti). In the author's hands, "hopping" the horse and checking its "CPs" (foot placing reactions) are not particularly helpful, so an extensive gait examination is performed instead to look for proprioceptive deficits. Evaluating the horse on both soft footing (arena) and hard footing (paved driveway) is sometimes beneficial. Neurologic deficits might be more evident on one surface than the other, and the same is true for orthopedic problems, particularly for horses with sore feet.

As the practitioner is observing the gait exam, some of the most important aspects to assess are stride length and regularity of foot placement (refer to Table 1). Spinal cord disease affecting the upper motor neuron and general proprioceptive tracts tends to cause an elongated, floating gait. Diseases that affect the lower motor neurons or neuromuscular system tend to cause a short, choppy gait that more often mimics an orthopedic problem. Neurologic deficits tend to be most evident at the walk, while orthopedic problems tend to be more evident at the trot. The rate, rhythm, and regularity of foot placement can be very revealing. Horses with ataxia tend to have irregularly irregular foot placement, while horses with orthopedic disease have regularly irregular foot placement. If you can nod your head in time with the gait abnormality, it is less likely to be a neurologic problem! If the pelvic limbs are affected, horses with lameness tend to drift away from the lame leg, versus horses with neurologic disease that might drift toward the most affected limb or drift in both directions. Horses with upper motor neuron paresis have increased tone/spasticity and tend to have a particularly bouncy gait (up and down) as well as truncal instability that leads to more side-to-side movement when viewed from behind.

In the author's opinion, proprioceptive deficits suggestive of neurologic disease are most easily observed when the horse is changing directions, circling tightly, or walking up and down a hill with the head elevated. Practitioners should watch carefully for toe scuffing, foot dragging, delayed protraction (shift in body weight and torso position prior to foot movement), knuckling or buckling of limbs, abnormal limb crossing or interference, pivoting on the inside limb or circumducting the outside limb when circling, and stepping on the opposite foot.

If evidence of ataxia is not observed, a more extensive lameness examination is performed, which might include trotting in circles, flexion tests, and working on the lunge line or under saddle. Ridden exam or even lunging with side reins will allow evaluation of the horse "in a frame," with additional neck flexion that might exacerbate subtle deficits.

3. Diagnostic Testing—General Principles

If the clinical exam clearly points the examiner towards musculoskeletal or neurologic diseases, appropriate diagnostic testing is pursued. If musculoskeletal disease is suspected and the lameness is severe

Table 1. Differentiating Neurologic Disease from Orthopedic Lameness – Clinical Characteristics

	Orthopedic Lameness	Neurologic Disease
Stride length	Short, choppy	UMN/GP – long, floating LMN – short, choppy
Foot placement	Regularly irregular (predictable)	Irregularly irregular (unpredictable)
Gait most evident	Trot	Walk
Hindquarter drift (assuming pelvic limb involvement)	Away from lame leg	Towards affected leg, or both directions
Additional comments		UMN/GP – bouncy trot (up/down) with truncal instability (excess side-to-side movement)

Abbreviations: UMN/GP = upper motor neuron and general proprioceptive tract involvement; LMN = lower motor neuron involvement.

enough to be considered "block-able," diagnostic analgesia is generally pursued. In more subtle cases, nuclear scintigraphy might be elected. Once a region has been localized, various imaging techniques (radiography, sonography, magnetic resonance imaging [MRI], and computed tomography [CT]) are pursued to characterize the lesion(s). If neurologic disease is suspected and localized to the cervical region, cervical radiography is usually performed as the first diagnostic test. Although detailed description of radiographic interpretation is beyond the scope of these proceedings, findings that increase the likelihood of cervical vertebral stenotic myelopathy (CVSM) include stenosis of the vertebral canal (intra- or inter-vertebral minimum sagittal diameter ratios of 50% or less), obvious mal-articulation or mal-angulation, caudal extension (overriding) of the dorsal laminae, flare of the caudal vertebral epiphysis of the vertebral body ("ski-slope" appearance), and osteochondrosis or osteoarthritis/osteoproliferation of the articular process joints.[4] Based on radiographic results, index of suspicion for CVSM, and client preferences, the next step might be either myelography or standing cerebrospinal fluid centesis.

If an abnormal gait is recognized but its origin is not clear, the next step is again often diagnostic local or regional analgesia to see if the abnormal gait will "block out," in which case musculoskeletal disease is assumed. If the abnormal gait is not considered "block-able," involves multiple limbs, or there are other reasons not to perform diagnostic analgesia, a systemic analgesia trial with phenylbutazone or similar non-steroidal anti-inflammatory drug might yield useful information. Repeated neurologic and lameness examinations are important, particularly after analgesia trials. In most cases, the appropriate diagnostic path will be identified at this point. Importantly, running serologic tests for EPM and Lyme or the biomarker pNF-H assay cannot help make the determination of whether an individual case is lame or neurologic—whether positive or negative, the practitioner cannot interpret results adequately without knowledge of whether the horse has musculoskeletal or neurologic disease.

4. Specific Diseases

In broad terms, "confusing" cases of neurologic disease are labeled as such because they mimic an orthopedic lameness, cause poor performance in the absence of overt neurologic disease, or manifest primarily as bad behavior. In the author's experience, neurologic diseases that most commonly mimic an orthopedic lameness are CVSM, foraminal stenosis causing nerve root or spinal nerve impingement, and EPM. An even wider variety of neurologic diseases can manifest as poor performance, including basically any neurologic disease that affects coordination, strength, information processing, or comfort. Therefore, the most common neurologic diseases—CVSM, equine neuroaxonal dystrophy/equine degenerative myeloencephalopathy (eNAD/EDM), and EPM—are also the most common neurologic diseases to cause poor performance, but any neurologic disease could do so. When bad behavior (such as bucking, bolting, spooking, refusing fences, or balking) is the primary concern, the practitioner should consider whether this behavior is a response to pain, reflective of brain dysfunction, or a learned behavior. Most horses that are presented for bad behavior fall into the first two categories. Many different conditions, both neurologic and non-neurologic, can cause chronic or intermittent pain that triggers bad behavior. Neck problems (CVSM, cervical arthropathies, and foraminal stenosis) are the most common painful neurologic diseases. Cervical arthropathies can be a particular diagnostic challenge, as their clinical manifestation ranges from subclinical to profound pain, with or without ataxia. Many horses without performance complaints have cervical osteoarthritis documented radiographically; recent observation of Warmblood jumpers without lameness or neurologic signs showed that most (approximately 67%) had caudal cervical osteoarthritis.[5] Horses with more severe synovitis or arthritis might show neck stiffness, while horses that develop intervertebral foraminal stenosis secondary to osteoproliferation can have intermittent, profound pain due to nerve root or spinal nerve impingement. Osteoproliferation or synovial proliferation within the vertebral canal can lead to spinal cord compression and variable or persistent ataxia, with variable pain. Frequently implicated non-neurologic conditions that cause pain include gastric ulcers, overriding dorsal spinous processes/back pain, myopathies, and poor saddle fit. Neurodegenerative disease (eNAD/EDM) is the most common cause of brain dysfunction to cause bad behavior. If uncertain whether the behavior might be learned, consider if the horse could be taught to perform its bad behavior. If the behavior would be difficult to teach, it likely is being triggered by either pain or brain dysfunction.

Once suspicious of neurologic disease, the most common diagnoses are CVSM, eNAD/EDM, and EPM. Lyme disease is a common client concern but is rarely the final diagnosis. History and clinical signs will usually provide enough information for the practitioner to make an educated guess about which disease is most likely, although additional diagnostic evaluation is necessary to confirm the diagnosis. Table 2 provides the author's interpretation of historical and clinical clues that might help increase suspicion for one of these conditions. Additional information to aid in clinical diagnosis is provided below.

5. CVSM

Some horses show clear indicators of a cervical vertebral problem (Table 3). The horse might show evidence of neck pain and have an abnormal head and neck posture such as carrying the head lower than normal or decreased range of motion when asked to bend laterally or raise and lower the head. The horse might adapt an unusual grazing position, with the

Table 2. Historical Details and Clinical Exam Findings That Might Provide Evidence for the Neurologic Diagnoses Cervical Vertebral Stenotic Myelopathy (CVSM), Equine Protozoal Myeloencephalitis (EPM), and Equine Neuroaxonal Dystrophy/Equine Degenerative Myeloencephalopathy (eNAD/EDM)

	CVSM	EPM	EDM
Chronic tripping or stumbling	*		*
Rapid worsening	*	**	
Improvement with NSAIDs	*		
Improvement with steroids	*	*	
Improvement with rest	*	(worse)	(worse)
Neck pain/stiffness	*		
Thoracic limb lameness	**	*	
Pelvic limb lameness		**	
Dullness or depression		*	*
Bad or unpredictable behavior	*		**
Focal or asymmetric atrophy		**	
Diffuse, symmetric atrophy	*		*
Cranial nerve deficits		**	

forelimbs widely spread. More severely affected horses rarely bend their necks, even when asked to circle, and appear to "weathervane" around. If nerve root compression is occurring, the horse might show thoracic limb lameness or even a "root signature," during which the affected thoracic limb is raised and held off the ground. Rarely, a horse will become "stuck" with the head and neck held in an abnormal position, often lowered. If spinal cord compression is present, the horse will usually display relatively symmetric general proprioceptive ataxia in all four limbs as well as paresis. However, some horses show mild to moderate asymmetry. Horses with mild lesions can appear to be unaffected in the thoracic limbs, with mild signs in the pelvic limbs, and it is common for deficits in the pelvic limbs to be more obvious than those in the thoracic limbs. Horses most commonly have an elongated stride with upper motor neuron paresis, though horses with caudal cervical problems might have a short stride in the thoracic limbs with lower motor neuron paresis. Abnormal musculature might be evident; some horses have poorly developed cervical musculature, others seem to have poor topline muscling that extends to their rumps, and some have neurogenic muscle atrophy, most commonly of the caudal neck and thoracic limbs. Horses might show only pain, only ataxia, or both.

Not every horse with a neck problem shows overt signs of pain or neurologic disease. In some cases, the first sign of the problem is a behavior change under saddle, such as head tossing, bucking, rearing, or stopping at fences. The horse might show resistance when working in one direction, be reluctant to move forward,

Table 3. Signs That Might Indicate a Cervical Vertebral Problem

Potential Indicator of Cervical Vertebral Problem	Specific Signs
Pain	• Abnormal head and neck posture • Persistently low head carriage • Decreased range of motion laterally or vertically • Abnormal grazing posture – forelimbs widely spread • "Root signature" – resting thoracic limb on dorsum of hoof or lifting thoracic limb off ground • "Stuck" – unable or unwilling to move head and neck at all (often in unusually low position)
Lameness	• "Unblockable" thoracic limb lameness • Variable lameness, dependent on head position/degree of neck flexion
Ataxia and paresis	• Classically, symmetric general proprioceptive ataxia with upper motor neuron paresis in all four limbs ○ In many cases, mild to moderate asymmetry is present ○ Elongated stride, toe-scuffing, irregular foot placement, limb interference, circumduction ○ Deficits more obvious in pelvic limbs than thoracic limbs • Lower motor neuron paresis in thoracic limbs possible with caudal cervical lesion ○ Muscle tremors, frequent shifting ○ Muscle atrophy ○ Standing with thoracic limbs placed abnormally under body (close together and caudally placed)
Muscle atrophy	• Poorly developed cervical musculature (abnormal head and neck carriage) • Symmetric over topline (disuse) • Focal and severe involving cervical region or thoracic limbs (neurogenic)
Bad behavior	• Problems under saddle: resistance in one direction, difficulty holding lead, reluctance to move forward or adopt correct frame, head tossing, bucking, rearing, stopping at fences • Change in behavior due to chronic pain: aggression towards people or other horses, anxiety

be reluctant to bring its head and neck up into a frame, or just lose its enthusiasm for its job. Difficulty with bending or lateral work (often worse in one direction) and mild thoracic limb lameness can be observed. The rider might notice an occasional stumble, or the horse might have had a fall under circumstances where it was not expected. Some horses have difficulty traversing hills but work well in other situations. The rider might comment that the horse feels lame or different, but no apparent lameness is present. In summary, many performance problems noted by the rider could stem from a cervical vertebral problem, and those horses without an obvious lameness should be carefully assessed for neck pain and neurologic disease.

When evaluating a horse with a potential neck problem, the author prefers to start with a thorough neurologic evaluation, with special focus on the gait examination as previously described. The horse is asked to bend laterally for a food reward and touch its nose to its flank bilaterally; normal horses accomplish this easily and bend evenly throughout the length of their neck, while abnormal horses cannot or will not reach back to their flank. They might also try to reach the food reward by twisting their head and bending only the cranial aspect of their neck. The horse is also asked to reach up in the air and down to the ground for food and observed grazing. Hesitation in lowering the head or abnormal limb position while grazing with thoracic limbs widely spread can be observed in horses with neck pain.

If no neurologic deficits are identified, more thorough performance examination is performed, often by evaluating the horse under saddle. Some horses with neck problems show a marked change in gait when ridden with their head and neck in a relaxed position compared to in a tighter frame, or they might show a distinct difference when ridden in one direction compared to the other.

Confirmation of CVSM and other vertebral abnormalities is achieved through imaging. Typically, these efforts begin with survey cervical radiographs and progress to more advanced techniques such as CT-myelography. Obtaining and interpreting images is beyond the scope of these proceedings. The author finds survey radiographs to be quite useful at predicting whether the horse is likely to have CVSM when radiographs are interpreted in conjunction with historical and clinical examination findings. However, as aforementioned, the mere presence of radiographic abnormalities does not confirm that these abnormalities are the cause of the horse's clinical signs. Additional diagnostic testing, either to confirm the relevance of the imaging findings or to exclude other differentials from consideration, is often warranted. This diagnostic testing might include diagnostic analgesia of cervical articular process joints, response to targeted therapeutic injections (intraarticular or perineural), electromyography (if available), cerebrospinal fluid analysis (including cytology and immunodiagnostic testing for infectious diseases), and determination of serum vitamin E concentration. Ultrasonography and advanced imaging techniques, including standard cervical myelography, CT-myelography, and CT-arthrography can provide more sensitive and definitive structural information that confirms or allows inferences regarding soft tissue and bony effects on the spinal cord, nerve roots, and spinal nerves. Standard cervical myelography allows detection of many horses with spinal cord compression, although horses with dorsolateral or lateral spinal cord compression might be missed. CT-myelography is required to detect those cases. In the author's experience, it would be unusual for a horse to have spinal cord compression that is not detected using these imaging techniques. Most horses that are suspected to have spinal cord compression but do not have corroborating imaging findings are diagnosed with neurodegenerative disease (eNAD/EDM) if postmortem histology is performed.

6. eNAD/EDM

Horses with eNAD/EDM typically have a chronic course of disease. Many have an initially promising performance career, with gradual deterioration that seemingly cannot be attributed to a cause. Others might be difficult to train from the beginning, seemingly unable to gain the strength and coordination to advance up the levels. Although not observed in every case, behavior changes are a very common clinical feature that should alert the veterinarian to the possibility of EDM. The behavior changes cannot always be detected by people less familiar with the horse's "normal" behavior, so veterinarians should listen carefully to the observations of those who know the horse well. Bad behavior under saddle, particularly unpredictable spooking, is frequently the first sign detected. This spookiness might lead clients to suspect eye problems, but ophthalmic exam is usually normal. Many of these horses were considered unusually calm prior to onset of uncharacteristic spooking. Although some horses become very reactive to sound and others reactive to visual stimuli, many spook for no apparent reason, often after they have gone past an area uneventfully several times. In addition to excessive and unpredictable spookiness, other bad behaviors are common, including bucking, bolting, rearing, spinning, refusing fences, and becoming unwilling to stand at the mounting block. Importantly, these bad behaviors are a marked change from the horse's normal behavior and are usually unprovoked and unpredictable. "Personality" changes are also common, including changes in the horse's general level of awareness, reaction to stimuli, and interactions with people, animals, and the environment. Some horses become increasingly dull and lethargic, sometimes to the point of appearing sedated, and they seem to lose interest in social interactions with people and other horses. This overly dull/sedate behavior might be interspersed with periods of uncharacteristic anxiety, spookiness, and aggression towards horses, other

animals, or people. Other horses appear to be persistently anxious or on edge, becoming cranky or aggressive.

Ataxia is often subtle at first. Horses might start knocking rails, struggle with lateral movements, have difficulty holding leads at a canter or changing leads, or feel weak. Tripping with the thoracic limbs and "falling out behind" (tripping, stumbling, or buckling with the pelvic limbs) are common observations. Dynamic gait evaluation typically reveals proprioceptive deficits and signs of mild to moderate ataxia and paresis consistent with a cervical or diffuse myelopathy. Most horses are graded 1-2/5 on the modified Mayhew ataxia scale at time of first evaluation. Repeated evaluations over months might show progression of neurologic disease. Horses with EDM often have more obvious proprioceptive deficits than ataxia, meaning that their limb positioning at rest and during more complicated maneuvers is obviously abnormal while their gait in a straight line appears normal. Circling the horse in hand tightly in both directions is usually the most helpful test to detect proprioceptive deficits. Horses often show delayed protraction, such that their body leans to the side, but they are slow to initiate limb movement—their feet never seem to catch up with their center of gravity. Limb interference might be seen from the level of the tarsi/carpi down to the hooves. The toe of the outside limb might scuff or drag on the ground as it is widely and spastically swung into position. The inside foot might pivot for an abnormally long time on the ground. When the horse is stopped suddenly or asked to rapidly change direction, excessive truncal sway and loss of balance might be observed. Horses often spontaneously place their limbs in unusual positions relative to their center of gravity and then fail to replace them in a more normal position.

Diagnosis of eNAD/EDM in the living horse is challenging and based primarily on ruling out other potential differentials. Horses with EDM usually have a normal cerebrospinal fluid (CSF) nucleated cell count (NCC, <5 cells/uL) and normal cytology (very low number of mononuclear cells, without neutrophils, eosinophils, or other abnormal cells). CSF total protein can be normal (<90 mg/dL) or mildly increased; these mild increases are typically in the 90–120 mg/dL range. Vitamin E deficiency has been associated with EDM, and vitamin E concentration should be assessed in suspect cases.[6] Low vitamin E concentration (less than 2 ppm or 200 ug/dL) is supportive of EDM diagnosis, particularly when other causes of neurologic disease have been excluded. However, adequate vitamin E status does not preclude the diagnosis of EDM. Current evidence suggests that abnormally high concentrations of pNF-H in serum and CSF are suggestive of EDM if diseases such as EPM have been excluded.[7] However, pNF-H testing has a low sensitivity for EDM diagnosis, and many confirmed cases have normal pNF-H concentrations in blood, spinal fluid, or both. Normal survey cervical radiographs and/or negative cervical myelography make CVSM highly unlikely and increase clinical suspicion for EDM, assuming infectious causes of disease are also excluded. EDM diagnosis currently requires postmortem examination, but the characteristic degenerative changes can be missed if the pathologist is inexperienced, or the brainstem is not carefully evaluated.

7. Infectious Diseases: EPM (and Lyme Disease)

EPM is usually caused by the protozoan parasite *Sarcocystis neurona*, although infection with other protozoa such as *Neospora hughesi* has also been reported. General proprioceptive ataxia is one of the most common clinical signs of disease and is often asymmetric, with a mixture of upper and lower motor neuron paresis. Due to lower motor neuron involvement, muscle atrophy, often asymmetric, is also common. EPM is a great mimicker and can cause clinical signs that are indistinguishable from CVSM, eNAD/EDM, and orthopedic problems. Therefore, it should always remain in the back of the practitioner's mind for unusual lameness cases that cannot be adequately localized or diagnosed.

However, antemortem diagnosis of EPM remains challenging. Many normal horses are exposed to parasites and develop antibodies in the absence of clinical disease. Therefore, performing serology, regardless of test chosen, will only reveal whether the horse has been exposed to *S. neurona* or *N. hughesi* and does not indicate the current disease status of the central nervous system. To achieve the best possible diagnosis in the live horse, three criteria must be met: presence of neurologic disease; exclusion of other likely causes, such as cervical vertebral stenotic myelopathy; and confirmation of specific antibodies in the CSF, serum, or both.[8] Ideally, evidence of intrathecal antibody production is obtained through serum:CSF titer ratio or specific antibody index. Treatment trials with antiprotozoal medications are frequently used in the field as diagnostic aids. If clinical signs are relatively acute and diagnosis is accurate, the author expects most horses to begin to show clinical improvement within 2 weeks of treatment initiation and continue to improve or stay stable while on treatment and usually for months after treatment discontinuation. Worsening signs while receiving treatment or immediately after discontinuation often suggests misdiagnosis. If clinical signs are very chronic, failure to respond to treatment could represent either misdiagnosis or permanent neurologic damage from infection.

Horses are frequently infected with *Borrelia burgdorferi*, the gram-negative spirochete that causes Lyme disease. One of the major problems in diagnosing Lyme disease is that many horses have been exposed to *B. burgdorferi* but do not show clinical signs. Exposure occurs when the horse is bitten by an *Ixodes* spp. tick carrying *B. burgdorferi*, and the organism infects the horse. Some horses likely eliminate the infection on their own, some horses likely become

chronically infected but asymptomatic, and some horses are chronically infected and symptomatic. Documented syndromes attributed to *B. burgdorferi* infection in horses include neuroborreliosis, uveitis, cutaneous pseudolymphoma, and nuchal bursitis.[9,10] Many practitioners attribute other clinical signs, such as sporadic lameness, arthritis, muscle soreness, and infection. However, these syndromes are not as well-documented.

Diagnosis of Lyme disease is complicated. Positive serology is not sufficient for definitive diagnosis, even in the presence of compatible clinical signs. Positive serology in the absence of compelling clinical signs has very poor predictive value for disease. Suggestive clinical signs depend on the organ system involved. Neurologic sequelae to infection might include behavioral changes (especially hyperesthesia or hyper-reactivity), gait abnormalities, cranial nerve deficits, neck stiffness, muscle atrophy, and muscle tremors or fasciculations. Additional systemic signs might occur concurrently, including weight loss, uveitis, cardiac arrhythmias, and dermal masses at the sites of tick bites (pseudolymphoma).

Antemortem diagnosis of Lyme disease is best achieved by fulfilling several criteria, which include potential *B. burgdorferi* exposure (via residence in or travel to an endemic area); presence of clinical signs documented to occur after infection; diagnostic testing to rule out other potential diseases; documentation of abnormal CSF, ocular fluids, or dermal histopathology; and identification of the organism or immunologic evidence of infection.[11] Cytological analysis of CSF is strongly recommended for horses with suspected neuroborreliosis, as results are often abnormal with neutrophilic or lymphocytic pleocytosis and increased total protein concentration. Although identification of the organism via culture, immunohistochemistry, or PCR in tissue, CSF, ocular, or synovial samples from the patient provides strong evidence for active infection, positive results are uncommon in horses with confirmed neuroborreliosis.

8. Other Causes

Some of the most confusing cases are horses with neuropathies, neuromuscular disease, or a combination of neurologic and orthopedic problems. Additional diagnostic testing geared toward these types of diseases might include pre- and post-exercise muscle enzyme activities, muscle or nerve biopsies, and electrodiagnostic testing such as electromyography. Pattern recognition is important in differentiating certain neuropathies from orthopedic disease; interested individuals should visit Dr. Alexander de Lahunta's excellent collection of videos on the Cornell web site: http://neurovideos.vet.cornell.edu/ Equine videos can be selected using "advanced search," and those from chapter 5 show examples of horses with diffuse or focal neuromuscular (lower motor neuron) disease, which can mimic orthopedic problems.

9. Conclusion

One of the most important points to remember when dealing with a vague, complicated lameness or poor performance case is that these cases are, by definition, complicated! The answer is unlikely to be identified immediately, which can lead to owner frustration. Frank discussion about the challenges that might lie ahead and thoughtful construction of a logical diagnostic plan will increase the chances of owner satisfaction and successful diagnosis.

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.

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Equine Glandular Gastric Disease: Approach to Diagnosis and Management

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1. Introduction

Equine glandular gastric disease (EGGD) is a common disorder of horses, particularly horses in training or competition. However, gaps in knowledge remain regarding the pathophysiology of disease, diagnosis, and treatment. This session will provide a review of EGGD, focusing on diagnosis and approach to treatment.

2. Epidemiology

The prevalence of EGGD is variable and may depend upon several factors, including breed and performance discipline. EGGD prevalence appears to be higher among sport horses and Warmblood show jumpers,[1–3] compared to other breeds and disciplines,[4–10] although variability exists between studies and direct comparisons among breeds are uncommon.[2] One study in sport horses in the United Kingdom found no association between signalment and EGGD.[3] However, another study in horses presenting to a hospital demonstrated that Warmbloods were at increased risk relative to other breeds.[11] In both showjumping Warmbloods and racing Thoroughbreds, 5 to 7 exercise days per week was associated with increased risk for EGGD.[1,10] Lower level of performance (national versus international) was found to be a risk factor in Warmblood horses,[1] and racing below expectations was an increased risk for EGGD in Thoroughbred horses,[10] suggesting EGGD may be associated with decreased performance. Other factors that have been associated with EGGD include fewer years playing polo (polo horses),[12] trainer (racing Thoroughbreds),[10] and currently showing (showjumping Warmbloods).[1]

3. EGGD Scoring Systems

Clinical signs of EGGD can be variable and vague, so diagnosis based on clinical signs is unreliable. In one study, common clinical signs included poor performance, change in behavior, or girthing pain.[13] Relatively non-invasive tests, such as blood sucrose and salivary response to administration of adrenocorticotropin, have been documented to be unreliable in diagnosis.[14,15] Endoscopic evaluation of the stomach, including the pylorus, is currently the only method to achieve a definitive diagnosis. However, interpreting endoscopic lesions can be challenging, as there is no validated scoring system for EGGD. The most commonly used scoring system in the literature was reported by the Equine Gastric Ulcer Syndrome (EGUS) Council in 1999 and later modified by Sykes.[16,17] In general, there does not appear to be a strong relationship between endoscopic findings, the severity of clinical signs, and gross and histologic appearance.[18–20] When evaluating differences across observers in scoring systems, the system based upon the original EGUS scale has been shown to have acceptable interobserver agreements, which may be due to practitioners' familiarity with this system.[21,22] Other systems, including visual analogue and descriptive terminology scoring systems, did not

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demonstrate good interobserver agreement across EGGD phenotypes.[22,23] This may lead to variability in interpretation and complicate the monitoring of treatment success. Therefore, using both an ordinal scoring system and descriptive terminology may be the best approach to ensuring an accurate diagnosis. Saving digital gastroscopic images as part of the medical record should also be considered. For a complete examination of the equine glandular gastric mucosa, fasting duration may need to be 16 hours or more.[24]

4. Pathophysiology

The pathophysiology of EGGD appears to be multifactorial. Although acid exposure may play a role in lesion development or persistence, this is unlikely the primary mechanism for the development of EGGD due to the protective mechanisms of the glandular mucosa and the poorer response of EGGD to proton-pump inhibitor (PPI) therapy.[25] Other potential factors that have been proposed to contribute to the development of EGGD include decreased protective factors (prostaglandins), nonsteroidal anti-inflammatory drug (NSAID) administration, decreased gastric blood supply, stress, bacteria, and inflammatory cell infiltrate.

A decrease in prostaglandins has been speculated to play a role in the formation of EGGD.[17] Misoprostol, a prostaglandin analogue, effectively treats disease, suggesting that altered prostaglandins may play a role in disease development.[13] However, no studies to date evaluate mucosal prostaglandin levels in naturally occurring disease. Nonsteroidal anti-inflammatory drugs have been speculated to play a role in the induction of EGGD. Experimentally, high doses of NSAIDs have led to the development of EGGD but with no evidence of decreased prostaglandin levels.[26–28] However, administration of a synthetic prostaglandin analogue was demonstrated to prevent NSAID-induced glandular ulceration, suggesting that prostaglandins are protective.[27] Field studies to date have not identified NSAID administration as a risk factor for EGGD.[6,12] The role of prostaglandins and NSAIDs in developing EGGD remains unclear.

Decreased gastric blood supply has also been suggested to play a role in development, particularly with the recognition of exercise as a risk factor. Exercise has been demonstrated to decrease splanchnic blood flow, which could lead to decreased gastric perfusion.[29] In people, exercise has been documented to lead to decreased gastric perfusion.[30,31]

Stress has been linked to gastric disease in people, possibly through impaired mucosal healing and defense.[32] The adrenocorticotropic hormone (ACTH) stimulation test demonstrated that horses with more severe EGGD had an exacerbated response to ACTH,[33] supporting a potential association between stress responses and EGGD in horses.

In other species, including people, *Helicobacter pylori* plays a central role in the development and persistence of peptic ulcers.[34] However, to date, there is no evidence that *Helicobacter* contributes to equine gastric ulcer syndrome or EGGD in horses.[35–38] In people with non-*Helicobacter*, non-NSAID-associated gastritis, differences in the gastric microbiome have been reported with disease.[39] In horses, modest differences have been found in association with EGGD, but specific taxa responsible for these differences have not been identified.[38] These associated alterations in the microbiome with EGGD suggest a bacterial component may contribute to the formation or persistence of lesions.

Inflammatory infiltrate has been identified histologically on glandular mucosal biopsies but does not appear to consistently relate to endoscopic findings.[18–20,35,40] The clinical relevance of histologic gastritis remains to be determined.

Evidence to date suggests that several pathophysiological mechanisms may play a role in the formation of EGGD. Potential contributing factors should be carefully assessed at the individual horse level and may help inform recommendations for management or treatment.

5. Treatment

Controlling risk factors, including days per week of exercise, competing, and training, may be useful in preventing EGGD.[2,8]

In addition to management recommendations that avoid or remove risk factors, treatment targeted towards acid suppression, coating agents, and synthetic prostaglandins can be prescribed. Omeprazole is a proton pump inhibitor that has long been used to treat equine gastric ulcer disease. Omeprazole at 4 mg/kg PO q 24 h has been shown to maintain gastric pH >4.0 for approximately 12 hours after administration. Administration in the morning prior to the first hay meal and before exercise is recommended to maximize efficiency.[41,42] Efficacy of compounded products is variable and should be avoided if possible.[41] Caution should be used if considering using omeprazole in a horse concurrently receiving NSAIDs, as adverse intestinal events can occur.[43]

Sucralfate, an aluminum coating agent, binds to areas of disrupted mucosa to provide a physical barrier.[44] The dose for sucralfate may vary, although 12 mg/kg PO 2-4 times daily has been recommended for treating EGGD.[45] It has typically been used in conjunction with omeprazole rather than as a sole agent because it does not decrease gastric acidity. Since sucralfate is a binding agent, it may interfere with the bioavailability of other drugs and should be administered 1-2 hours after other medications.

Misoprostol, a prostaglandin analog, promotes mucosal healing and gastric acid suppression. The reported dose is 5 ug/kg PO q 12 h.[13,46] Recent studies have suggested misoprostol may improve response rates compared to a combination of omeprazole and sucralfate.[13] However, this is not a consistent finding, with one retrospective study demonstrating no

difference across groups.[47] Overall, healing rates of EGGD remain poor,[13,17,47] with a prolonged duration of treatment often necessary (>6–8 weeks). Follow-up gastroscopic examinations should be performed to evaluate the response and determine the duration of treatment, as the prediction of healing is challenging.[47] Lesion severity but not phenotype has been shown to predict improvement with treatment.[47]

In cases refractory to management adjustments and medical therapies, additional diagnostics may be pursued, including biopsy for histopathologic examination and/or culture. However, limited information remains on how these diagnostic findings may impact treatment decisions. Based on anecdotal evidence, glucocorticoids have been suggested as a last-line treatment option for refractory cases with histologic evidence of gastritis. The use of antimicrobials for the treatment of EGGD is not recommended at this time as there has been no evidence that this improves healing rates.[48] This practice also increases horses' risk of complications, including antimicrobial-associated diarrhea.

6. Conclusion

Equine glandular gastric disease remains a challenging disorder to treat and monitor. Current management and treatment recommendations for EGGD still require prolonged treatment time and do not consistently lead to the healing of lesions. Identifying underlying pathophysiologic mechanisms contributing to disease could help identify more effective, targeted therapies.

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Approach to the Diagnosis of Chronic Diarrhea in Horses

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1. Introduction

Chronic diarrhea in horses has been described as the continuous or intermittent passage of soft or watery feces for a prolonged period.[1] There are, however, some inconsistencies with this description. Continuous passage of diarrhea has never been reported and is unlikely to occur. Some authors categorize diarrhea as chronic if present for 7 to 14 days, although the period from the diarrhea onset to the point where it becomes chronic has not been agreed upon.[2,3]

In humans, chronic diarrhea is defined as a decrease in stool consistency for more than 4 weeks, and most of those causes are due to noninfectious causes, compared to acute diarrhea.[4] They are divided into three basic categories: watery, fatty, and inflammatory. In some cases, these categories can overlap. Further, these three categories are divided into subcategories according to etiopathogenesis. Watery diarrhea can be divided into secretory, osmotic, and functional; fatty includes malabsorption and maldigestion function; while inflammatory comprises several causal forms of chronic diarrhea such as inflammatory bowel disease, infectious diseases (bacterial, viral, parasitic), and neoplastic and radiation colitis.[5]

Chronic diarrhea is often challenging for human clinicians and equine practitioners.

2. Clinical History

A detailed, chronological history recording the onset, duration, pattern, aggravating factors, and progression of the clinical signs should be recorded. Age, sex, and breed have not been identified as risk factors, although one report suggested Standardbred horses are more commonly affected.[6] Regarding duration, diarrhea can last for weeks to months, and the consistency can vary from soft to watery.

Weight loss is a common clinical sign, although signs may vary according to the inciting cause. Categorization of chronic diarrhea with the inciting cause is variable and mostly unknown. For example, a group of horses diagnosed with inflammatory bowel disease were classified as either granulomatous enteritis, multisystemic eosinophilic epitheliotropic disease, lymphocytic-plasmacytic enterocolitis, or idiopathic eosinophilic enterocolitis. For each category, chronic diarrhea was recorded in 30% for granulomatous enteritis, 65% for multisystemic eosinophilic epitheliotropic disease, 35% for lymphocytic-plasmacytic enterocolitis, and 0% for idiopathic eosinophilic enterocolitis.[7,8] Colic or recurrent colic is an uncommon clinical sign.

An episode of acute diarrhea may become chronic, and chronic diarrhea may be interspersed with periods of normal feces. Intermittent periods of inappetence and dullness are also reported.

3. Physical Examination

Physical examination is frequently normal, and vital parameters are invariably within normal ranges. When abnormalities are identified, increased gastrointestinal

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sounds may be auscultated, and subcutaneous edema may be present in cases with protein-losing enteropathy. Rectal examination should be performed in all cases, searching for masses, enlarged lymph nodes, or thickening or roughness of the intestinal wall, for example, although abnormal findings are uncommon.[3]

4. Ancillary Testing

Clinical Pathology

Complete blood count and serum biochemistry findings are likely affected by the cause of the chronic diarrhea and the stage of the disease when the samples are collected. In some cases, anemia may be present due to blood loss or nutritional deficiencies, such as in granulomatous enteritis or other inflammatory disorders.

A consistent clinicopathologic finding of horses with chronic diarrhea is the presence of hypoproteinemia, primarily characterized by low albumin concentration. The globulin concentrations are variable and may be reduced, normal, or elevated. Serum electrolyte concentrations are usually normal, but abnormalities may include hyponatremia, hypokalemia, hypochloremia, and hypocalcemia. Acid-base abnormalities may be observed in more severe cases, mostly due to electrolyte derangements or increased lactate concentrations. Acute phase protein inflammatory makers, including fibrinogen and serum amyloid A protein concentrations, can be normal or mildly elevated.[3]

Hepatic diseases such as inflammatory disease, fibrosis, or fat infiltration have been associated with chronic diarrhea. In these cases, hepatic markers of liver disease (γ-glutamyl transferase, aspartate aminotransferase, glutamate dehydrogenase) and liver function (serum bile acids) may be indicated.[3]

Although uncommon, prerenal azotemia may occur in dehydrated horses.

Abdominocentesis

Abdominocentesis should be routinely performed in horses investigated for chronic diarrhea. Peritoneal fluid should be analyzed for total protein concentration and cytological abnormalities. The presence of inflammatory cells such as neutrophils or eosinophils may help establish a cause. Abdominal neoplasms are uncommon; however, occasionally, exfoliated neoplastic cells may be detected. An example is finding abnormal lymphocytes on peritoneal fluid cytology from cases with abdominal lymphosarcoma.

Fecal Examination and Microbiological Investigations

Visual inspection of the feces may provide clues regarding digestion or transit time abnormalities of the gastrointestinal tract. Dental or masticatory disorders, colonic microbial dysbiosis, or abnormal colonic transit times may result in increased fecal water content or poorly digested feed particles.

Larval cyathostomiasis is among the most common causes of chronic diarrhea.[9] Cyathostomins are acquired while pasturing. After ingestion, the larvae invade the intestinal mucosa and undergo arrested development, lasting for weeks to months within the large colon and cecal mucosa and submucosa. Diarrhea occurs with further larval stage development in the wall of the intestine and release into the lumen, initiating an inflammatory protein-losing enteropathy and alterations in intestinal motility.[10]

Adult cyathostomins, fourth-stage larvae, or both may be observed in the feces, but microscopic examination of wet fecal smears may be more helpful in identifying the larvae. The absence of larvae does not rule out cyathostomins as a cause of clinical disease, but antemortem identification of cyathostomin larvae in the feces supports diagnosing these cases. Fecal flotation for parasites should be performed in any horse with hypoalbuminemia, weight loss, and/or chronic diarrhea. Nevertheless, fecal egg count tests do not correlate with the intra-host burden of cyathostomins. A commercial enzyme-linked immunosorbent assay (www.austindavis.co.uk) based on specific antibody level measured, which also considers the grazing management and historic parasitological (fecal egg count) parameters of the individual or group being tested, has been available in the United Kingdom since 2019.[11] The "serum score" given to a particular sample was developed to aid in selecting thresholds for anthelmintic treatment.

The detection of sand or gravel in the feces can be easily performed with a simple sedimentation test and is highly suggestive if significant quantities are present in the manure. Hart and co-workers reported the presence of sand or gravel in the feces during transrectal examination in 10/27 (24%) horses, and fecal sedimentation for sand was positive in 12/25 (48%) horses.[12] Another study in Finland reported a sensitivity, specificity, positive predictive value, and negative predictive value of 83%, 71%, 90%, and 56%, respectively, for the fecal glove sedimentation test when it was compared with radiography.[a] Of note, 29% of horses in the study had received treatment prior to the fecal sample collection, which may have affected the sensitivity of the test. In horses, the detection of a single causative agent in each case is often negative; nevertheless, the submission of fecal samples for testing of common enteropathogens is recommended. Fecal culture and, more recently, molecular test panels are used to screen for enteropathogens associated with horse diarrhea. Positive results should be carefully interpreted and used to build large databases for further analyses. For example, *Salmonella* spp. infection is currently associated with chronic diarrhea in horses; however, evidence of causation remains to be proven.

There are reports of intestinal trichomoniasis and equine protozoal diarrhea as etiological agents for chronic diarrhea. *Trichomonas faecalis* has been discovered in large numbers in the feces of horses with chronic diarrhea, but causality has not been established.[13]

Campylobacter fetus subspecies *fetus* was also isolated from a 2-year-old Quarter Horse with chronic diarrhea.[14]

Lawsonia intracellularis is a well-characterized cause of chronic diarrhea in young horses, and fecal polymerase chain reaction is the current method of choice for a confirmatory diagnosis. Serological testing is also commercially available, and the immunoperoxidase monolayer assay confirms the presence of circulating antibodies to *L. intracellularis* and is indicative of active or recent infection. The sensitivity of serology and polymerase chain reaction are 90% to 91% and 39% to 67%, respectively, with a specificity of 100% for both techniques reported in pigs experimentally challenged with *L. intracellularis*.[15]

5. Diagnostic Imaging

Ultrasonography

Transabdominal ultrasound is one of the most widely used imaging modalities in the field and in referral centers to assess internal organs. Ultrasound evaluation is also very useful for choosing a site for peritoneal fluid sampling, assessing parenchymal organ appearance, detecting abnormal structures (masses, abscesses), and measuring intestinal wall distension, motility, and thickness.

Horses with infiltrative bowel disorders, including lymphoma and various forms of inflammatory or infiltrative bowel disease (IBD), can present with increased small intestinal wall thickness.

Circumscribed increased colonic wall thickness at the right 12th intercostal space has been reported in some cases of right dorsal colitis.

Ultrasound can be useful in diagnosing sand impactions, with a reported sensitivity and specificity of 87.5% when compared with radiography.[16]

Abdominal Radiology

Abdominal radiographs have limited diagnostic value due to the size and thickness of the average adult horse's abdomen.

Chronic diarrhea is a common clinical sign in a horse diagnosed with sand enteropathy, and radiography is considered the reference standard for diagnosing sand accumulation.[17] An owner-reported survey in Finland described diarrhea and "feces with water" in 53% of horses confirmed with sand impaction.[18] A grading system has been used to categorize sand accumulations based on height and length of the accumulation visible in the radiographs. However, sand accumulation in the intestine can be found in horses with no apparent clinical significance, and therefore the clinical applicability of the grading system is questionable.[19]

6. Endoscopic Examination and Biopsy

With the advent of endoscopic equipment designed for horses, adequate assessment of the pylorus and proximal segment of the duodenum can be performed. In suspected IBD cases, duodenal biopsies should be taken to assess for infiltration of the intestinal mucosa by different cell types. Gastric ulcers have been observed in horses with chronic diarrhea, but the significance of these lesions in the pathogenesis of chronic diarrhea is unknown.[20]

Rectal mucosal biopsies are commonly recommended for investigating cases of chronic diarrhea; however, these findings may not represent the entire gastrointestinal tract since only a small section of the caudal rectal mucosa is examined. Pathological findings in such samples are likely clinically relevant, and a diagnosis is reached. For example, the presence of neoplastic cells confirms gastrointestinal neoplasia, and neutrophils within the surface epithelium or crypts on biopsy histopathology are always considered abnormal.[21]

7. Intestinal Absorption Tests

Absorption tests are used to assess the absorptive capacity of the small intestine by measuring the efficiency of sugar absorption from the intestinal lumen.

Oral D-xylose glucose absorption tests are indicated in chronic diarrhea and/or weight loss with hypoproteinemia where an overt cause is not established. The oral D-xylose glucose absorption test is a simple test to perform stall side, although factors such as dietary history, gastric emptying rate, intestinal transit, age, hormonal effects, and the metabolic state of the horse should be considered when interpreting the results. D-xylose absorption is not affected by hormonal or metabolic factors and therefore may be a better test modality. It can be affected, however, by other factors such as gastric emptying, intestinal motility, intraluminal bacterial overgrowth, and renal clearance.[22]

8. Abdominal Exploratory Laparotomy/Laparoscopy

These diagnostic evaluations are usually recommended as a last resource due to the expense and invasive nature of the procedures. The most common reason for exploratory surgery is to collect full-thickness intestinal biopsies of abnormal intestines, as in cases of suspected IBD or neoplastic infiltration. Further, to investigate suspected or confirmed cases with intra-abdominal masses, abscesses, and neoplasia for diagnostic and/or treatment purposes.

Exploratory laparoscopy is a minimally invasive technique highly desired for such cases. However, there are several limitations when laparoscopically exploring the abdomen, including potentially poor visualization of targeted organs/structures, limited access, and inability to collect adequate samples, particularly full-thickness intestinal biopsies.

Incisional healing has been a concern in horses that are systemically compromised (hypoproteinemia), but no definitive information supports such concern.

9. Conclusions

- Chronic diarrhea in horses may occur due to several gastrointestinal disorders.
- Horse owners often are compliant about environmental, tail, and hindlimb cleanliness.
- An etiological investigation may require a great deal of economical and time investment.
- Tests results are often negative, and therefore targeted therapy cannot be prescribed.

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.

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Treatment Approaches in Horses with Chronic Diarrhea

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Chronic diarrhea is a frustrating disease faced by equine practitioners. The difficulties in reaching a final diagnosis results in challenges when instituting appropriate therapy. Most cases of chronic diarrhea remain idiopathic, but specific and targeted therapy can be instituted in horses with a definitive diagnosis. In horses with no definitive diagnosis, therapies aiming to modulate the bacterial communities of the colon should be considered. Author's address: Department of Clinical Studies, Ontario Veterinary College, University of Guelph, Guelph, ON N1G 2W1, Canada; e-mail: dgomezni@uoguelph.ca. © 2023 AAEP.

1. Introduction

Equine chronic diarrhea is a frustrating disease encountered by practitioners due to the difficulties in reaching a final diagnosis, which prevents the implementation of appropriate therapy.[1–3] Chronic diarrhea appears to be an uncommon problem in horses. However, the prevalence of this disorder is currently unknown. Its prevalence can be difficult to determine because many owners may not seek veterinary advice unless the diarrhea is associated with other clinical signs such as weight loss, hematochezia, or colic. The lack of a clear definition of chronic diarrhea also compounds this problem. In humans, chronic diarrhea is defined as an individual with diarrhea of >4 weeks duration.[4] In dogs, chronic diarrhea can be defined as diarrhea of >3 weeks duration.[5] Several definitions have been proposed in horses, including diarrhea of duration >7 to 14 days[2] or diarrhea of >4 weeks duration.[3] A consistent definition of chronic diarrhea in horses is necessary to develop clinical trials to determine the efficacy of the proposed therapies for managing this disorder.

2. Causes of Chronic Diarrhea in Horses

Most cases of chronic diarrhea in horses are idiopathic. However, a broad range of conditions are associated with this disease, making it problematic to take a particularly prescriptive approach regarding the diagnostic and therapeutic practices veterinarians should implement. Chronic diarrhea can result from a myriad of disorders, including intestinal neoplasia, inflammation, malabsorption, maldigestion, or motility abnormalities. However, separating these conditions based on clinical findings alone can be challenging for practitioners. The causes of chronic diarrhea can be divided into two main categories: a chronic inflammatory condition in which histopathologic changes can be detected in tissue specimens, and colonic dysfunction associated with the abnormal fermentation of cellulose.[6] Chronic inflammatory conditions can be further subdivided into infectious and noninfectious categories. Infectious causes of chronic inflammation leading to chronic diarrhea include *Salmonella* spp.,[7] nontuberculosis mycobacteria (NTM),[8] *Rhodococcus equi*,[9]

NOTES

Lawsonia intracellularis,[10] *Strongylus vulgaris*,[11] larval cyathostomins,[12] and septic peritonitis.[2,6] Noninfectious inflammatory conditions associated with chronic diarrhea include alimentary lymphosarcoma,[13] inflammatory bowel disease (i.e., granulomatous, lymphocytic-plasmacytic, and eosinophilic enteritis),[14] nonsteroidal anti-inflammatory drug (NSAID) toxicity,[15] and sand enteropathy.[16] Colonic dysfunction is associated with alteration in the microbiota and, therefore, in the fermentation of cellulose.[17,18] Altered cellulose fermentation can lead to increased production of acetate, isobutyrate, and propionate, resulting in greater luminal water retention due to the resultant heightened osmolality.[17,18]

3. General Principles of Treatment of Chronic Diarrhea in Horses

When the cause of chronic diarrhea can be determined, the treatment approach depends on this primary cause. In many cases, a primary cause cannot be identified, so a targeted treatment cannot be instituted. Practitioners should consider a general and supportive therapeutic approach for managing horses where the specific causative factor for chronic diarrhea cannot be identified.

Diet Modification

In horses with colonic dysfunction or noninflammatory causes of chronic diarrhea, diet modification can assist in recovery from the disease. Complete pelleted feed diets can modify the fermentative capacity of the colonic bacteria and modulate the production of short-chain fatty acids (SCFAs).[6] These changes can lead to a regulation of the luminal osmolarity and water absorption and secretion.

Fluid and Electrolyte Therapy

Dehydration is a rare problem in horses with chronic diarrhea. These animals appear to compensate for the gastrointestinal loss of water and electrolytes by increasing water, food, and salt intake and decreasing urine output.[19] However, ensuring the horse always has access to fresh and clean water is important. The maintenance requirement of water for a healthy, nonworking horse is approximately 30 L/day (60 mL/kg/day). Horses with chronic diarrhea should meet those requirements and the estimated water loss through feces.

Fresh Frozen Plasma Transfusion

Hypoalbuminemia is commonly reported in horses with chronic diarrhea, especially those with granulomatous enteritis associated with NTM. Historically, fresh frozen plasma (FFP) transfusion has been recommended for horses with chronic diarrhea and a total plasma protein concentration <50 g/L or plasma albumin concentration <15 g/L.[1,20] Proponents of this therapy argue that FFP transfusions in horses with chronic diarrhea restore or improve colloid osmotic pressure edema.[1,20] However, administering FFP to hypoproteinemic horses with acute diarrhea fails to increase total plasma protein concentrations.[21,22] These findings are not unexpected after considering the volume of FFP usually administered (5 L) and the fate of the albumin present in the FFP after transfusion. A 500-kg horse with a total plasma protein of 35 g/L and albumin concentration of 15 g/L with a blood volume of 50 L [blood volume of 100 mL/kg of body weight $\times$ 500 kg = 50 L] would have an intravascular content of albumin of 750 g. Administration of 5 L of commercial FFP with a total plasma protein of 65 g/L and an albumin content of 36 g/L would contribute 180 g of albumin.[22] Assuming the transfused albumin in FFP remains in the intravascular space and the blood volume increases by 5 L, the final albumin concentration will change from 15 g/L to 17 g/L.[22] However, in disease states, the transcapillary escape rate (exchange rate between the intra- and extravascular compartments) is increased, which results in the rapid movement of albumin into the extravascular space. Approximately 10% of the transfused albumin escapes from the intravascular space within 120 minutes, and 75% escapes into the extravascular space within 48 hours.[22] Although the administration of FFP to diarrheic horses appears to provide few benefits with respect to protein concentration, clinical studies are needed to confirm any clinical advantages of administering FFP to horses with chronic diarrhea.

Antimicrobial Drugs

Oral or parenteral antimicrobial therapy is generally not recommended in cases of chronic diarrhea because of its potential to negatively impact the gastrointestinal microbiota. Antimicrobial drugs commonly used in equine practice alter the microbial communities within the equine gastrointestinal tract, which can result in a loss of colonization resistance and changes in bacterial metabolic function, promoting gastrointestinal inflammation and facilitating pathogen proliferation.[23] Therefore, the advantages and disadvantages of antimicrobial therapy must be weighed prior to their use in cases of chronic diarrhea.

Treatment with antimicrobial drugs in cases of chronic diarrhea should be limited to those horses with proven bacterial etiology as the cause of diarrhea, such as foals with *L. intracellularis* or *R. equi*. The standard treatment recommendation for foals infected with *L. intracellularis* is tetracyclines (oxytetracycline 6.6 mg/kg intravenously every 12 hours; doxycycline 10 mg/kg orally every 12 hours; minocycline 4 mg/kg orally every 12 hours), chloramphenicol (44–50 mg/kg orally every 8–12 hours), or macrolides (azithromycin 10 mg/kg orally every 24 hours; clarithromycin 7.5 mg/kg orally every 12 hours) with or without rifampin (5 mg/kg orally every 12 hours). *R. equi* infection can be treated with macrolides alone or in combination with rifampin. The use of rifampin in combination with macrolides is currently under scrutiny as it has been reported that concurrent administration resulted in a 68% decrease in the peak serum concentration of clarithromycin in humans

with mycobacterium avium complex infection.[24] Relating the macrolide serum concentrations to minimum inhibitory concentration or treatment response is problematic. Clarithromycin and azithromycin have excellent tissue penetration and can reach a high concentration in lung tissue and epithelial lining fluid. Clarithromycin can concentrate in these tissues from 2 to 30-fold and azithromycin from 10 to 100 times when compared to plasma concentrations.[25] Furthermore, clarithromycin and azithromycin can reach concentrations within macrophages up to 800 times higher than plasma concentrations.[25] A small randomized clinical trial involving foals with *R. equi* pneumonia treated with azithromycin alone or combined with rifampin found that the clinical outcome was similar for both groups.[26] Therefore, it is likely that despite low serum concentrations of macrolides when used concurrently with rifampin, the concentrations at the site of infection are still within the therapeutic levels.

In a recent report involving 9 horses with chronic diarrhea due to granulomatous enteritis associated with NTM, the use of antimicrobial drugs such as trimethoprim-sulfadiazine, doxycycline, oxytetracycline, clarithromycin and rifampin, enrofloxacin, or metronidazole failed to ameliorate or resolve the clinical signs.[8] These results suggest that common antimicrobial therapies are unrewarding in cases of alimentary mycobacteriosis. Chronic diarrhea is an uncommon clinical manifestation of *Salmonella* spp., and even when this bacterium is isolated from the feces of affected horses, an underlying cause of diarrhea should be investigated.[1,6] Some authors have indicated that antimicrobial therapy against *Salmonella* spp. fails to alter the course of the disease.[27] In addition, administering antimicrobial drugs to hospitalized horses in a critical care unit has been noted to increase the shedding of *Salmonella* spp.[28] Therefore, the use of antimicrobial drugs in horses with chronic diarrhea positive for *Salmonella* spp. should be carefully considered. The use of metronidazole, bacitracin, and sulfonamides have been suggested for the treatment of chronic diarrhea.[14,29–31] However, there is no evidence of any beneficial effect of utilizing these drugs for managing horses with chronic diarrhea.

Anthelmintics

Anthelmintics are recommended in cases where chronic intestinal parasitism (*Strongylus vulgaris*, *Strongylus edentatus*, or larval cyathostomins) is suspected to be the cause of chronic diarrhea. In cases of suspected chronic larval cyathostomins, moxidectin (a single 0.4 mg/kg orally, once) or larvicidal doses of fenbendazole (15 mg/kg orally every 24 hours for 5 days) are recommended. Treatment with either drug is efficacious in eliminating larvae of cyathostomins, but administration of fenbendazole is associated with severe tissue damage, which can be observed with histopathology.[32] The clinical relevance of these microscopic findings is yet to be determined. Concurrent administration of corticosteroids (prednisolone 1 mg/kg orally every 24 hours for 7 days) could aid in ameliorating the inflammatory effects of anthelmintics in horses infected with the larvae of cyathostomins.[6]

Motility Modifiers Agents and Antisecretory Drugs

Several opioid drugs that decrease intestinal motility have been suggested to treat chronic diarrhea to increase water retention. These drugs include codeine phosphate and loperamide. Administration of loperamide (0.1 mg/kg orally) to healthy ponies delays intestinal transit and decreases the volume of water present in the feces.[33] However, administering a single dose of codeine (0.6 mg/kg orally) to healthy horses does not alter fecal output.[34] Currently, only anecdotal evidence exists regarding the potential benefits of these drugs in managing chronic diarrhea in horses.

Intestinal Protectants and Adsorbents

Bismuth Subsalicylate

Administration of bismuth subsalicylate (BSS) is recommended for treating traveler's diarrhea in humans.[35] The beneficial effects of BSS observed in humans with diarrhea are associated with inhibiting fluid secretion, increasing water absorption, and decreasing intestinal motility.[35] In vitro studies also show that BSS has antimicrobial activity against enteric pathogens, including *Escherichia coli*, *Salmonella* spp., *Clostridiodes difficile*, and norovirus.[36] In horses, no information is available regarding the efficacy of BSS for managing horses with acute or chronic diarrhea. However, some authors indicate that administering 1 to 4 L of BSS every 12 to 24 hours in a 500-kg horse can be effective in cases of chronic diarrhea.[1,6]

Di-Tri-Octahedral Smectite

Di-tri-octahedral (DTO) smectite is commonly used to treat acute colitis in horses at some facilities. This treatment is based on results from a single nonblinded randomized clinical trial that found that the administration of DTO smectite clay orally every 24 hours for 3 days beginning 4 hours postoperatively decreased the prevalence of postoperative diarrhea from 41% (controls, $n = 30$) to 11% (cases, $n = 37$).[37] Administration of DTO smectite clay did not significantly affect any of the assessed clinical variables, total white blood cell count, or survival of the horses. The results of this study were limited by the small number of animals, inclusion of the use of a complex and subjective score to classify postoperative diarrhea, and inclusion of horses with different surgical lesions at different risks of developing postoperative diarrhea. The potential beneficial effects of DTO smectite in horses with acute or chronic diarrhea are yet to be determined.

Iodochlorhydroxyquin

Iodochlorhydroxyquin is a drug with antiviral, antifungal, antibacterial, and antiprotozoal activity inhibiting certain DNA replication enzymes. The main use of iodochlorhydroxyquin in human medicine is as a topical antifungal. Oral administration of iodochlorhydroxyquin

(10–20 mg/kg/day) effectively resolves chronic diarrhea in horses suspected of having colonic dysfunction associated with alteration in the microbiota and the metabolism of cellulose.[18] The exact mechanism of action leading to the resolution of chronic diarrhea is unknown. The broad activity against different classes of microorganisms present in the gastrointestinal tract suggests that modulation of the intestinal microbiota and its metabolic activity can partially explain this drug's efficacy in treating certain cases of chronic diarrhea associated with colonic dysfunction.

Corticosteroids

Corticosteroids have been recommended for treating horses with confirmed or suspected infiltrative inflammatory intestinal disease. In cases of lymphosarcoma and granulomatous colitis, treatment with corticosteroids is ineffective. Most horses with lymphocytic-plasmacytic infiltration are euthanized because of the poor response to the therapy. In some horses with this condition, the diarrhea resolves during corticosteroid treatment, but the weight loss persists, and the horses are ultimately euthanized.[14] Some horses with eosinophilic enteritis respond to a prolonged course of dexamethasone or prednisolone. However, the reported number of horses with successful corticosteroid responses is small.[14]

Prostaglandin E_1 Analogues

Therapy with prostaglandin E_1 analogues is indicated in horses with right dorsal colitis (RDC), an ulcerative disease of the colon associated with the administration of NSAIDs, particularly treatment with phenylbutazone. Although most horses with RDC have acute onset diarrhea, some can develop chronic diarrhea with marked hypoalbuminemia and ventral edema. The pathogenesis of RDC is not fully understood. However, it is widely accepted that the toxic effects of NSAID administration, including gastric ulceration, RDC, and acute kidney injury, are associated with a reduction in mucosal blood flow to the gastrointestinal tract resulting from the inhibition of prostaglandin E_2.[38] In addition, the administration of synthetic prostaglandin E_2 in ponies with experimentally induced phenylbutazone toxicosis prevented the development of lesions associated with NSAID toxicosis.[39] Therefore, providing exogenous prostaglandin E such as misoprostol (2–5 mcg/kg orally every 8–12 hours) appears to be a reasonable therapeutic approach in horses with RDC.

Psyllium

Accumulation of sand in the intestinal tract can damage the colonic mucosa resulting in inflammation and diarrhea (sand enteropathy), which usually becomes a chronic problem. Psyllium has historically been recommended for the treatment of sand enteropathy. Disagreement on psyllium's efficacy for treating sand enteropathies exists in the literature. While some studies demonstrate a lack of efficacy of psyllium on the evacuation of sand from the colon,[40] other studies show the administration of psyllium (0.5–1 g/kg once a day for 3–5 days) with mineral oil (2 L)[41] and psyllium with $MgSO_4$ (1 g/kg)[42] are effective in removing sand from the gastrointestinal tract. An additional beneficial effect of psyllium involves its fermentation by colonic bacteria, producing SCFAs. These metabolites reduce gastrointestinal inflammation, provide enterocyte nutrition, and promote a healthy balance of intestinal microbes.[43] These beneficial effects can facilitate recovery from ulcerative colitis. Therefore, the use of psyllium should be considered in horses with chronic diarrhea associated with inflammatory causes other than sand enteropathy.

4. Gastrointestinal Microbiota Modulators

Importance of the Gastrointestinal Microbiota

In the last decade, next-generation sequencing technology has allowed researchers to identify novel bacterial populations present in the gastrointestinal tract of horses that were previously unknown due to the limitations of culture-based methodologies. Microbiota studies highlight the importance of commensal bacteria in maintaining local and systemic health. The beneficial effects of these commensal bacteria include intestinal barrier enhancement, immune response modulation, bacterial establishment, and inhibition of pathogen colonization.[44] Commensal bacteria attached to the intestinal mucosa promote tight junction development, mucus secretion, and immunoglobulin A and antimicrobial peptide production.[44] Disruption of healthy microbial communities, otherwise known as "dysbiosis," is associated with gastrointestinal disorders in horses, including diarrhea.[45] Dysbiosis in horses is related to the loss of microbial diversity and key bacterial microorganisms and an overall shift from obligate anaerobic bacteria (e.g., Clostridia class, Ruminococcaceae and Lachospiraceae families, and *Treponema*) to facultative anaerobes and lactic-acid-producing bacteria (e.g., Enterobacteriaceae, *Lactobacillus*, and *Streptococcus*).[45,46] This bacterial shift has several negative effects on the physiologic and metabolic functions of the gastrointestinal tract. The proliferation of facultative anaerobes and lactic-acid-producing bacteria promotes inflammation and chemical damage of the colonic mucosa, facilitating the colonization of pathogenic bacteria and absorption of toxin and bacterial by-products.[47,48] Loss of key anaerobic bacteria results in an altered fermentative capacity of the colon with a reduction in the production of acetate, propionate, and butyrate.[49] These SCFAs contribute significantly to a horse's daily energy requirement. In addition, butyrate is a key metabolite necessary for maintaining the health of the gastrointestinal tract. Butyrate is a major energy source for enterocytes and contributes to maintaining an anaerobic environment within the colon.[50] These factors indicate that modulation and restoration of the gastrointestinal microbiota could facilitate recovery from diarrhea

regardless of the cause of the disease. Currently, two main approaches to restoring healthy microbiota have been proposed, including the administration of probiotics and fecal microbiota transplantation (FMT). However, studies assessing the potential benefit of these approaches are limited by the small number of enrolled horses and some flaws in the experimental design.

Probiotics

The use of probiotics is widespread, but scientific, peer-reviewed evidence demonstrating the beneficial effect of these products in horses is severely limited.[51] A small clinical trial including 14 horses with acute diarrhea showed that S*accharomyces boulardii* reduced the duration of diarrhea by 2 days but had no effect on survival, duration of hospitalization, or recurrence of diarrhea.[52] Limitations of this study included the small number of enrolled horses (7 control and 7 treated horses) and the confounding effect of the additional treatments administered to the horses. In a second randomized placebo-controlled clinical trial including 12 horses with acute diarrhea, S*accharomyces boulardii* failed to affect cessation of diarrhea or improve any other clinicopathological variables.[53] In foals, administration of probiotics (*Lactobacillus pentosus* WE7, *Lactobacillus* spp., and *Bifidobacterium* spp.) for prevention of diarrhea results in higher rates of diarrhea in treated compared to untreated animals.[54,55]

Fecal Microbiota Transplantation

Fecal microbiota transplantation (FMT) consists of administering fecal matter from a healthy donor into the intestinal tract of a recipient to modify the recipient's gastrointestinal microbiota. FMT is used to treat *C. difficile* infections in humans, with a 90% success rate of clearing the infectious disease.[56] Although the beneficial effects of FMT therapy are reported in people with *C. difficile* infection, FMT also shows promising benefits for individuals suffering from irritable bowel disease and ulcerative colitis.[56] In dogs, FMT also reduces the number of days of diarrhea and decreases the mortality rate in puppies suffering from parvoviral gastroenteritis.[57] In young pigs, FMT protects against diarrhea and prevents necrotizing enterocolitis in premature pigs.[58,59] Furthermore, FMT decreases water content in the feces of diarrheic calves regardless of the cause of diarrhea.[60] The recovery of diarrhea after FMT in humans and calves is associated with increased blood and fecal concentrations of SCFAs.[60] This is of interest in horses because cases of equine chronic diarrhea can exhibit altered fermentation and a resultant dysregulation in the production of SCFAs.[17,18] Thus, FMT represents a treatment approach that could potentially restore microbial production of SCFAs and normal fermentation capacity in horses.

A standard protocol for FMT in horses has not yet been developed, but preliminary guidelines extrapolated from human literature and expert opinions are available elsewhere.[61] Similarly, recommendations regarding screening tests for donors have been proposed to prevent disease transmission from donor to recipient.[61] However, these preliminary guidelines have not yet been validated in clinical settings. A few studies have investigated the effect of FMT in horses with acute diarrhea but not in cases of chronic diarrhea. FMT consisting of 2.5 pounds of fresh manure mixed in 4 L of water administered via nasogastric tube for 3 consecutive days improved the diarrhea scores in 5 horses admitted to a referral facility for treatment of acute or progressive diarrhea.[62] The improvement in diarrhea scores correlated with increased microbial diversity of the feces. However, these results need to be interpreted with caution as the study did not include a control group, and therefore it is not possible to determine whether the beneficial effects observed were due to treatment with FMT. The same research group performed a follow-up study, enrolling 12 horses with colitis treated with FMT and 12 control horses.[63] This study found FMT (utilizing the same protocol as the previous study) recipients had a greater overall reduction in diarrhea scores than control horses. The improvement in diarrhea scores was again associated with increased bacterial diversity. However, this study was limited by the management of the FMT and control groups in different facilities. Thus, the confounding effect of additional treatments administered to the horses by different facilities could not be differentiated within the clinical and microbiological analyses.

Despite the limitation of these studies in investigating the use of FMT as a treatment in horses with diarrhea, results from clinical trials in humans, lab animals, and food-producing animals indicate that FMT is a safe, well-tolerated, and efficacious approach to managing individuals with an inflammatory process of the gastrointestinal tract. These positive results in other species could be extrapolated to horses with chronic diarrhea due to infectious causes or colonic dysfunction. Randomized clinical trials with larger sample sizes are needed to establish the beneficial effect of FMT on equine diarrhea. Also, further research is warranted to identify the beneficial bacteria in the feces that promote recovery from diarrhea and establish the criteria for individuals to be considered recipients or donors.

5. Conclusions

Chronic diarrhea is a frustrating disease faced by equine practitioners. The difficulties in reaching a final diagnosis result in challenges when instituting appropriate therapy. The causes of chronic diarrhea can be divided into chronic inflammatory conditions and colonic dysfunction associated with abnormal fermentation of cellulose. Although most cases remain idiopathic, specific and targeted therapy can be instituted in horses with a definitive diagnosis. However, for horses with no definitive diagnosis, approaches aiming to modulate the microbial communities of the gastrointestinal tract (e.g., FMT) are reasonable.

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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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Responsible and Intentional Leadership for Early Career Veterinarians

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Retention of early career equine veterinarians is a staggering problem for the industry. This paper describes ways for established equine veterinarians to model healthy and inclusive behaviors and practices to better support the workstyles and growth of young colleagues and, subsequently, the future of the profession. Author's address: Rhinebeck Equine, 26 Losee Lane, Rhinebeck, NY 12572; e-mail: jtyma@rhinebeckequine.com. © 2023 AAEP.

1. Introduction

It is no secret that equine veterinary practice is in peril—a large and growing sector of equine veterinarians are retiring, and fewer veterinary students are choosing equine practice.[1] Of those new grads that are starting their career as an equine veterinarian, half are leaving the profession within 5 years.[2]

A call for change has been recognized both on an organizational level by the AAEP[2,3] and on a community level via the formation of networking groups and seminars to collectively brainstorm how to navigate the growing challenges of equine clinical practice.[4–6] These groups have acknowledged and dissected pain points, and paradigm shifts are in motion. Where there is substantial work remaining is on the individual level; each and every equine veterinarian can and should recognize their impact on up-and-coming equine practitioners and the future of the profession.

Whether official by title or not, equine veterinarians are all "leaders" among their colleagues, support staff, and in the eyes of equine-focused vet students, interns, and early career veterinarians. Equine veterinarians lead as business owners, practice managers, specialists, internship coordinators, formal and informal mentors, trailblazers, and innovative thinkers, amidst other roles. All leaders have an inherent responsibility to recognize their power and influence and how they might project their own experiences onto those watching and listening in both formal and informal mentorship scenarios.

As early career equine veterinarians continue to opt out of the profession at an alarming rate, the blame is often ascribed to the individuals leaving, suggesting that they are in some way fundamentally lacking in the qualities it takes to become an equine veterinarian. Can the perspective shift? Is there liability in those who may have had the opportunity to create a more supportive and inclusive work environment and, thus, a healthier practice culture to nurture early professional growth?

It is time that focus on change in the equine veterinary industry extends beyond the organizational and community level to the individual level—to ask that every equine veterinarian recognizes the behaviors they model and their influence on others who aspire to be the future of the profession. More thoughtful, more authentic, more intentional, and more responsible mentorship and leadership have the potential to

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transform the experience of an early career veterinarian. It is easy to become settled in routines of comfort or to continue operating in specific systems because it is "the way things have always been done." However, with the changing landscape of the equine veterinary profession, it is time that all established equine veterinarians consider some self-reflection, vulnerability, and stepping outside of their comfort zones to better accommodate the needs and growth of those trying to find their way in the profession. Points of consideration include respecting generational differences, leaning into and celebrating teamwork and letting go of egos, eliminating hustle culture and exhibiting healthy professional boundaries, and creating a psychologically safe workspace free of toxic positivity and perfectionist tendencies.

2. Solution and Discussion

While these thought exercises and solutions are most easily applied to those in explicit positions of leadership in equine group practice, the principles apply to all equine veterinarians in practice and community with other veterinarians: in daily, casual conversation, in interactions within meetings and at conferences, in commentary and discussion on listservs or Facebook groups, and representation on webinars or panels.

Honoring Generational Differences

It is imperative to acknowledge and honor generational differences in the workplace. Workflows and communication styles can be vastly different between generations, and often the path of least resistance for an established practitioner is to assume that a young colleague is not "working hard" or "communicating well" simply because they have a different set of experiences and learned approach in the workplace. Brené Brown states that "not getting clear with a colleague about expectations because it feels too hard, yet holding them accountable or blaming them for not delivering, is unkind."[7] Leaders should clearly communicate their expectations and misunderstandings in these contexts and initiate discourse on achieving good intergenerational communication and understanding.

In consideration of early career practitioners, both millennials and generation Z crave collaborative approaches, dedicated mentorship, regular feedback, and the opportunity to grow their lives outside of the workplace.[8] This does not mean they are any less dedicated to or passionate about the horse, their clients, or their responsibilities to their practice than their predecessors. However, it is often perceived and dismissed as such. Shortsightedness and judgment in this realm can be harmful to the inclusivity of the early career veterinarian in a mixed-generation practice and discourage participation and contribution. Intergenerational teams should acknowledge and respect the different paths of their peers, recognize and honor strengths in distinct approaches, maintain an open mind about how this diversity can fortify their group mission and work, and challenge their own beliefs to better support the growth of young colleagues.

Promoting Teamwork over Individualism and Ego

Being able to "do it all" as an individual has far too long been glamorized in equine veterinary medicine—whether that be in professional services, on-call coverage, practice management, or otherwise. This act of stubborn individualism and siloing is neither sustainable nor healthy for any equine practitioner. Moreover, a single-minded approach is unlikely to provide a diverse clientele with a spectrum of care that may be desired and indicated. This conduct, however, continues to be regarded positively, applauded, and even aspired to in many facets of equine veterinary medicine. These self-adulating and egocentric tendencies are toxic in a group setting; they fail to create a sense of team purpose. Clients learn that they are best served by a single individual versus any other team member. Any early career practitioner will struggle to ingratiate themselves in the eyes of clientele who have put their trust toward a pedestaled individual versus a collective vision shared by a team. Additionally, this standard often feels unachievable by an early career veterinarian, taking an already daunting task of the "real-world" learning curve and making it steeper.

The importance of teamwork over individual achievement in the workplace must be demonstrated and celebrated for early career veterinarians. This is best realized not by discussing how to be a good team player but by prioritizing a team-forward culture and inspiring the group toward a collective purpose. Examples of creating this type of workstyle include communicating with clarity and kindness, appropriately delegating tasks, being present to listen to a teammate's observations and contributions, asking for and accepting help with humility and curiosity, and providing and receiving feedback graciously. Simon Sinek says that "a team is not a group of people that work together. A team is a group of people that trust each other."[9] This starts with those seen as leaders; a good leader instills trust in their team, and that trust is reciprocal.

Eliminating Hustle Culture

Hustle culture is a paradigm that necessitates working long hours and sacrificing self-care to succeed.[10] It ascribes a hypothetical badge of honor to those who burn the candle at both ends, never say no in the act of people pleasing and personal ego fulfillment, and prioritize work and productivity above all else. This has long been celebrated as one of the key tenets of excellence in the equine veterinary industry. Work all night, show up to work the next day exhausted, head down, and power through, just because that is what the generations ahead have demonstrated and normalized.

Hustle culture was never healthy, but in its current state, it prohibits equine veterinarians from cultivating a life that's more than just work. Brené Brown

suggests "let(ting) go of exhaustion as a status symbol and productivity as self-worth." It is time to start listening.[11] When these behaviors are modeled for early career veterinarians, they learn that hustle culture is expected and required of them to excel and advance their careers. It is unlikely that younger generations who thrive on collaboration and work-life integration will find a workstyle of siloing and hustle culture appealing and may opt out of equine practice if they do not see a more sustainable path. Alternatively, they will feel immense pressure to step outside of their values to honor the example set forth by their leaders, which may lead to compassion fatigue and burnout. Modeling and normalizing behaviors more aligned with mentees' values and goals is accommodating and forward-thinking and will allow early career veterinarians to more naturally see themselves as the future of the profession.

Exhibiting Healthy Professional Boundaries

Unhealthy boundaries are an all-too-common theme across equine practitioners and have been recognized as contributing to industry-wide compassion fatigue and professional burnout. Establishing healthy professional boundaries is profoundly important for every equine veterinarian. Boundaries allow one to practice within a system that meets their needs and respects their limitations. On a bigger scale, normalizing this behavior amongst peers and young practitioners and teaching mentees how to preserve their resources is also crucial. Early career veterinarians, whether interns or young associates, are often in practice for the first time and have no sense of what their boundaries should be because it usually takes the experience of overt or accumulative boundary violations to understand personal limitations. Early career practitioners also commonly feel they are in a position where they may need to please their boss(es), colleagues, and potential clients to win their good favor and earn their trust. This combination can quickly lead to resentment and frustration that their boundaries are too porous. It can feel overwhelming and becomes even more challenging to backpedal and change.

Established practitioners should carefully evaluate their own professional boundaries to ensure that those they are modeling align with a sustainable lifestyle. By exemplifying healthy boundaries, leaders are showing that it is normal to have limits. Leaders should also recognize the impact of initiating open dialogue with early career veterinarians, encouraging them to think about how one establishes boundaries and that their words and actions in the workplace teach others how to treat them. Common pain points in equine practice relevant for young practitioners include work-related communication outside of business hours, being overly accessible to clients, working hours and on-call duties, and safety in the workplace. Early career practitioners would likely feel more comfortable upholding their boundaries and communicating their needs in practice if these conversations happened proactively versus reactively. They would experience less stress, shame, and overwhelm around their limitations, which often otherwise lead to departure from a specific practice or the equine profession.

Eliminating Perfectionism and Toxic Positivity

Eliminating perfectionistic and toxic positivity tendencies in the workplace can cultivate a more authentic and inclusive professional community. Brené Brown's work has shown that perfectionism is a suit of armor protecting one's vulnerabilities: "Perfectionism is the ultimate fear… People who are walking around as perfectionists… They are ultimately afraid that the world is going to see them for who they really are and they won't measure up."[12] As equine veterinarians, the professional stakes feel high; it is tough to think that anything less than perfect could ever be acceptable, even if this paradigm is founded on entirely unrealistic expectations.

When leaders embody perfectionism, impressionable early career veterinarians see this and experience an unspoken pressure to conform to unattainable standards with an internal dialogue that they will never measure up. Who will they feel comfortable approaching for advice or guidance when they need help or make a mistake if their peers and mentors have not normalized this behavior? How will they ever feel confident stepping out of their comfort zone to take risks in their own practice? Will they be too afraid of failure to try? Unsurprisingly, Adam Grant echoes that perfectionism is a counterproductive goal that will likely lead to burnout.[13] Experienced clinicians should instead model excellence, which is putting their best efforts toward performing a task to the best of one's abilities. With excellence versus perfection, there is room to be human, for growth, and for learning without fear of failure. Early career veterinarians must see their leaders be human to feel safe that they can be, too.

Toxic positivity, the outward manifestation of "good vibes only," can be similarly crippling in a professional setting. Those that exhibit toxic positivity dismiss a range of negative emotions in favor of more comfortable thoughts and inauthentic reassurance.[14] When space is not made for negative feelings, it is easy to create a narrative that those feelings are unfounded and invalid and that something is inherently wrong with the individual experiencing them versus the objectively challenging situation at hand. Eliminating toxic positivity from professional rhetoric would help normalize the experience of having negative emotions in difficult professional situations. An empathic leader sees these situations as an opportunity to start a conversation around managing and processing both the situation and resulting emotions, thus normalizing the process. For a profession filled with disease, death, emergencies, and often challenging clientele, it is myopic not to make space to talk about challenging circumstances and negative feelings with early career practitioners who may be experiencing the emotional burden of these experiences for the first time.

Creating Psychological Safety and Leaning into Hard Conversations

Quite likely, the most essential thing that established practitioners can do amidst their younger colleagues is to manifest a psychologically safe workplace. A psychologically safe space is one in which individuals feel collectively supported to take risks, contribute, question, and admit mistakes without fear of negative consequences.[15] In the context of equine practice, this requires courageously leaning into one's own professional vulnerabilities and sharing them, thus normalizing these types of conversations between colleagues and teammates. Brave and meaningful leadership looks like talking about mistakes and errors, sharing bad experiences and the subsequent hard-earned lessons, discussing struggles and strategies for working through them, creating space for reflection and growth, and encouraging early career practitioners to do the same. Further, showing examples of kind and curious self-reflection and inviting discussion with humility creates a safe haven for discourse and builds trust.

Being an equine veterinarian is not an easy job, and the challenges associated with practice, even in the best of scenarios, can be daunting. Every veterinarian's experiences of these challenges are their own, and one person's "hard" may look quite different from another person's "hard," but that does not make either less valid. By normalizing having conversations about what is hard, early career veterinarians can feel safer initiating dialogue when they are struggling and looking for support and guidance. This should allow for increased opportunities to brainstorm actionable strategies and a more collaborative system to work through challenges and empower early career practitioners to speak up and be a part of the solution. Good leaders will create space for early career practitioners to feel seen, heard, and supported, allowing them to see their future selves as equine practitioners not just by their hopes and dreams but also by their fears and struggles. The equine veterinary industry will be better off for it.

3. Conclusion

This is an invitation for every current equine veterinarian to recognize their impressionable audience of early career veterinarians, evaluate their practices and the messages they are putting forth about the profession, and consider a more sustainable, collective, and open-minded approach. According to Simon Sinek, "The great leaders are not the strongest, they are the ones who are honest about their weaknesses. The great leaders are not the smartest; they are the ones who admit how much they don't know. The great leaders can't do everything; they are the ones who look to others to help them."[16] It is time for every equine practitioner to see themselves as a leader for the future of the profession and to seize the opportunity and accept the responsibility ahead.

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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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Incorporating the Nine Dimensions of Wellness into an Equine Internship to Reduce Burnout

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It is difficult to attract students to the equine specialty, and once they are practicing, it is difficult to retain them in the profession. Several factors contribute to this, including difficulty with life-work integration, lower pay compared to other areas of veterinary practice (other species), and higher on-call hours. Thus, during the internship year, it is imperative to start building practitioners who are able to achieve the additional training while learning skills that will enhance their quality of life in the future, thus retaining well-qualified and happy practitioners. Authors' address: The Ohio State University, College of Veterinary Medicine, 601 Vernon L. Tharp Street, Columbus, OH 43210; e-mail: yardley.8@osu.edu. *Corresponding and presenting author. © 2023 AAEP.

1. Introduction

Veterinarian well-being is an important topic and has been an area of concern within the profession, driven by high burnout and double the national average rate for suicide completion.[1–3] The Merck Animal Health Wellbeing Study found that young female veterinarians were the most likely group to have serious psychological distress.[1] They cited long work hours, high client expectations, compassion fatigue, limited personal finances, and litigation.[1] Married individuals also had a higher burnout score and lower quality of life scores, which has not been reported in other studies.[1] A recent survey of residents at the University of California Davis School of Veterinary Medicine showed a high level of burnout as indicated by personal accomplishment and emotional exhaustion scores.[4] Medical residents that are burned out are at a greater risk for causing a medical error, being depressed, and having suicidal ideation.[2] The most common drivers for human physician burnout are excessive workload, work inefficiency, lack of work support, lack of work-home integration, loss of control and autonomy, and loss of meaning in work.[2]

It is important for equine hospitals with a training program to provide young veterinarians with the learning environment to support their well-being. In the authors' hospital, the internship program is modeled to promote or allow the 9 dimensions of wellness, which may improve the wellness of the trainees, staff, and faculty. One can reach an optimal level of wellness by understanding how to maintain and optimize each of the 9 dimensions of wellness. These nine dimensions of wellness include physical, emotional, financial, spiritual, social, career, intellectual, creative,

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and environmental wellness.[3] In the workplace, the goal is to allow the employee to reach optimal health and to be productive and happy at work. It has not been an easy task, but the authors' hospital strives to create an internship grounded in wellness to not only promote a healthy lifestyle, reduce burnout, and help retain equine veterinarians in their chosen career field but also further promote sustainability in equine practice.

2. Solution

Design an internship to support the 9 dimensions of wellness, which address the common drivers of burnout.

3. Physical Wellness

Physical wellness encompasses a holistic approach to maintaining optimal health through regular exercise, balanced nutrition, and preventive healthcare measures.[3] The authors' internship program is designed to prioritize the physical wellness of trainees by offering a flexible work schedule that allows time off to ensure they are maintaining their health. For example, interns are able to schedule medical appointments during the workday and take the time to attend these without penalty.

The authors' practice believes that regular exercise is important for physical wellness and provides access to a small gym with cardio equipment within the building as well as discounted gym memberships across the city. A new benefit that has been offered is a $125 allowance per quarter that employees can use toward lifestyle expenses (e.g., gym memberships, subscription food services, books, stress management programs/apps, exercise equipment, and many others). Access or recommendations for gym memberships or group fitness classes can be incorporated into internship orientations in even smaller practices. Modeling these behaviors may be particularly important in smaller practice scenarios. Sharing a portion of client emergency fees with intern veterinarians can assist in providing financial support for physical wellness.

In addition to regular exercise, healthy eating habits are prioritized as a key component of physical wellness. To encourage healthy eating, the ambulatory clinicians model good habits by packing healthy lunches from home rather than eating fast food. Additionally, taking time to have a lunch break separate from working time is encouraged.

The work of an equine veterinarian can be physically demanding, so it is important to take proactive measures to prevent work-related injuries and promote physical wellness. By structuring a program with a goal of a 40-hour work week and allowing for 2 weekends per month free from clinical or on-call duty, the authors' practice allows the trainees the opportunity to prioritize their interests and hobbies.

In summary, the authors' hospital is committed to promoting physical wellness among interns by offering a supportive work environment that encourages regular exercise, healthy eating habits, preventive healthcare, and work-life balance.

4. Emotional Wellness

Emotional wellness is the ability to successfully handle life's stresses and adapt to change and difficult times.[5] The National Institutes of Health suggests 6 strategies for improving emotional health, and the authors' practice/hospital has adapted these for the internship program. They include building resilience, reducing stress, getting quality sleep, strengthening social connections, coping with loss, and being mindful.

At the start of the year, interns participate in a cognitive-behavioral skills-building workshop that lasts 8 hours but is held over multiple days so as not to overburden them with information. The workshop provides them with cognitive-behavioral skills to enhance their daily interactions and incorporates mindfulness and reframing techniques. The clinical day starts with a gratitude exercise. Everyone on the team expresses something they are grateful for and something to which they are looking forward. Research has shown that being grateful increases happiness.[6] After difficult cases, debriefing is done on a local level to review what went well and what could be improved in regard to communication and veterinary medical/surgical management. The interns are required to present a difficult clinical case to the faculty twice yearly, and there is also a monthly communication seminar for all hospital interns to discuss challenging communication cases. Some faculty are certified in Mental Health First Aid and suicide prevention. All employees, including interns, are offered 5 free therapy appointments through the employee assistance program and free health coaching. The authors' practice can support larger programs as part of a large university with many resources already available to staff and students. However, with cultural changes and demand from practitioners, the authors hope that governing bodies such as the American Association of Equine Practice (AAEP) and American Veterinary Medical Association can provide resources for cognitive-behavioral skills-building workshops and other support (communication seminars, therapy access) to private practices to assist both intern and staff veterinarians.

5. Financial Wellness

Financial wellness is the ability to meet basic needs and manage money for the short and long term. A 2015 American Psychological Association survey of Americans found that 72% of people experienced financial stress, worrying about bills, emergencies, and their financial future in retirement. Financial wellness is an essential aspect of the commitment to ensure the well-being of interns at the hospital/clinic. The important role that compensation plays in promoting financial stability and job satisfaction is recognized. An online financial literacy program

is offered to all employees. It is suggested during the intern orientation and the 1-month review that interns take some time to work through the self-paced literacy program. In addition to this program, equine intern salaries have been steadily increased to meet the living wage of the city. Last fiscal year, the starting salary for interns was $36,316. However, the rising cost of living is understood, and the work interns do is valued. Therefore, starting in 2023, the salary for interns will be $44,000, which is a 72% salary increase from just 5 years ago and a 20% increase from last year. A commitment to fair and competitive compensation for interns further defines them as integral members of the healthcare team. According to the Massachusetts Institute of Technology living wage calculator, the living wage for a 1-adult household with no children is $33,945.60. The current salary is 7% above the living wage. For fiscal year 2023 to 2024, the base salary will be 29% above the living wage. Very affordable healthcare insurance ($150 per month) with a low deductible ($975) and a maximum out-of-pocket cost of $4,350 is offered. The insurance covers all preventive care, screenings, and immunizations at no charge. All other healthcare costs are covered at 80%. The prescription coverage deductible is $50. While this is a benefit of a large university, a desirable alternative would be for companies to assist interns with insurance premiums. This insurance allows interns to feel comfortable seeking healthcare without worrying about the cost. In addition to increasing salaries, opportunities for interns to earn extra income during their free time are provided. For instance, in the past, interns have participated in drug testing for the United States Equestrian Federation for additional income. They have also attended local horse shows on the weekend, for which they receive direct compensation from the horse show venue. Extra hours on the weekends that they are off are not promoted, but support is given for them to work these jobs to help support their financial needs. While they do not currently receive additional emergency fee compensation, this avenue is being explored, and more opportunities are hoped to be provided for interns to earn additional income. Promoting financial wellness among interns is believed to be not just about increasing salaries but also about providing them with opportunities to grow their income and achieve financial stability. The goal is to support the financial well-being of interns, which is believed to translate to better overall job satisfaction and performance. As a nonprofit, the 1-year internship will also have interns qualify for 1 year of the 10-year public service loan forgiveness program. Other avenues for promoting financial stability can include providing free or low-cost housing options for intern veterinarians, particularly in areas with higher costs of living.

6. Spiritual Wellness

Spiritual wellness can be pursued through various avenues, such as self-reflection, engaging in open dialogue with others, and reading.[2,3] At the internship, spiritual wellness is considered to encompass being open to exploring one's own beliefs while respecting those of others. It is essential to foster a culture that allows everyone to hold unique beliefs and understandings. As part of the commitment to creating an inclusive environment, the internship program is very flexible with regard to religious holidays of any faith, often allowing interns time off to observe them. Additionally, the importance of self-reflection in spiritual growth is recognized, and interns are provided with opportunities to disconnect from their work responsibilities and digital devices to facilitate this process during the 2 weekends off per month. The commitment to fostering spiritual wellness is grounded in the belief that it contributes to the overall well-being of the interns and the community served.

7. Social Wellness

Social wellness can be achieved by creating a supportive network of interdependence, mutual respect, and trust with friends, family, and colleagues.[3] At the internship, there is a commitment to supporting one another and maintaining an open-door policy with the trainees. The value of taking time out of the day to provide support to others is recognized, as it strengthens the workplace. When rounding on cases together, the interns are encouraged to present diverse ideas, even if they conflict with one another, as mutual respect and trust are crucial in creating a robust and dynamic work environment. In addition to this, the internship program provides interns with time off call to spend together outside of work, which fosters a stronger sense of community. Research has shown that a strong sense of community can be very helpful in supporting interns and residents through difficult times.[4] To further enhance social wellness, the internship program also organizes intern happy hours, where interns can socialize with one another and with doctors outside of the work environment. For example, once a year, the entire equine section goes curling, which is open to all members of the equine services, including interns. This event has become very popular because it allows everyone to be a novice and have fun. Small changes like incorporating workplace happy hours, group exercise, or other social activities can support social wellness.

8. Career Wellness

Career wellness is essential for maintaining personal satisfaction, enrichment, and professional health. It involves engaging in work that aligns with one's values, goals, and lifestyle, enabling one to utilize their abilities to their full potential.[3] At the internship, there is a strong belief in empowering interns to design their own schedules after the first 6 months of their internship. This experience has shown that granting autonomy over their schedules leads to improved well-being among interns, including their on-call schedule. The interns receive formative evaluations

at 1 month, 4 months, 6 months, and 10 months into the internship. During these reviews, open and honest conversation is promoted. The faculty view themselves as coaches when giving feedback to improve the trainee's clinical skills and acceptance of future feedback.[7]

To guide intern development, the clinical skills document provided by the AAEP that describes what a postinternship graduate should be able to perform has been translated into an entrustability questionnaire. The interns rate themselves, attendings rate the interns, and the scores are analyzed. This allows for the determination of whether the intern will need remediation on certain skills, but it also helps to determine if the intern might be suffering from imposter syndrome or overconfidence. The entrustability scale has been found to be very helpful in guiding interns' development.

The philosophy at the internship is that the hospital and field services should function independently of interns, allowing for prioritization of teaching and hands-on training for the interns. While interns can choose to participate in research, it is not required. Several members of the medical team are actively involved in clinical research, which provides the interns with personal enrichment and allows them the opportunity to experience research. If they choose to pursue a residency, this experience will make them more competitive and understanding of residency research expectations. Providing mentorship and the opportunity for collaborative research or publication opportunities (case reports or case series) as well as timely feedback conversations can go a long way in promoting career wellness during an internship.

9. Intellectual Wellness

Intellectual wellness is reflected in a flexible mind, just as physical health is indicated by a flexible body. When individuals prioritize intellectual health, they value lifelong learning, cultivate critical thinking skills, develop moral reasoning, expand their worldviews, and engage in education for the pursuit of knowledge.[3] At the internship, education is recognized as a vital component of intellectual wellness, and there are multiple avenues for fostering lifelong learning. Interns participate in preparatory classes for board exams with the residents, present in surgery and/or medicine journal clubs once weekly, and present a case in mortality and morbidity rounds twice per year. During the first 4 months of the internship, interns are accompanied on every field emergency until all doctors are comfortable with them seeing emergencies independently, which allows interns to build confidence and approach emergencies with less anxiety. After the 4-month probation period, interns have a designated back-up doctor who they are required to check in with before, during, and after emergencies. In the hospital, interns on emergency will work up the cases with a faculty member present before the workup is completed and findings are presented to the client. Including structured case rounds, journal clubs, and case mentorship should be an essential component of intellectual development in equine internship programs.

10. Creative Wellness

Creative wellness means valuing and participating in a diverse range of arts and cultural experiences to understand and appreciate one's surrounding world.[3] Expressing emotions and views through the arts can be a great way to relieve stress. In the clinic, the interns have a bulletin board where they post fun pictures, schedules, memes, and personal drawings. The interns have also used their creative skills to make TikTok videos to promote the clinic. Honestly, creative wellness has been difficult to promote within the work environment, but the hope is that with somewhat normal work hours and a culture of flexibility, the interns will be able to participate in creative outlets of their own choosing.

11. Environmental Wellness

Being environmentally well means recognizing the responsibility to preserve, protect, and improve the environment and appreciating a connection to nature.[3] The hospital is situated in an area where many public green spaces exist. Miles of hiking trails and kayaking opportunities are within a 15-minute drive of the hospital. Just spending time outside has been shown to increase mental health and act as a protector of mental health within the veterinary profession.[8] Being a rotating internship guarantees the interns spend time outside. People that work outside a building report being happier than people that work indoors.[9] Equine ambulatory clinicians are always aware of how the environment impacts the horse. Recycling and composting bins are available within the office and field services to encourage sustainable practices.

12. Results

Overall, the interns have reported great mentorship, great job satisfaction, and a feeling of being supported in exit interviews. After internship, 100% of the interns have continued in veterinary medicine, with 82% continuing in equine practice. Twelve percent have taken a job in small animal general practice, and 6% have taken a mixed animal medicine general practice position. During the exit interview, they commonly list salary or location as to why they did not take an equine job. They do not report burnout from equine practice or this internship. Further data on their level of burnout, anxiety, and quality of life is needed. Because the internship class is smaller (2–3 individuals), it may be difficult to gather honest data and maintain their anonymity. A multicenter study of all internship programs could be helpful in gathering additional data.

13. Discussion

This organization has made well-being a priority for the past 5 years. However, there is still a struggle against cultural norms within faculty and staff veterinarians that an internship should be "hard" with little sleep, no days off, and being on-call for extended periods of time, like it was 15 years ago. This is clearly becoming unsustainable for the next generation of veterinarians, leading to the shortage of equine veterinarians in practice. The internship has been designed with the 9 dimensions of wellness as a core value to address burnout from both an individual and organizational level to address these growing concerns. The internship is part of a larger organization that provides benefits such as excellent health insurance, a lifestyle savings account, and a diverse range of wellness programing, which is obviously beneficial and provides support for making cultural and substantial improvements in intern well-being. It is believed that an internship based on the 9 dimensions of wellness can be implemented even in smaller practices if there is a cultural shift and small changes are implemented. Small practices have the advantage of being nimbler in implementing change than large organizations. The AAEP provides a lot of well-being tools on their website to help small practices make these changes, and more can be demanded in the future to provide support to equine practices making efforts to improve well-being for all veterinarians. Changing work culture takes time and cannot be done overnight. However, by focusing on the most vulnerable population, there is optimism that cultural change will occur for everyone. It has been found that it is easier to implement changes to the internship that affect the individual, but these changes could have a profound effect on the entire hospital.

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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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Coping Strategies for Managing On-Call Stress in Equine Practice

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On-call duty is a fact of life in equine practice. Numerous conversations are currently in progress to discuss the on-call burden in practice and how to take the strain off of the practitioner; however, most of these are logistical in nature. Studies have shown that many of the deleterious effects of on-call shifts occur regardless of any actual calls attended to. By applying coping mechanisms and building resiliency, veterinarians can better protect their mental and physical health from the stressors of on-call work. Author's address: 3128 Indian Way, Lafayette, CA 94549; email: cara.wright.dvm@gmail.com
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1. Introduction

Emergency on-call duty is a necessary part of veterinary medicine. This duty can be overwhelming in equine practice due to the ambulatory nature of some jobs and the lack of dedicated ER clinics for horses. One aspect of being on call is a perceived lack of control; the doctor does not have control over who will call, when they will call, and what the problem is. Another aspect is the more abstract anxiety that some practitioners experience that manifests differently in individuals. Some doctors may feel paralyzed and may not feel that they can run errands or cook dinner due to the anxiety of being on call, while others may feel generalized irritability and exhaustion.

A summary survey conducted in 2017 looked at over 1,900 veterinarians (various species focus) and their relationships with on call.[1] Over half of the respondents said they agree or strongly agree that they experience a great deal of anxiety while on call, regardless of whether they get called in. Almost 70% of respondents said they are unable to relax while on call, and 83.8% did not get the next day off if called in the previous night.

A study by Dettmers[2] showed that participants experienced lower moods the morning after being on call compared to mornings after days when they were not required to be available.[2] The researchers believe this occurs because readiness to respond makes it harder to recover from work and does not count as true rest. This means that the simple possibility of being called in can impede recovery from work, as the deleterious effects persisted even when no calls came through. This study also evaluated levels of cortisol in participants, which showed that an individual's morning levels of cortisol increased more quickly when participants would be on call, resembling the higher hormone levels seen in job stress. This indicates that stress levels were similar between actual scheduled work and the mere possibility of being called. Cortisol is the fight-or-flight hormone, and its presence indicates the body is preparing for anticipated stresses.

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Several studies have looked at the effects of on-call duty in regard to sleep. Results show that, even in the absence of an actual call, sleep during on-call nights is of lower quality and has less restorative value. Participants reported longer sleep onset latencies (the time it takes to fall asleep) and time spent awake after initially falling asleep during the on-call night.[3] These participants reported more sleep problems and a lower overall sleep quality and felt less recuperated after the on-call night compared to their reference night of sleep.[3] An electroencephalogram study of ship engineers showed that on-call sleep registered both less slow-wave sleep (or deep sleep) and rapid eye movement sleep, as well as a higher heart rate compared to testing during normal sleep.[4] In a study of Swedish merchant marines, the anticipation of alarms that would wake them up was seen as an obstacle preventing workers from relaxing enough to allow normal sleep patterns to develop.[5]

According to the American Psychological Association, resilience is the process and outcome of successfully adapting to difficult or challenging life experiences, especially through mental, emotional, and behavioral flexibility and adjustment to external and internal demands. Resilience has been linked to perceiving stressful events in less threatening ways; this cognitive reappraisal allows individuals to re-evaluate or reframe adverse experiences in a more positive light.[6] In a study of intensive care unit nurses, highly resilient nurses were less likely to allow their work environment to interfere with their overall life functioning when away from work. Intensive care unit nurses who are highly resilient are significantly less likely to develop psychological disorders including posttraumatic stress disorder and burnout syndrome.[7] Being resilient does not mean not having feelings or being stressed; it means adapting to and controlling one's stressors. An example of resiliency in veterinary medicine is any instance in which a case did not go as planned. If you learned something and did something different the next time you are presented with a similar case, then you are exhibiting resiliency.

Coping mechanisms are actions or thought processes used to modify one's reaction to stressful or unpleasant situations. Coping strategies, defined by the American Psychological Association, typically involve a conscious and direct approach to problems. By applying coping mechanisms and building resiliency, veterinarians can better protect their mental and physical health from the stressors of on-call work. Examples of coping mechanisms in this paper can be generally categorized as tangible and abstract.

2. Discussion

Tangible Changes

In veterinary medicine, there is a certain amount of day-to-day work that is out of the veterinarian's control. Putting parameters on the aspects that can be controlled, or "controlling the controllables," can be a powerful tool in building resiliency and changing your mindset.

- Phone calls:
  - Change expectations for the time of callback. For example, increasing from 10 to 20 minutes may give practitioners a chance to take a shower or run an errand without needing to stop in the middle to attend to the phone.
  - Some doctors experience anxiety related to answering the phone without any information. Sending calls to voicemail for screening or using an answering service/vet tech to answer calls may give the veterinarian more time to prepare for the case and phone call at hand.
  - Use technology to screen your calls; services such as Google Voice and Grasshopper can funnel ER calls to a specific line, as well as provide text messages with the voicemail transcript.
  - If nervous about missing a call, set a backup for calls such as text or landline. Ensure that your voicemail tells people to call back within a specific time if they have not heard back.
  - Change ringtone to something calming or fun.
  - Consider asking a team member to cover the phone while you do something that needs your full attention, such as putting kids to bed.
- Case outcomes:
  - How often is a case going to call that is out of your ability to handle? Think about this realistically.
  - Everyone has types of cases that they are less comfortable with. Make a cheat sheet for "what to do" in these cases so you have a quick reference if needed. Just by thinking about this case, you are now more prepared.
  - Know your referral center and call them for guidance if you are feeling overwhelmed.
  - Phone a friend; running through the case with someone else on the way there will help you feel prepared.
- Creative scheduling before or after being on call:
  - Consider scheduling a full day off after a weekend on call to promote rest and recovery.
  - Re-examine the practice parameters for what constitutes a true emergency and give the on-call veterinarian some autonomy to triage their cases.

- Personal time:
  - Plan your schedule for personal time as best you can around being on call.
    - For example, plan your workouts for early mornings before the phone is likely to ring.
    - Take two cars to family events and have a change of clothes with you.

- Take care of your body:
  - Sleep, healthy nutrition, and exercise are not always possible, but prioritize them in your schedule as best you can.
  - Have a snack drawer where you can grab healthy options on your way out the door to a call.
  - Physical exercise, which can be viewed as a form of active coping, has positive effects on mood and attenuates stress responses.[6]

Abstract Coping and Reflection

Taking control of and reframing your thoughts is another tool for building resiliency and changing your mindset. A discussion with Dr. Jamie Goldstein, licensed clinical psychologist, helped form some of the following actions.[a]

- Recognize your thoughts; think about why being on call makes you anxious. Is it the cases that might come up? Is it the lack of planning? Are you worried about failure? What are you actually worried about?
  - Self-reflect about what it actually means to you to be on call. Do you see it as a chance to serve your clients or just as a barrier to your freedom? Defining this for yourself is the first step in reframing your thoughts.
- Externalize your thoughts.
  - Journaling or writing them down can be a way to create literal space from yourself to negative thoughts.
- Create a perspective shift.
  - Reframe your thoughts about on call. Approach it as a neutral fact. Pick one or two thoughts you can focus on when you start to feel yourself veering into the negative-thought territory.
    - If you get paid emergency fees, try thinking about a savings goal every time the phone rings. Growing the new saddle fund or the vacation account is a great mindset shift to try.
    - Consider paying doctors per on-call shift to reframe the commitment to on-call duty.
    - Instead of "I have to," think "I get to" help horses and people in their time of need.
    - Remember that every situation is temporary. "It's not forever, it's just for now" can be a powerful phrase.

- Detachment is the ability to not think about work-related issues when not at work.
  - People who could detach from work even while on call were most likely to regain their energy and avoid deleterious effects on mood and cortisol. Alternately to reducing work availability, practicing mental detachment from work might be the next best approach.[8]
  - Really being off from work when not scheduled is a key measure of detachment from work and the ability to recover.
    - Setting boundaries about day-off phone calls, emails, and catching up on records can help with this.
    - Remember that letting go of things you cannot control does not mean you do not care about your job.
    - Schedule "worry time" if needed; give yourself a concrete amount of time to focus on work or worries during your off time, and then turn it off. This is recognizing your feelings but not allowing them to take over.

By using some of the above mentioned methods, veterinarians can decrease the anxiety surrounding on-call work. Applying coping mechanisms will also ameliorate some of the physiologic stressors apparent with on-call demands. Making tangible changes as well as committing to a mindset shift are both integral for reducing the stress and increasing the health of veterinary on-call practitioners.

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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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Adaptability: The New Core Competency for Success (Adapt or Die)

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1. The Adaptability Quotient Can Contribute Positively to the Crisis in the Profession

Equine veterinary medicine has been described as a profession in crisis, with indicators revealing a worsening rather than improving situation. There is a shortage of veterinarians entering equine practice. Of those, 50% are reported to leave equine practice within 5 years. While many factors have been identified to be contributors, with solutions certain to be complex, one of the prominent contributors cited is burnout.[1] Indeed, veterinary medicine is not unique in experiencing an epidemic of stress and anxiety today, both within and beyond the healthcare professions. The adaptability quotient (AQ) offers an important consideration as a potential positive contributor that could favorably influence recruitment and retention in equine practice, not only for new graduates but also for seasoned practitioners. It is likely that improving AQ could increase resilience, decrease burnout, and increase job satisfaction, job performance, and even life satisfaction, as has been shown in other sectors.[2]

Different "quotients" have been used over time as indicators of likely success of individuals and organizations. For many years, the intelligence quotient (IQ) was considered a major measure of success.[3] Next on the scene was emotional intelligence (EQ).[4,5] Social scientists and psychologists increasingly acknowledged that EQ was more important than IQ for business and life accomplishment.[6] The AQ has more recently emerged as an indicator of success and is deemed to be more valuable than either IQ or EQ.[7] The term "adaptability quotient" was first referenced in 2010 by Stuart Parkin.[8] In 2011, the Harvard Business Review announced that adaptability is the new competitive advantage, a statement only recently appreciated.[9] Deeper dives have resulted in well-designed research on the topic and resulting validation of AQ as a critical component of success today.[10] Adaptability is the only way a business can prepare for the unknown.[11]

2. The Meaning of Adaptability Quotient

Understanding the power of adaptability for survival or performance can be traced back to Charles Darwin in his well-known treatise, *On the Origin of the Species*.[12] The AQ has been described in a number of ways.[13–17] It has been defined broadly as "the capacity to adjust one's thoughts and behaviors in order to effectively respond to uncertainty, new information, or changed circumstances."[15] Amin Toufani has described AQ in his public lectures at Singularity University as the ability to realize optimal outcomes based on recent or future change. Ross Thornley and Mike Raven have defined AQ as "measuring the abilities, characteristics, and environmental factors which impact the successful behaviors and actions of people, and organizations to effectively respond to uncertainty, new information, or changed circumstances."[18] As such, AQ measures an individual's or

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an organization's ability to adjust to change and new conditions in real time. In a Ted Talk, Natalie Fratto called adaptability a form of intelligence.[19]

3. Benefits of Developing One's Adaptability Quotient

There are personal, professional, and business benefits to improving one's AQ.[20–23] The AQ correlates significantly with real-world outcomes and performance, such as job satisfaction, job performance, and even life satisfaction.[2,24] Studies have shown that adaptability is correlated with coping skills and personal growth.[25] High levels of adaptability are associated with higher levels of learning ability, better performance, more confidence, and greater creative output. They have been shown to maintain deliberate calm under pressure and display curiosity amid change.[26] Individuals with a high AQ score are more likely to perform above their basic job requirements and score 4 times higher on the ability to develop worthy leadership.[27]

Several studies have recognized the relationship between resilience and burnout in the medical profession. One study documented correlations between academic adaptability and academic burnout, immersion in learning, and academic performance among Chinese medical students.[28] The conclusion of this controlled study was that higher levels of academic adaptability were associated with lower levels of burnout and higher levels of immersion in learning and academic performance. Academic burnout was correlated with lower adaptability levels. It was hypothesized that it would be helpful for medical schools to consider academic adaptability and ways of enhancing such skills in order to enhance student performance and engagement while in school. Similarly, a study of nurses concluded that there was a significantly negative relationship between burnout symptoms and resilience such that higher resilience related to lower burnout.[29] While burnout in the veterinary profession, including veterinary students, veterinary graduates, and veterinary technicians, is likely complex and multifactorial, it makes sense to consider adaptability as one measure to lessen burnout.

Experienced equine veterinarians have witnessed dramatic changes during their practice lifetimes, and new graduates are entering a world that is very different from the world of those hiring them. A high AQ should enhance the ability of veterinarians across generations to benefit from each other as experience is shared and new ideas are considered.

A strong message for veterinary practices and other veterinary organizations is that in this rapidly changing world, the strongest predictor of success is the ability to respond to change. Combining the linear changes to date with the fact that change is now exponential elucidates the importance of not only dealing with change but also leveraging change for greater success. Additional significance comes from the business world outside of veterinary medicine, where a higher AQ is directly correlated with success, including better financial outcomes.[7,30] All organizations, within and beyond veterinary medicine, struggle with the "execution gap." New technologies, novel practice management tools, innovative business models, telemedicine, and much more are enticing, yet execution and upskilling the team remain evasive. The AQ should contribute to incorporation of needed innovations in veterinary practices and related business.[31]

4. A Successful AQ Model

When AQ is maximized, the "rockstar formula" has been proposed as Rockstar = AQ (IQ + EQ). There are even individual dimensions within AQ. The AQ includes AQ character, AQ ability, and AQ environment. (AQai) It is referred to as the ACE model inside AQ. The AQ character is an individual's innate aspects of self, with some individuals being inherently more adaptable than others. The AQ character refers to who adapts and why, as influenced by emotional range, extroversion, hope, motivational style, and thinking style. The AQ ability refers to how and to what extent one adapts. It includes learned adaptability skills and abilities like grit, mental flexibility, resilience, and unlearning. The AQ environment refers to when someone adapts and to what degree, as influenced by a supportive workplace in which adaptation is helped, not hindered. Such an environment fosters team support, emotional health, organizational support, and diminished work stress. The ideal model is when all three are high.

Four subdimensions of adaptability are also described.[32] Resilience is the capacity to recover quickly from difficulties. Flexibility is the ability to bend easily without breaking. Learning drive is described as the passion and hunger for more knowledge. Mindset refers to where an individual falls on the continuum from a fixed, unchangeable mindset to an incremental, changeable mindset.

5. What Characteristics Are Associated with a High Adaptability Quotient?

There are many attributes ascribed to adaptability.[33] Those with a high AQ tend to be curious. They are resourceful, resilient, and flexible. They are good problem solvers who prepare for possible outcomes. They are aware that fear of failure stifles creativity and innovation, so they accept and embrace failure with full realization of the growth opportunities associated with risk taking. They constantly learn, including incorporation of new technologies. They also unlearn, which is much harder to do yet often more valuable than learning. Ghandi underscored the importance of unlearning in a quote from the last page of his autobiography, "I must reduce myself to zero," as he constantly turned himself to a beginner's mindset. Individuals with a high AQ say yes and avoid saying no. They are open-minded, question their own assumptions, and condition themselves to be receptive to new and different possibilities. They are willing to give new ideas a chance. They embrace change and learn to leverage change for optimal outcomes. They persevere confidently and are constantly aware of their own

motives, behaviors, and impacts on others. They are resilient, even being enthusiastic and positive when discussing how they navigated challenges and effectively responded to change. They view stressors as challenges, but not threats. Their emotional health is strong, as they report a more positive state of well-being. They understand that the way people work today will not be the way they will work tomorrow. Imagine describing all members of the veterinary healthcare team, and the practice itself, in this way.

Are younger people or older people more adaptable? Some studies show that younger adults are faster at responding to the interruption of a routine task.[34] Other studies show age-related deficits that result in acquired experience frequently interfering with new learning.[35] However, this premise has been challenged.[36] Some hypothesize that younger people are more likely to do the new because it is all they know. Older people have more to unlearn as they face adopting the new. Another study concluded that as older adults deal with adversity at an ever-increasing rate, they are able to adapt more readily and to seek aid from other sources of support.[37] In the end, it is important for veterinary practices to avoid making assumptions of adaptability based on age alone. Adaptability varies among individuals, and both younger and older people can be adaptable or not such that all individuals on a veterinary healthcare team can be encouraged and expected to adapt.

Businesses with a high AQ are more likely to survive and thrive in a constantly changing and often challenging world.[14,38] A high AQ allows businesses to prepare for the unknown, such as the pandemic, economic recession, and advancing technologies, all of which are relevant to equine veterinary medicine. Improving adaptability within and across an organization helps a business successfully encounter inevitable changes on the horizon. Businesses with a high AQ are more likely to be able to implement needed behavioral changes and sustainable business practices within the organization as needed. Adaptable businesses are more likely to be able to adopt new technologies and then successfully adjust to their implementation. They are likely to incorporate adaptability assessments into their hiring processes and to provide adaptability training once selected individuals are hired.

6. Can the Adaptability Quotient Be Learned, Improved, and Taught?

Yes, adaptability can be learned, improved, measured, and tested.[18,39–41] Mike Raven, co-founder of AQai, a company that teaches adaptability, stated, "We believe that adaptability is a magic key, not only to survival, but to thriving into abundance—to a new, better existence for humanity. What got us here will not be enough to get us where we need to go to avoid major catastrophic consequences for the biosphere and our species." Others have made similar statements about what got us here will not get us there.[42,43] Some have referred to adaptability training as the magic answer to survival beyond 2022.

Formal adaptability training programs are available for individuals and businesses.[44,45] While little has been written or presented on the topic until relatively recently, information and programs are burgeoning. Dr. Amin Toufani is known for developing the first scientific quantification of adaptability in individuals and organizations, which he referred to as the AQ. He is also the creator of Adaptability University, which can be accessed at https://www.adaptability.org/. Many additional training companies and universities are now offering adaptability training.

Individuals can improve their own AQ in many ways other than formal training. Intentionality is key in developing a mindset to become more self-aware about how they think and the reasoning behind their actions. They can intentionally develop an intense curiosity that includes learning on their own and seeking opportunities to pick up new skills. They can deliberately step out of their comfort zone to tackle new projects and responsibilities. Proactively meeting new people will expand their horizons and create valuable collaborations. They will embrace change and use change as a force for good, rather than fight it. As they develop comfort with ambiguity, they will see new opportunities for beneficial change. They will then convince others to get on board with the innovative ideas. The latter requires a thoughtful approach to creating the narratives that will entice others.

Leaders must set the culture of adaptability, such as within their veterinary practices and other organizations of which they are part (e.g., AAEP leaders). They must model adaptability themselves, make others aware of the concepts and benefits, and encourage all to improve their own adaptability. Adaptability training, whether formal or informal, should be an integral part of professional development throughout the organization. Adaptability should be part of hiring practices, performance reviews, reward strategies, strategic planning, and other activities that are critical in determining the future of individuals and the organization.

An essential component of improving one's AQ is to be aware of the major trends, not only within veterinary medicine but also in the world in which veterinary medicine resides. Included will be the impacts of adapting to the trends and the impacts of ignoring them. Improving the AQ of individuals and organizations within the veterinary profession will surely contribute to future success of the profession in its entirety. To remain relevant, individuals, businesses, and the profession must be adaptable.

7. Summary Recommendations for Improving Adaptability Within a Practice or Other Organization

- Create an AQ environment.
- Leaders should become familiar with the value of AQ, along with IQ and EQ, and ensure all members of the veterinary healthcare team in the practice are also aware.

- Make AQ a core competency in the practice or other organization.
- Model high AQ behavior throughout the practice or organization.
- Incorporate assessment of AQ into hiring practices (resumes and interviews).
- Provide adaptability training within the practice or other veterinary organization.
  - Examples of formal training programs are listed below.
    - Adaptability University at https://www.adaptability.org/
    - AQai at https://www.aqai.io/
    - Others
  - Training can be accomplished locally:
    - Reading with group discussion
    - Online access to educational materials
    - Formal presentations within the practice or organization
- Create a culture of adaptability.
  - Stimulate curiosity.
  - Say yes to new ideas.
  - Embrace change.
  - Give permission to fail.
  - Help people unlearn.
  - Recognize and celebrate successes resulting from adaptability, as individuals and as an organization.
- Make adaptability part of performance reviews.
- Reward high AQ throughout the practice.
- Contribute to the AQ of veterinary students by supporting the inclusion of AQ in growth and development of the equine veterinary student; this can be done by practitioners to externs and mentees and through AAEP in its AAEP Commission to Alleviate Equine Veterinary Shortage.

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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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How to Combat Decision Fatigue in Equine Practice

Cara Wright, DVM, MS

Decision fatigue is the state of mind where mental resources are depleted and/or when the motivation to exert mental effort declines over time. Veterinary medicine hosts several factors that can lead to decision fatigue: unpredictable days, lack of downtime, demanding decisions, and serial decision-making. Solutions exist to decrease decision fatigue in equine practice that may reduce practitioner exhaustion and increase practice efficiency. Author's address: 3128 Indian Way, Lafayette, CA 94549; e-mail: cara.wright.dvm@gmail.com. © 2023 AAEP.

1. Introduction

Various sources have stated that humans make up to 35,000 conscious and unconscious decisions per day.[1] This number is astronomical, and it stands to reason that people may decrease their effective decision-making capabilities after making a certain number of daily decisions. Decision fatigue, coined by social psychologist Roy Baumeister, is the emotional and mental strain resulting from a burden of choices.[2] Another group defined decision fatigue as "a state occurring when mental resources become depleted and/or when motivation to exert mental effort declines over time, resulting in a measurable shift towards easier, safer, or more gratifying decisions and actions."[3] This means people experiencing decision fatigue may be making worse decisions or feel paralyzed and unable to make a choice. Another common occurrence is choosing the status quo when experiencing decision fatigue. Classic signs of decision fatigue include procrastination, impulsivity, avoidance, and indecision.[4] Examples are saying "I will deal with this later," "Flip a coin and choose," or "Just do what we did last time." A typical example of decision fatigue in action is deciding what to eat for dinner at the end of a draining day; simply deciding where to get takeout from the options available may feel paralyzing.

Real consequences can occur from decision fatigue that extend beyond ordering dinner. Decision fatigue is related to picking the default option, which often requires little cognitive effort. A study of bank loan officers showed that loan approval rates dropped in the afternoon compared to the morning, and it was estimated that the bank lost over $500,000 in revenue for 1 month due to lost fees and interest.[5] A list of sequential choices and the apparent mental depletion evoked may also increase the tendency to accept the status quo. In a 2010 study, German car buyers were more likely to accept the default attribute level offered by a manufacturer later in a sequence of attribute decisions than earlier, especially when these choices followed decisions between many alternatives that had required more mental resources to evaluate.[6] In emergency rooms, physician decision fatigue leads to lower inpatient admission rates, fewer task orders, and shorter patient length of stay;

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both patient revisit rates and mortality rates increased.[7] In a study of over 4,000 clinical decisions made by nurses in Scotland, the nurses made progressively more conservative and therefore more expensive and less efficient decisions as the time and number of decisions made since their last rest break increased.[8] One study in human healthcare showed that compliance with hand hygiene protocols declines predictably from the start to the end of shifts but increases after a break,[9] and another showed that doctors prescribe more unnecessary antibiotics toward the end than the start of clinic sessions.[10]

Several other factors can contribute to decision fatigue, most notably general fatigue, sleep deprivation, low blood sugar, and time of day.[11] Veterinary medicine is a potential perfect storm for decision fatigue: long, unpredictable days; too little downtime; demanding life-and-death decisions; and serial decision-making. Decision fatigue can be a contributing factor and occur concurrently with generalized burnout and compassion fatigue. One of the significant signs of burnout is exhaustion, which can be mental, emotional, and physical.[12] Burnout is common in veterinary medicine; it is seen in nearly 1/3 of veterinarians and up to 1/2 of support staff surveyed in the Merck Animal Health Veterinarian Wellbeing Study III.[13] Decreasing mental exhaustion by streamlining decision-making is one method for decreasing the chance of burnout in veterinarians.

2. Solution

Many solutions exist to decrease the toll of decision fatigue experienced in equine practice.

1. Minimize the number of independent daily decisions that must be made.
    a. Consider a work uniform. Several successful people like Barack Obama and Bill Gates talk about minimizing their decisions about mundane tasks to free up brain power for difficult decisions.[14]
    b. Schedule time for administrative tasks. For example, going through distributor invoices at a scheduled time each week may prepare you better than squeezing it in before the credit card is due.
    c. Use practice software to set standard time lengths for different types of appointments to minimize staff having to decide this when scheduling.
2. Delegate certain decisions to your team.
    a. Delegation shows people that you trust them and empowers your staff. This also eliminates the need for you to answer questions that do not need your expertise to answer.
    b. Consider delegating tasks based on your team member's strengths, not just to get tasks off your plate. It will take groundwork to match tasks with people's strengths, but the results will be better, and your staff will feel more empowered when tasked in this manner.
    c. For example, task someone else to schedule the monthly staff meeting or order food for the client seminar.
3. Make harder, more complex decisions earlier in the day when possible.
    a. Schedule callbacks and bloodwork discussions for first thing in the morning.
    b. Consider scheduling appointments that are more challenging earlier in the day when possible.
4. Attempt to use evidence-based medicine whenever possible, eliminating the questioning around anecdotal experiences.
5. Apply systems to regularly occurring choices or tasks.
    a. Schedule and batch similar tasks together, such as blocking out time for practice management tasks at the same time each week. This will create routine and consistency with these tasks.
    b. Set inventory parameters for reordering so that staff do not have to ask when to reorder regular supplies.
        i. Set boundaries on price changes; if a minimal amount, do not shop around for the best price and instead ensure your software is set to change the sale price based on cost.
    c. Set prescription defaults so that you are not repeatedly calculating and re-entering the dose for a 1,100-lb horse.
    d. Apply zone days to routine ambulatory scheduling to decrease travel, as well as set expectations with clients and staff for availability.
6. Apply a team-based approach to care by hosting case rounds to encourage discussion and broader viewpoints on problem-solving.
    a. This can help when you are struggling to decide on a course of action or doubting your choices.
7. Significant deadlines can often seem overwhelming. Break the task down into micro-deadlines to combat procrastination. For example, instead of "I have to write this client education article by the end of the month," schedule a small weekly task to reach the more significant deadline.
    a. For example: Week 1: Write the outline. Week 2: Complete the first draft. Week 3: Find the photos. Week 4: Revise and complete.

8. Remove distractions to decrease procrastination; that is, set timers on social media or use your "do not disturb" mobile functions while focusing on tasks.
9. Commit to decisions once they are made. Only some decisions are permanent, but continuing to second guess yourself leads to fatigue.
10. When having difficulty making a decision, remember that low blood glucose and dehydration can affect executive function.[15] Have a snack, take a break, and return to the task.

3. Discussion

Decision fatigue may play a role in the exhaustion of the equine practitioner. Several solutions exist to minimize decision fatigue that will also increase practice efficiency. By minimizing menial decisions, applying systems and processes to daily tasks, and delegating to team members, the practitioner can decrease the number of decisions they make daily. Applying a team-based approach to care can ease the burden of significant decisions by encouraging a broader viewpoint. Breaking deadlines down into microdeadlines and time blocking without distractions can make an individual feel more relaxed about administrative tasks. By utilizing these approaches to decrease decision fatigue, the practitioner will be better positioned to make clear decisions and decrease emotional exhaustion.

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Declaration of Ethics

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Conflict of Interest

The author has no conflicts of interest.

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Harvesting a Workplace Culture of Sustainability in Equine Private Practice

Becky Tees, DVM

Creating a workplace culture focused on long-term veterinarian and support staff sustainability is an achievable and financially feasible goal, but not necessarily a one-size-fits-all rubric. This paper will explain how an equine private practice was able to successfully eliminate veterinarian turnover, create high job satisfaction amongst veterinarians and clinic employees, and harvest an excellent workplace culture all while increasing practice profitability over a 2-year period. Author's address: Energy Equine Veterinary Services, 273012 RR 42, Rocky View County, AB, T4C 2X8, Canada; e-mail: rtees3@gmail.com. © 2023 AAEP.

1. Introduction

The estimated economic cost of burnout within the veterinary profession has been estimated to cost the United States veterinary industry $1 to $2 billion annually.[1] The issue of burnout and retention within the profession has also been recently highlighted within the equine veterinary sector, and in 2019, the AAEP identified veterinarian retention in the profession as the top priority of their strategic plan. As outlined by past AAEP president Dr. Emma Read,[2] "an estimated 1.3% of new veterinary graduates enter equine practice directly each year, and another 4.5% pursue further training in equine internship positions. Within five years, however, 50% of all these veterinarians leave for small animal practice or quit veterinary medicine altogether. The primary reasons are burnout due to the personal demands of the profession and personal struggle due to the lower starting salaries for equine practice when compared to companion animal practice."

These statistics fit within the previous reality of Energy Equine, an equine sports medicine practice located near Calgary, Alberta, Canada. Over a 2-year period prior to 2020, the practice suffered a 50% veterinarian turnover rate, which was primarily due to burnout, uncompetitive salaries, and low job satisfaction. With the goal of eliminating their high burnout and turnover rates, the clinic embarked on a multiyear initiative starting in January 2021 to address these issues. They succeeded in their goal whilst managing to increase practice profitability year over year.

2. Solutions

Compensation

Interns and first-year associates in the practice are paid an annual salary. Emergency compensation is also provided. The intent of the first year in the practice is to get comfortable performing procedures, build relationships with clients, and become a well-rounded clinician. The practice owners do not want

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the associate to be concerned about finances for the first year they are establishing themselves within the practice. Following their first year, the veterinarian transitions to a base salary + bonus compensation model, where the associate receives a commission of professional services over a pre-established billings threshold. This practice has the threshold currently set at $250,000. Following that year, the veterinarian then moves to a straight commission-based model. The clinic finds that this compensation system best supports a newer veterinarian during their first couple years in the practice and ensures they are financially supported while they grow their clientele and perfect their skillset. Since implementing this system, there has not been an instance where a veterinarian has lost income year over year while transitioning up through the various compensation types.

Four-Day Work Week

All associate veterinarians employed at the clinic for over 1 year have adopted a shortened 4-day work week. The option to work a 5-day week remains available, but all veterinarians on this schedule have attested that they prefer the shorter work week. Vets continue to work on average 8 hours a day, but if any vet were to prefer a longer workday, that option remains available. Intern veterinarians that transition to an associate position work 5-day work weeks in their first year as an associate. As mentioned previously, these veterinarians are paid on a base salary + bonus compensation structure. Because these veterinarians are typically growing their clientele and honing their skillset, their workdays are generally not as busy as the more mature associates, and so the 5-day work week is manageable. All veterinary technicians and assistants work 10-hour days, 4 days a week. This reduces the amount of overtime paid if a day runs longer than usual for the veterinarian and allows the support staff ample time for clinic maintenance, cleaning, and stocking trucks.

Shared Caseload

There is a general philosophy amongst the practice that clients should be shared between senior and junior veterinarians. The practice owner, who remains the highest grossing veterinarian in the practice with traditionally the highest-grossing clientele, has discontinued performing certain procedures such as dental floats and gastroscopies. This gives a way for associate veterinarians to harvest relationships with these clients. It also keeps their schedules booked and actively builds their skillset. An effort at actively transitioning these clients to an associate as their primary veterinarian is always being pursued by both the practice owner and the associate veterinarians. This is with the goal of a relatively seamless transition for clients as the practice owner enters retirement in the future. The veterinarians have also found that having clients comfortable with multiple veterinarians in the practice eases the stress of managing bigger barns or facilities independently.

Desired Caseload

Each associate has provided a list to management with the types of cases they prefer to see. The clinic sets a goal each week of every veterinarian's schedule containing 60% of their desired caseload. This statistic is reported on a biweekly basis at clinic staff meetings. If a veterinarian is consistently far below the goal percentage, reception is to take note and make efforts to book the veterinarian accordingly in the future, within reason. Caseload categories within the practice include lameness, surgery, prepurchase exams, internal medicine, dentistry, wounds, rehabilitation, gastroscopy, respiratory, ophthalmology, reproduction, and chiropractic. Basic procedures like wellness exams, vaccines, deworming, and Coggins tests are usually designated to interns as much as possible. This not only removes low-revenue appointments from the associates' caseload but also gives the new veterinarian an opportunity to establish an independent relationship with clientele.

Development Time

One morning or afternoon is blocked off in the schedule per week for the veterinarian to utilize as development time. This is typically utilized as an opportunity to return phone calls and emails or to catch up on medical records. Performing nonurgent client callbacks in a dedicated block format allows for more focus on the client and less daily mental strain on the veterinarian. Reception informs the client of when the veterinarian's development time is so the client knows when to expect a call. Most clients are understanding of a weekly callback system, provided they know ahead of time how long the wait will be. This format also seems to transition a lot of phone calls into appointments instead. This weekly callback format does not apply to urgent cases or emergencies. Veterinarians also often utilize development time for continuing education, specialist referrals, and research for cases.

Cell Phones

Every veterinarian is given a company cell phone to utilize for client communication and emergency on-call use. Associates only utilize the company cell phone for work purposes during business hours or when they are on call. The company cell phones are otherwise set to silent or turned off during nonbusiness hours. Staff and veterinarians communicate with one another through their company phones during business hours. All associate veterinarians within the practice maintain a personal phone for their own use, and clients generally do not have knowledge of the veterinarians' personal phone numbers.

Emergency on Call

Emergency on call is divided evenly amongst all veterinarians, including interns and newer associates. During their first 2 months of practice, interns have a senior associate assist them with emergencies.

Following that 2-month period, a senior clinician is available by phone to advise on case management. If needed, the practice owner (who lives on site) is willing to come and assist with complicated emergencies.

Weekends on call are evenly divided amongst the veterinarians on a rotating basis, including interns. Following a weekend on call, the veterinarian receives the following Monday off. If the veterinarian is on call during a long weekend, they receive 2 days off the following week.

The clinic's call radius is quite extensive due to having two clinic locations. To help alleviate the distance traveled to emergencies, the practice has implemented a call radius of 50 km surrounding each clinic. Emergencies outside of this area need to haul into one of the two clinic locations. Current clients that live outside of the call radius were made aware of this policy when it was implemented, and any new clients are informed of this when they establish a relationship with the practice.

An answering service is not utilized for emergencies. Emergency calls are automatically forwarded through the office number to the on-call veterinarian's work phone. Clients are always seen by the vet on call, not their usual vet within the practice. This is strictly adhered to by all veterinarians in the practice.

Invoicing

Veterinarians are given relative freedom when billing for procedures. If a veterinarian feels that they can learn from a case and become a better veterinarian by performing additional procedures, they may do so at a discounted rate if finances are a concern for the client. This is obviously done judiciously and within reason. Inventory items and labs are generally not to be discounted.

Weekly Team Meetings

Meetings are held on a weekly basis for both the entire clinic staff as well as a separate medical meeting for veterinarians. Every staff meeting traditionally starts with each person present saying a personal and professional "grateful" for the week. In the staff meeting, weekly clinical statistics are transparently reported including gross clinic billings, average client transaction, the number of new clients obtained by the practice that week, and each veterinarian's individual schedule capacity. Any days that a veterinarian team worked after 5 PM are reported and discussed, as well as what percentage of each vet's schedule met their desired caseload. Any client highlights are discussed and celebrated.

Medical meetings generally involve informal case rounds discussions. This gives veterinarians the opportunity to discuss difficult or interesting cases in a casual and relaxed setting. Journal articles and new research findings are also often discussed. These meetings are found to harvest excellent discussion amongst the veterinarians, build camaraderie, and provide support and learning opportunities to less seasoned veterinarians.

Quarterly Meetings and Team Building

At the completion of every quarter, there is a clinic-wide, day-long meeting where all staff are mandated to attend. These meetings go over the clinic's quarterly earnings, discuss clinic goals for the upcoming quarter, and involve a half-day team-building opportunity. Team-building activities in the past have included scavenger hunts, barbecues, axe throwing, and fun photoshoots. Lunch for staff is always provided by the clinic on these meeting days. This is generally a fun and rejuvenating occasion where staff can socialize and build relationships without sacrificing personal time out of work hours.

Equipment

In order to maximize earning potential and scheduling of each associate veterinarian, the practice has adopted a nontraditional approach to purchasing equipment. The clinic currently owns 5 digital radiography units, 5 ultrasound machines, 5 dental float systems, 5 fully stocked ambulatory trucks, 2 gastroscopes, 2 respiratory endoscopes, and 2 shockwave systems for the practice's 6 veterinarians to utilize.

Continuing Education Opportunities

Aside from each associate veterinarian receiving a $2,500 annual stipend for continuing education, the clinic also holds regular in-house private continuing education opportunities for both veterinarians and registered veterinary technicians. These are typically wet-lab style or clinical sessions where the practice hires a specialist veterinarian to teach practical, relevant procedures to the staff. Previous continuing education events have included advanced ultrasonography of the stifle and metatarsus, general anesthesia training, and advanced digital radiography techniques.

Preserving Positive Workplace Culture

Although the practice recognizes that the current job market has few qualified veterinarians and technicians available for hire, hiring the right people that fit into the clinic's culture has been prioritized. The practice values an applicant's attitude and core values over their knowledge and experience. Previous bad experiences with toxic employees have shown that it takes just one person to ruin the rest of the team's positivity and workplace enjoyment. There is little tolerance for consistent negativity from employees. New hires have a 60-day probationary period after hiring, and if their values and personalities do not align with the rest of the staff, they are not retained past the probationary period.

3. Results

The company's financial and employee statistics have been routinely analyzed by the practice owner since starting the sustainability measures in 2021. This was to ensure that the clinic remained profitable while trialing different solutions and to ensure that these methods would be viable into the future.

Energy Equine Revenue Growth	
2021	2022
20.40%	20.50%

Fig. 1. Energy Equine Veterinary Services annual revenue growth since implementation of improved sustainability measures in 2021.

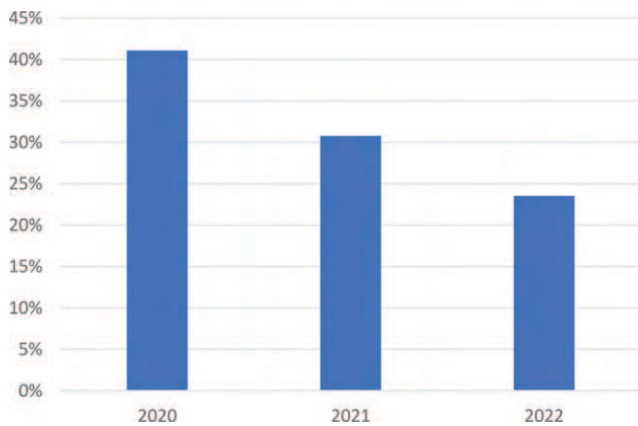


Fig. 2. Annual employee turnover at Energy Equine Veterinary Services over a 3-year period following implementation of employee sustainability measures.

A notable statistic has been the practice's revenue growth since the clinic implemented their sustainability initiative in January of 2021 (Fig. 1). The year 2021 showed a 20.4% growth in revenue compared to the previous year where no sustainability measures were in place. In 2022, there was another additional 20.5% growth in revenue. The clinic attributes these revenue increases to retaining their existing veterinarians and increasing the size of the veterinary team to prevent staff burnout. Interestingly, one associate veterinarian that transitioned from a 5-day work week to a 3-day work week for a 6-month period in 2021 increased their individual average net profit by 9%. This higher productivity is attributed to increased motivation, better time management, and improved workplace energy and enjoyment from the veterinarian.

Another significant statistic is regarding employee turnover. Over a 3-year period, the practice's employee turnover has overall decreased by 18% (Fig. 2). Moreover, since the implementation of a 4-day work week in 2021, there has been 0% veterinarian turnover. Turnover in 2020 and 2021 was largely attributed to employee dissatisfaction and burnout based on employee exit interviews. Comparatively, turnover in 2022 was mainly employees leaving due to extrinsic personal reasons and not related to workplace unhappiness or burnout.

4. Discussion

When creating sustainability measures for a practice, it is important to take into consideration that each practice is unique and certain strategies that work for one clinic may not work for another. It is unlikely that all the strategies discussed in this paper will work for all practice types. It is also important to note that implementation of these changes was a gradual process and these solutions were refined over time with a lot of trial and error. Having an open mindset to try different things and to not be afraid of change was crucial to the success of this initiative. Many solutions that were attempted by the practice simply did not integrate well into the culture or clinic structure. For example, a dedicated lunch hour for veterinarians and technicians was attempted as one of the first changes in improving practice culture. This simply did not work for the practice due to 1.5-hour appointment blocks for lameness exams. It also made ambulatory scheduling too complicated for the reception team. Another point worth mentioning is that these solutions were not realized all at once. They arose incrementally over several months and years, and several strategies discussed in this paper are a heavily modified version of their originally planned version. The main requirement is to be flexible, persistent, and creative when trying to create sustainability measures for one's practice. Clinics that support positive change and find sustainable solutions for their team are the first step in improving the state of equine medicine as a whole.

Acknowledgments

Thank you to the owners of Energy Equine, Chad and Nancy Hewlett, for allowing full transparency into your practice to facilitate positive changes for our industry.

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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Equine Financial Statement Benchmarks

John Chalk, Jr., CPA, JD, CFP®, BBA*; Alec Maixner, BBA; and Max May, BS

Over the last decade, profitability in the U.S. equine veterinary industry has increased. The industry has increased profitability through growth in revenue and operational efficiency. The most significant increase in profitability came from a reduction, on a percentage of revenue basis, in cost of lay staff. If a practice owner is going to sell to an associate, this study indicates the value, on average, should be approximately 4.25 times the trailing 12 months of earnings before interest, taxes, depreciation, and amortization of the practice. Authors' address: Trinity Portfolio Advisors, LLC, 121 Countryside Ct, Suite 140, Southlake, TX 76092; e-mail: john@trinityportfolio.com. *Corresponding and presenting author. © 2023 AAEP.

1. Introduction

This study provides the equine veterinary industry with a current and applicable set of financial statement benchmarks with which owners and managers can compare their practices' expenses, profitability, efficiency, and value against the industry. In 2012, Trinity Portfolio Advisors created a comprehensive set of financial statement benchmarks, and this current study updates those financial statement benchmarks. The goal in undertaking this study was to update those benchmarks using current financial data. The scope of this study incorporates 3 years of financial data from 23 separate practices ranging in size, type of practice, and geographic location. Financial statements were studied from the 23 different practices for the years ended 2020, 2021, and 2022. All practices included are equine exclusive. Some were hospital based and some were ambulatory based. Each year of financial data examined includes over $100 million in total revenues. It is the authors' conviction that these results accurately represent the current financial dynamics of the U.S. equine veterinary industry, and the findings can be used as a benchmark or measuring stick that can be used to compare other equine practices.

2. Solution

This study provides the equine veterinary industry with a current metric to which owners and managers can compare their financial performance. The results are organized into three primary areas. First are the income statement and the corresponding benchmarks of the expense items on the income statement. Second are balance sheet ratios and other data that provide users with a standard with which to compare their balance sheet. Last are overall valuation and profit distributions data, which ultimately conclude a benchmarked value, stated as a multiple of earnings before interest, taxes, depreciation, and amortization (EBITDA).

3. Results

The results will be presented in the discussion to follow and are organized into three sections: Income Statement, Balance Sheet, and Valuation.

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4. Discussion

Income Statement

The income statement reports on the financial performance of a practice over a period of time. The basic income statement equation is Revenue – Expenses = Net Income. Expenses in an equine veterinary practice can be categorized into cost of professional services, administrative expenses, facility and equipment costs, payroll and employee costs, as well as interest, tax, depreciation, and amortization expenses.

Each category was examined in detail for the years of 2020, 2021, and 2022 on both an independent basis as well as on an aggregated, industry average basis in order to accurately benchmark the financial performance of the equine veterinary industry today. All expenses and measurements of profitability are stated as percentages of total revenue. The tables and discussion to follow will further examine each section of the income statement and the findings therein. Table 1 summarizes the results of the study of the income statement.

Revenues are inflows from rendering services, dispensing drugs, sale of goods, or other activities that constitute the practice's ongoing operations. Of the practices included, total annual practice revenues ranged from under $750,000 per year to over $10,000,000 per year. Each year analyzed includes the financial data from practice income statements for the calendar year ending on December 31, 2020, 2021, and 2022.

Table 2 shows the aggregated total revenue of the practices that participated as well as average revenue per practice. The table also includes the total revenue annual growth rate for the years of 2021 and 2022. Total revenues grew at a rate of 15.68% in 2021 and 13.65% in 2022. From 2020 to 2023, total revenues grew at a rate of 31.47%.

From total revenue, the income statement calculates gross profit. Gross profit is measured by deducting cost of professional services from total revenue (Table 3). The column titled "2023 Equine Benchmark" represents the 3-year average of each expense category for the years 2020, 2021, and 2022. The column titled "2012 Equine Benchmark" represents the 3-year average of each expense category for the years 2009, 2010, and 2011.

Over the past decade, total costs of professional services in the equine industry have decreased by only 0.07%. Within costs of professional services, the greatest expense item for equine practices is drugs and supplies. As illustrated in Table 3, today, on average, the cost of drugs and supplies accounts for 21.03% of total revenue. Since 2012, the expense of drugs and supplies has increased by 0.70%, from the 2012 benchmark amount of 20.33%.

According to the 2023 equine benchmark, the costs of administrative expenses now account for 6.28% of total revenue (Table 4). This is a 0.73% increase from

Table 1. Income Statement Summary

	2023 Equine Benchmark	2012 Equine Benchmark
Total Revenue	**100.00%**	**100.00%**
Cost of Professional Services	27.05%	27.12%
Gross Profit	**72.95%**	**72.88%**
Total Administrative Expenses	6.28%	5.55%
Total Facility and Equipment Costs	7.96%	10.18%
Depreciation Expense	2.59%	1.19%
Total Payroll and Employee Costs	40.78%	44.49%
Net Ordinary Income	**15.33%**	**11.47%**
Net Other Income and (Expenses)	0.71%	−0.21%
Net Income	**16.05%**	**11.26%**
EBITDA	**17.93%**	**12.66%**

Abbreviation: EBITDA, earnings before interest, taxes, depreciation, and amortization.

Table 2. Revenues Summary

	2020	2021	2022
Total Revenue	$ 101,672,266	$ 117,613,213	$ 133,667,618
Average Total Revenue per Practice	$ 3,177,258	$ 3,675,413	$ 4,177,113
Total Revenue Annual Growth Rate	-	15.68%	13.65%

Table 3. Cost of Professional Services

	Jan.–Dec. 2020	Jan.–Dec. 2021	Jan.–Dec. 2022	2023 Equine Benchmark	2012 Equine Benchmark
Total Revenue	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**
Cost of Professional Services					
Drugs and Supplies	21.73%	21.41%	19.96%	21.03%	20.33%
Animal and Medical Waste Disposal	0.27%	0.33%	0.35%	0.32%	0.32%
Hospitalization	0.62%	0.71%	0.74%	0.69%	0.62%
Laboratory	2.11%	2.18%	2.30%	2.20%	1.88%
Field Service Costs	1.60%	1.63%	1.77%	1.67%	1.97%
Imaging	0.66%	0.77%	0.90%	0.78%	1.09%
Outside Services	0.20%	0.24%	0.18%	0.21%	0.00%
Other – Cost of Professional Services	0.12%	0.15%	0.22%	0.16%	0.91%
Total Cost of Professional Services	**27.30%**	**27.44%**	**26.41%**	**27.05%**	**27.12%**
Gross Profit	**72.70%**	**72.56%**	**73.59%**	**72.95%**	**72.88%**

Table 4. Administrative Expenses

	Jan.–Dec. 2020	Jan.–Dec. 2021	Jan.–Dec. 2022	2023 Equine Benchmark	2012 Equine Benchmark
Administrative Expenses					
Dues, Licenses, and Subscriptions	0.54%	0.49%	0.50%	0.51%	0.34%
Advertising and Promotion	0.74%	0.72%	0.68%	0.72%	0.62%
Office Supplies, Meals, and Expenses	0.40%	0.44%	0.51%	0.45%	0.59%
Postage Expense	0.40%	0.37%	0.33%	0.37%	0.36%
Bank Charges	0.23%	0.09%	0.11%	0.14%	0.27%
Collections and Bad Debt Expense	1.33%	1.67%	1.94%	1.65%	1.34%
Professional Fees	0.99%	0.93%	1.00%	0.98%	0.97%
Consultant Fees	0.32%	0.39%	0.49%	0.40%	0.38%
Sales and Miscellaneous Taxes	0.50%	0.64%	0.75%	0.63%	0.33%
Charitable Contributions	0.10%	0.11%	0.06%	0.09%	0.15%
Miscellaneous Expenses	0.31%	0.25%	0.33%	0.30%	0.17%
Uniforms	0.05%	0.07%	0.07%	0.06%	0.03%
Total Administrative Expenses	**5.91%**	**6.16%**	**6.77%**	**6.28%**	**5.55%**

Table 5. Facility and Equipment Costs

	Jan.–Dec. 2020	Jan.–Dec. 2021	Jan.–Dec. 2022	2023 Equine Benchmark	2012 Equine Benchmark
Facility and Equipment Costs					
Real Estate Rental Expense	4.61%	4.02%	4.15%	4.26%	5.65%
Equipment Expense	0.33%	0.36%	0.37%	0.35%	0.11%
Outside Storage Expense	0.01%	0.03%	0.06%	0.03%	0.00%
Repairs and Maintenance Expense	0.77%	0.88%	0.57%	0.74%	0.98%
Service Contracts and Maintenance Agreements	0.29%	0.26%	0.25%	0.26%	0.17%
Computer-Related Costs	0.45%	0.47%	0.53%	0.48%	0.61%
Other – Real Estate and Equipment Costs	0.00%	0.00%	0.23%	0.08%	0.26%
Property and Casualty Insurance Expense	0.58%	0.53%	0.52%	0.54%	0.70%
Property Taxes	0.31%	0.26%	0.29%	0.29%	0.34%
Utility Expense	0.49%	0.45%	0.46%	0.47%	0.66%
Telephone Expense	0.50%	0.44%	0.41%	0.45%	0.70%
Total Facility and Equipment Costs	**8.34%**	**7.71%**	**7.84%**	**7.96%**	**10.18%**

the previous benchmark. The majority is attributed to increases in the expense of collections and bad debt and sales and miscellaneous taxes. This trend can be seen both year over year and benchmark to benchmark. These expense increases are likely not unique to the equine veterinarian industry but representative of the macro-economic trends of higher usage of electronic payments and tax increases.

What practices spend on their facility and equipment is the next expense category of focus. As seen in Table 5, the equine industry today spends 7.96% of total revenue on the total costs associated with facility and equipment. The leading cost in this category is real estate rental expense, which today accounts for 4.26% of total revenue on average. In the 2012 benchmark study, real estate rental expenses accounted for 5.65% of revenue. This significant decrease (−1.39%) indicates a more substantial growth in practice revenues in comparison to escalation of rental rates. It is important to note that these facility and equipment costs do not include the cost of purchasing new equipment. These costs include facility rent and the cost to maintain the equipment used by the practice.

The single biggest expense category on every practice's income statement is total payroll and employee costs ("people costs"). In this study, total people cost was separated into three subcategories. Total professional compensation includes total wages paid to owner, associate, and intern veterinarians. Next, total lay staff compensation includes total wages paid to management, administration, technicians, contract labor, and all other support staff. Lastly, total other payroll and employee costs includes all other costs related to the employment, support, and benefit of all equine veterinary practice employees.

Overall, total people cost experienced the most significant change within the equine veterinary industry. As seen in Table 6, total people cost decreased by 3.71% since the 2012 study. This decrease indicates that total people costs have not grown as quickly as revenue and that the work force in the equine veterinary industry has become more efficient.

In total professional comp, there is little to no difference (+0.06%) between the prior benchmark and the current benchmark. A professional compensation trend worthy of note is the trade-off between owner and

Table 6. People Costs

	Jan.–Dec. 2020	Jan.–Dec. 2021	Jan.–Dec. 2022	2023 Equine Benchmark	2012 Equine Benchmark
Payroll and Employee Costs					
Compensation – Owner DVMs	10.67%	10.22%	9.42%	10.11%	9.70%
Compensation – Associate DVMs	9.86%	10.02%	12.46%	10.78%	11.09%
Compensation – Intern DVMs	0.94%	0.72%	0.83%	0.83%	0.86%
Total Professional Compensation	**21.48%**	**20.96%**	**22.71%**	**21.71%**	**21.65%**
Compensation – Management	1.15%	0.97%	1.17%	1.10%	1.46%
Compensation – Other Support Staff	2.61%	2.46%	1.73%	2.27%	1.28%
Compensation – Technician	4.74%	5.04%	5.60%	5.13%	5.59%
Compensation – Resident	0.03%	0.03%	0.03%	0.03%	0.00%
Compensation – Barn Crew	0.72%	0.67%	0.74%	0.71%	1.04%
Compensation – Administrative	2.09%	2.00%	1.59%	1.90%	3.66%
Compensation – Clerical	0.72%	0.53%	0.35%	0.53%	0.99%
Contract Labor Expense	0.16%	0.17%	0.16%	0.16%	0.85%
Total Lay Staff Compensation	**12.22%**	**11.88%**	**11.37%**	**11.82%**	**14.87%**
Payroll Tax Expense	2.29%	2.44%	2.21%	2.32%	2.54%
Workers Compensation	0.34%	0.29%	0.27%	0.30%	0.38%
Employee Benefits Expenses	3.38%	2.91%	3.21%	3.16%	3.60%
Other – Payroll and Employee Costs	0.31%	0.40%	0.20%	0.30%	0.13%
Officer Insurance Expense	0.23%	0.20%	0.18%	0.20%	0.40%
Continuing Education Costs	0.12%	0.18%	0.26%	0.19%	0.29%
Seminars and Meetings	0.02%	0.03%	0.02%	0.02%	0.12%
Travel, Meals, and Entertainment Expense	0.61%	0.76%	0.86%	0.74%	0.51%
Total Other Payroll and Employee Costs	**7.31%**	**7.22%**	**7.21%**	**7.25%**	**7.97%**
Total Payroll and Employee Costs	**41.01%**	**40.05%**	**41.28%**	**40.78%**	**44.49%**

Abbreviation: DVM, Doctor of Veterinary Medicine.

associate compensation. From 2020 to 2022, owner compensation decreased at a rate of 11.76%, while associate compensation has increased over those same years by a rate of 26.30%. Higher, more competitive compensation for associate equine veterinarians has been a topic of discussion for years, and this trend suggests an increase in both associate production and overall compensation. Also, bigger practices tend to have a bigger percentage of total professional production performed by associates rather than owners.

Lay staff compensation decreased the most of the three people costs categories. The 2012 benchmark reported lay staff compensation as 14.87% of total revenue, and the current study finds lay staff compensation as 11.82% of total revenue. This decrease of 3.05% of total revenue is over a 20% reduction. The largest contributor to this decline is in administrative compensation (−1.76%). These findings indicate an increase in efficiency and management of lay staff. The industry is getting more done (revenue increases) with less staff.

Overall, the changes observed in total payroll and employee costs represent material differences in how equine veterinary practices are managed today versus in 2012. Through advancements in both business and field technology as well as in veterinary medicine, the equine veterinary industry has become more efficient in its management of people costs.

As seen in Table 7, the equine veterinary industry averaged 11.26% of total revenues carried to net income and 12.66% of total revenues carried to EBITDA in the previous study. Today, the industry looks substantially better in terms of profitability as net income and EBITDA have increased by respective margins of 4.79% and 5.27%. This represents a 42.5% increase in net income and a 41.6% increase in EBITDA.

Balance Sheet

While the income statement presents a picture of a practice's financial performance over a period of time, balance sheets report a practice's financial position on a specific date. The balance sheet consists of three elements: assets, liabilities, and owner's equity. Assets are probable current and future economic benefits obtained or controlled by a particular entity as a result of past transactions or events. They are a practice's economic resources and represent what the practice owns. Assets can be created through operating activities (i.e., generating and retaining net income), investing activities (i.e., purchasing equipment), and financing activities (i.e., borrowing). Examples of assets include cash and cash equivalents, accounts receivables, inventory, prepaid expenses, property plant and equipment, pension assets, and intangible assets. Furthermore, assets are classified as current assets, fixed assets, other assets such as intangible assets, and long-term accounts receivables.

Liabilities are probable future economic costs and creditor claims on the company's resources and represent what a practice owes. They are created by financing activities (i.e., borrowing) and operating activities (i.e., generating net income). Liabilities arise from

Table 7. Profitability

	Jan.–Dec. 2020	Jan.–Dec. 2021	Jan.–Dec. 2022	2023 Equine Benchmark	2012 Equine Benchmark
Net Ordinary Income	**14.59%**	**15.10%**	**16.31%**	**15.33%**	**11.47%**
Other Income					
Loan Forgiveness	2.62%	0.42%	0.00%	1.01%	0.00%
Total Other Income	**2.62%**	**0.42%**	**0.00%**	**1.01%**	**0.00%**
Other Expenses					
Amortization Expense	0.17%	0.13%	0.00%	0.10%	0.07%
Interest Expense	0.20%	0.20%	0.19%	0.20%	0.14%
Total Other Expenses	**0.37%**	**0.33%**	**0.20%**	**0.30%**	**0.21%**
Net Income	**16.84%**	**15.24%**	**16.07%**	**16.05%**	**11.26%**
EBITDA	**17.44%**	**18.69%**	**17.65%**	**17.93%**	**12.66%**

Abbreviation: EBITDA, earnings before interest, taxes, depreciation, and amortization.

Table 8. Financial Ratios

	12/31/2020	12/31/2021	12/31/2022	2023 Equine Benchmark	2012 Equine Benchmark
Days of Operating Expenses in Cash	34.77	32.24	27.49	31.17	-
Days Sales in Accounts Receivable	26.29	21.12	22.04	23.15	40.25
Asset Turnover Ratio	3.55	3.63	3.69	3.62	3.65
Fixed Asset Turnover Ratio	12.96	10.49	8.88	10.77	4.00
Debt to Equity Ratio	0.73	0.64	0.71	0.69	0.31
Profit Distributions as a % of EBITDA	62.42%	58.47%	56.41%	59.10%	70.16%

Abbreviation: EBITDA, earnings before interest, taxes, depreciation, and amortization.

present obligations of a particular entity to transfer assets or provide services to other entities in the future as a result of past transactions or events. Examples of liabilities include accounts payable, short-term notes payable, unearned revenue, income taxes payable, and long-term notes payable. Furthermore, liabilities are classified as current liabilities and long-term liabilities.

Owner's equity is the residual interest in the net assets of an entity that remains after deducting liabilities and represents how much of the owner's money is invested in the business. Equity is created by financing activities and by operating activities. Owner's equity consists of capital contributed by the practice's owners and the cumulative earnings the practice has retained and not distributed. Examples of owner's equity includes contributed capital, par value of common stock, additional paid in capital, and retained earnings.

The relationship between assets, liabilities, and owner's equity is always a balance, and the use of financial ratios helps determine how the various parts of the balance sheet relate to each other. Financial ratios are based on historical data and provide insight into the financial relationships that are useful in forecasting future earnings and cash flow and on information about the financial flexibility of the practice, and they are also a means of evaluating management performance internally, to its peers and investors.

Table 8 includes financial ratios representative of the equine veterinarian industry. These ratios are inclusive of data from the income statements and balance sheets submitted for this study. The balance sheet data collected include practice assets, liabilities, and owner's equity as of December 31 for 2020, 2021, and 2022. The "2023 Equine Benchmark" column values represent a 3-year arithmetic average of each recent year's ratio calculation.

Days of operating expenses in cash represents the number of days a company can continue operations with the cash on hand, assuming there were no further receipts from revenue. Today, on average, equine veterinarian practices can maintain current operations, with no new revenue received, for a total of 31 days before running out of cash. If a practice were to use this standard, then conceivably, that practice could distribute all cash in excess of their 31 days of operating expenses on hand.

The days sales in accounts receivable ratio measures the average number of days it took to collect account receivable throughout a given. The lower the ratio, the more efficient a practice is at collecting accounts receivable. On average, the industry has become significantly more efficient in the collection of accounts receivable since 2012. As seen in Table 8, the change in averages from 40.25 in 2012 to 23.15 in 2023 represents a 42.13% decrease, or nearly 17 fewer days in the collections of account receivables. This improvement could be due to better systems for collecting outstanding accounts receivable or the continued adoption of the process of collecting fees and costs at the time the service is rendered.

The asset turnover ratio measures the company's effectiveness in generating sales from its total assets. If the asset turnover ratio is low as compared to the industry, it means that sales are low or that they have an inefficient abundance of assets. As seen in Table 8, the industry holds a current average asset

turnover ratio of 3.62. This means that for every dollar of assets, $3.62 of revenue is generated per year. In general, the asset turnover ratio will be lower for hospital-based practices as the total assets used to generate sales by a solely hospital-based practice should be greater than that of a solely ambulatory-based practice.

The fixed asset turnover ratio measures the company's effectiveness in generating sales from its investments in plant, property, and equipment. If the fixed asset turnover ratio is low as compared to the industry, it means that sales are low or the investment in plant and equipment is comparatively high. Today, on average, for every dollar of net fixed assets (adjusted for depreciation), $10.77 of revenue is generated in the equine veterinary industry. Since 2012, there has been a $6.77 increase (+169.25% increase) in revenues generated by each dollar of net fixed assets. This continues to confirm the overall trend of increased operational efficiency in the equine veterinary industry since 2012.

The debt to equity ratio indicates what proportion of equity and debt the company is using to finance its assets. A ratio greater than 1 means assets are mainly financed with debt, while less than 1 means equity (or the owner's money) provides a majority of the financing. In Table 8, this ratio has more than doubled in the last 10 years. Also, until recently, the economy had experienced decreasing interest rates for well over 10 years. In recent years, the cost of borrowing money was at historic lows. The decision to finance equipment purchases, practice expansions, and other capital expenditures using debt was economically sound. Moving forward, this ratio is expected to decline as interest rates rise and financing capital expenditures becomes more expensive.

Profit distribution as a percentage of EBITDA measures the amount paid out to owners as distributions out of the total profits or earnings of the company. The higher the percentage, the less a company is using cash flow on capital expenditures and/or debt service. In Table 8, when comparing the two studies' results, there has been a significant decrease in profit distributions as a percentage of EBITDA. As discussed below, profit distribution is the key element in the valuation of a practice.

Valuation

It is not only the authors' belief but also that of the majority of small business investors and Wall Street alike that the best way to determine what a "willing buyer and a willing seller" would pay for a business is based on the profitability of the company and the cash flow generated by the business and returned to the owners in the form of profit distributions or dividends. This approach to valuation is known as discounted cash flow analysis. Every business can be valued on this basis, and the key fact used in this type of analysis is the historical and projected cash the owner will make as a result of their ownership.

The cash flow of a business is determined by taking the net income of a business and adjusting for the noncash items contained within that net income number. Depreciation is one of the most obvious noncash charges against income that must be added back to determine net cash flow from a business. There are several others including adjusting the net income, if the business reports net income on an accrual basis, for changes in accounts receivable and accounts payable and other deferred or accrued items of income and expense. The final adjustment relates to capital expenditures. Cash flow should be reduced to the extent the business takes a portion of its profits and spends that money on capital expenditures such as equipment, real estate, or other assets.

Once a business has determined its current cash flow, it must consider how that cash flow is going to grow over time. Once that is determined, one can project how much cash flow a particular business might generate over time. Obviously, one would not pay the same for cash created 10 years from now that they would pay for cash created today. These future cash flows must be discounted back to today's dollars. This is done by taking each future cash flow that the business will create and determining how much money that cash flow in the future is worth today. Another way to think about this is to consider how much money would have to be put to work today, at a given interest rate, for that money to be worth the cash flow from the business in that future year.

The "interest rate" applied today to those future cash flows is also known as the discount rate. The riskier the business, the higher the discount rate. Another way to state this is that the discount rate is equal to the risk that the future cash flows of the business will not be realized.

There is a readily accepted formula for determining the discount rate in most situations. There are three components to the formula. First is a typical market return. Ten percent is used in this paper's calculations for market return. Over an extended period, the stock market has returned an average of approximately 10%. From this market return of 10%, subtract the risk-free rate of return. Over a long period, the 10-year U.S. Treasury bond yields approximately 2%. This results in an 8% risk-adjusted rate of return. Then, multiply this risk-adjusted rate of return by the beta of the individual company. Beta is a factor ranging from 0 to 2 and is designed to measure how much more risk a particular investment has when compared to an index—for instance, the S&P 500. Because equine practices are not traded on any exchange and are therefore relatively illiquid, a higher than average beta is reasonable. For this study, a beta of 1.04 was assigned (0 being no risk in the market, 1 being average risk in the stock market, and 2 being the most risk possible in the stock market). To get the final discount, multiply the risk-adjusted rate of return of 8% by the beta of 1.04 plus the risk-free rate of return, resulting in a discount rate of 10.32%. This appears reasonable as an overall measure of risk for a

business. The other way to consider this discount rate is: Would an owner be willing to buy their business if a 10.32% rate or return on that investment was possible? Lastly, for future years of profit distributions, conservative annual growth rates of 5% in years 1 to 5 and 2% in years 6 to 10 are assumed. Years 11 to infinity are represented by the terminal value. The terminal value is the present value of all future cash flows beyond the defined forecast period. In the study, as well as in general, the defined forecast period covers a period of 1 to 10 years and represents the period during which the company's future cash flows can be estimated with reasonable accuracy. However, beyond the defined period, forecasting becomes more uncertain, and it may be challenging to estimate cash flows accurately. Overall, a more conservative input for the terminal growth rate will reduce the risk of overvaluing all future cash flows outside of the defined forecast period of 10 years. In the current study of the equine veterinary industry, profit distribution cash flows grew at an average annual rate of 9.84%. In the discounted cash flow analysis calculation below, it is assumed that profit distribution cash flows outside of the defined forecast period grow at a conservative terminal growth rate of 1.0%.

The marketability discount is a reduction in the value of an investment due to its lack of marketability, which refers to the difficulty of converting an investment into cash quickly and with minimal transaction costs. In the case of a privately held veterinary practice, the marketability discount would reflect the lack of liquidity of the practice, the degree of competition in the same market, and the fact that it is not openly traded on any exchange. The appropriate marketability discount for a privately held veterinary practice would depend on various factors, including the size of the practice, the location, the quality of the financial statements, the competitive landscape, and the demand for similar practices in the market. In the study, a marketability discount of 42.5% was applied. In terms of the practices included in the study, this would mean that the estimated fair market value of the practices has been reduced by 42.5% to account for their lack of marketability. The applied discount rate of 42.5% is reflective of empirical industry research, case law, and the overall perceived difficulty of selling interest in a privately held veterinary practice.

Given the factors described above, Table 9 illustrates the calculation of the discounted, present value of all future, expected cash flows based on the total profit distributions made in 2022 from the practices included in the study.

As seen in the previous calculation, 2022 total profit distributions generate an aggregated discounted cash flow value of just over $95.8 million for the 23 practices included in the study. Therefore, as of December 31, 2022, the study's participating practices carried an average discounted cash flow value of $4,165,599 per practice. Another important metric to take note of is the valuation EBITDA multiple of 4.06. This metric calculation takes the discounted cash flow value ($95.8 million) divided by the year-end 2022 EBITDA ($23.6 million). Actual figures from the study can be seen in Table 10.

Table 9. Discounted Cash Flow Analysis 2022

2022 Total Profit Distributions	$13,308,612	
Year Range	**1–5**	**6–10**
Growth Rate	5%	2%
Discount Rate	10.32%	
Terminal Growth Rate	1%	

Year	Flows	Growth	Value
1	$13,308,612	5%	$12,063,644
2	$13,974,043	5%	$11,481,895
3	$14,672,745	5%	$10,928,199
4	$15,406,382	5%	$10,401,205
5	$16,176,701	5%	$9,899,624
6	$16,500,235	2%	$9,153,024
7	$16,830,240	2%	$8,462,731
8	$17,166,845	2%	$7,824,497
9	$17,510,181	2%	$7,234,398
10	$17,860,385	2%	$6,688,801

Terminal Year	$ 18,038,989
Present Value of Year 1–10 Cash Flows	$ 94,138,018
Terminal Value	$ 72,485,936
Total Present Value of Cash Flows	$ 166,623,953
Marketability Discount	42.50%
Total Value × Marketability Discount	$ 95,808,773
EBITDA Multiple	4.06

The same discounted cash flow value calculation was run using the profit distributions made in the years 2020 and 2021 (Table 10). Over the last 3 years, profit distributions grew at an average annual rate of 9.84%. But, as seen in Table 9, profit distributions as a percentage of EBITDA decreased year over year at an average annual rate of 4.93%. This combination of increasing profit distributions and decreasing profit distributions as a percentage of EBITDA indicates that the portion of EBITDA used on capital expenditures, debt service, and cash accumulation has increased.

A practice's use of EBITDA is an important metric of which to be aware. All else constant, higher profit distribution as a percentage of EBITDA translates into higher valuation EBITDA multiples. The higher the valuation EBITDA multiple, the more efficient the practice is in generating profit distributions. Using numbers, if the practices in the study maintained 2020 profit distribution as a percentage of EBITDA of 62.42% in 2021, total profit distribution in 2021 would total $13,723,095. Using that total, the discounted cash flow value generated would equal $98,792,636 with a corresponding valuation EBITDA multiple of 4.49.

As stated in the previous discussion of financial ratios (Table 8), on average, profit distribution as a

Table 10. Valuation Values

	2020	2021	2022	2023 Equine Benchmark
Profit Distributions	$ 11,067,330	$ 12,854,181	$ 13,308,612	-
Profit Distributions as a % of EBITDA	62.42%	58.47%	56.41%	59.10%
DCF Value	$ 79,673,775	$ 92,537,324	$ 95,808,773	-
EBITDA	$ 17,730,825	$ 21,985,590	$ 23,593,690	-
EBITDA Multiple	4.49	4.21	4.06	4.25

Abbreviations: EBITDA, earnings before interest, taxes, depreciation, and amortization; DCF, discounted cash flow.

percentage of EBITDA equaled 70.16% in the 2012 study. Today, on average, the industry distributes 59.10% of EBITDA. The change would suggest that the industry has become less efficient in generating profit distributions and that EBITDA multiples have declined. This long-term decline of EBITDA multiples is observed over the past 3 years in Table 10.

On average, the equine veterinary practice today can be valued on an internal basis by multiplying EBITDA by 4.25. This multiple can be used as a rough estimate of value when considering an internal succession. Internal succession occurs when an existing owner sells a portion of the practice to an associate that works in the practice. Much has been made of multiples of EBITDA in the industry over the last few years. Multiples used by a purchaser who is not working in the practice can be, and in many cases have been, much higher than this standard.

5. Conclusions

This study can be used to better inform practice owners and managers and help those stakeholders keep score with the finances of their practice. Properly applied, a practice owner and manager can identify the places where their practice differs from these industry benchmarks and have better understanding on where to focus their management efforts.

Acknowledgments

Declaration of Ethics

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

Conflict of Interest

John Chalk, Jr. owns the registered investment advisory firm Trinity Portfolio Advisors, LLC. Based in Southlake, Texas, Trinity Portfolio Advisors, LLC is a paid consultant to owners of veterinary practices. John has no conflicts of interest in this presentation. Alec Maixner and Max May are financial analysts employed by Trinity Portfolio Advisors, LLC. Alec and Max have no conflicts of interest in this presentation.

Exploring the Gender Wage Gap in Equine Veterinary Medicine

Amy L. Grice, VMD, MBA

Gender disparity in wages for equal work exists across the globe and in many professional career fields, including veterinary medicine. The reasons for the wage differences in equine veterinary practice are unclear, but the data on divergence in revenue production despite similar work hours suggest that the gap occurs for reasons unrelated to time spent working. Some possibilities to explain the disparity include gender differences in communication styles, gender differences in the importance of relationships for job satisfaction, gender differences in confidence/self-worth, and unconscious biases causing more lucrative work and effective mentoring to be provided to men than women. Author's address: PO Box 192, Virginia City, MT 59755-0192; e-mail: amyvmdmba@gmail.com. © 2023 AAEP.

1. Introduction

According to a recent gender wage gap study by the Pew Research Center, women working full-time in the United States in 2022 typically earned 82 cents for every dollar earned by men. Twenty years ago, in 2002, they earned 80 cents to the dollar. Thus, in 2 decades, an improvement of 2 cents has been achieved. This contrasts sharply with the progress made in the preceding two decades, when in 1982, women earned just 65 cents to each dollar earned by men, and 15 cents was gained by 2002.[1] If the slow pace of improvement continues, it will take about 132 more years for women to reach pay equality.[2] Until then, the gender wage gap will continue to impact women in all fields and industries, impairing their financial security and the quality of their lives through retirement.

Educational achievements have led to economic progress for women, but the gender wage gap still exists for women who have the same education as men. Even when adjusting the gender wage gap for education, college major, and occupation, women still earn 92 cents for every dollar paid to men.[3]

2. Discussion

Not surprisingly, veterinary medicine also has a gender-related wage gap, primarily affecting recent graduates and the top half of earners, according to research done by the Cornell University School of Veterinary Medicine. For the top quarter of earners, the annual difference is approximately $100,000. According to Dr. Clinton Neill, senior author on the research paper, "Similar to what's been found in the human medicine world, we found the wage gap was more prominent in the beginning of their careers, but dissipates after about 25 years. This has large implications for lifetime wealth and earnings, as men will consequently have a larger sum of wealth at the end of their careers because of this."[4]

NOTES

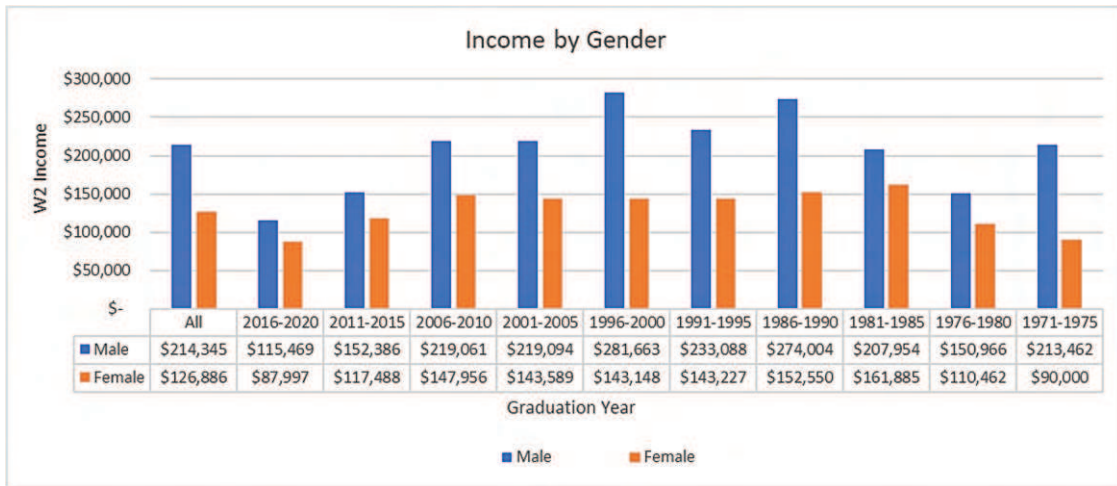


Fig. 1. Income by gender and graduation year cohorts.

Graduation Years	Male	Female	Difference
All	$ 214,345	$ 126,886	40.8%
2016-2020	$ 115,469	$ 87,997	23.8%
2011-2015	$ 152,386	$ 117,488	22.9%
2006-2010	$ 219,061	$ 147,956	32.5%
2001-2005	$ 219,094	$ 143,589	34.5%
1996-2000	$ 281,663	$ 143,148	49.2%
1991-1995	$ 233,088	$ 143,227	38.6%
1986-1990	$ 274,004	$ 152,550	44.3%
1981-1985	$ 207,954	$ 161,885	22.2%
1976-1980	$ 150,966	$ 110,462	26.8%
1971-1975	$ 213,462	$ 90,000	57.8%

Fig. 2. Percentage difference of income between genders by graduation year cohorts.

Veterinary medicine is not alone among the professions struggling with pay differences between genders. According to the 2022 Medscape Physicians Compensation Report,[5] a decade ago, male primary care physicians earned 23% more than their female colleagues. In 2022, that disparity has grown to 25%, with male doctors earning an average of $285,000 to the women's $228,000. In the specialties, the gap widens further, with the women's average earnings ($307,000) totaling 31% less than the men's ($402,000). In the profession of dentistry, 30 years ago, the gap between male ($143,900) and female dentists ($65,700) was exceptionally high, and although it has narrowed considerably, differences remain. Current Department of Labor statistics show median annual earnings of $167,574 for men and $140,040 for women in the dentistry career, just 83.6% of their male counterparts.[6] Attorneys also face wage gaps. The pay gap between male and female law partners is about 44%, with male partners averaging $1,130,000 and female partners $784,000.[7] Among employee attorneys, Bureau of Labor Statistics data show a gap of 26.5% between the women's earnings and that of the men.[8]

The 2016 AAEP AVMA Equine Economic Study offered some data concerning a wage gap in the equine veterinary industry. In that study, male equine practice owner respondents who graduated in the period between 2012 and 2016 reported an average starting salary post-internship of $61,867, while female respondents reported an average starting salary post-internship of $51,109. This gender disparity in starting salaries after internship for equine respondents in the last 5 years was approximately $10,000, or 16.2% lower for women. When separating mean income by gender in the study, in all comparisons, the mean income of male respondents exceeded female respondents by a statistically significant amount. Female equine practice owner respondents had a mean income that was $55,000 less than male owners ($85,000 female vs. $140,000 male). A $24,000 difference between male and female equine respondent associates was also found. When considering these findings, it is important to remember the age and experience differences between the male and female respondent cohorts, as the less experienced practitioners overwhelmingly were female. The highly significant wage gap that was noted between male and female respondents was calculated by multiple linear regression analyses to be about $30,000 for equine respondents.[9]

To glean more current compensation data, in 2022, the AAEP Commission for Equine Veterinary Sustainability's Compensation Subcommittee contracted with Comer Research Consultants to perform a survey under the guidance of the leadership of the Compensation Subcommittee. The survey was emailed to 6,564 active members of the AAEP in September 2022, and the 1,378 respondents yielded a participation rate of 21%. The questions had a broad range but concentrated on compensation. Respondents were asked to provide their 2021 W2 income from employment as a veterinarian or, if owners, their earnings for their efforts as a veterinarian, not including ownership-related distributions or return on investment.

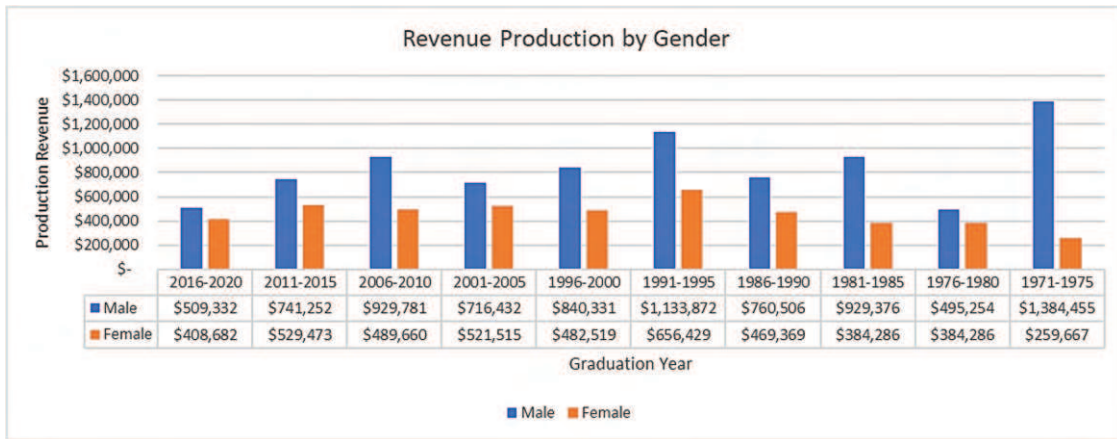


Fig. 3. Revenue production by gender and graduation year cohorts.

Graduation Years	Male	Female	Difference
All	$ 836,929	$ 487,732	41.7%
2016-2020	$ 509,332	$ 408,682	19.8%
2011-2015	$ 741,252	$ 529,473	28.6%
2006-2010	$ 929,781	$ 489,660	47.3%
2001-2005	$ 716,432	$ 521,515	27.2%
1996-2000	$ 840,331	$ 482,519	42.6%
1991-1995	$ 1,133,872	$ 656,429	42.1%
1986-1990	$ 760,506	$ 469,369	38.3%
1981-1985	$ 929,376	$ 384,286	58.7%
1976-1980	$ 495,254	$ 384,286	22.4%
1971-1975	$ 1,384,455	$ 259,667	81.2%

Fig. 4. Percentage difference of revenue production between genders by graduation year cohorts.

The results of the survey were evaluated by graduation year, type of practice, location, revenue production, average number of hours worked, as well as gender. Five- and 10-year graduation year cohorts were utilized to report the results. Because 2021 graduates were students for half the year, their W2 wages were only for 6 months. Because many 2022 graduates were interns for half the year, their wages as an associate were for only 6 months of the year. Consequently, both 2021 graduates' and 2020 interns' data were removed from the analysis.

Distinct gender differences in earnings were noted (Fig. 1). Across all respondents and graduation years, there was a negative disparity in female income compared to male income (Fig. 2). It is interesting to note that the disparity is less during the entry-level decade compared to nearly all of the middle and later decades.

In exploring the reasons behind these differences in income, it is necessary to consider the gross production revenue personally earned by the veterinarians. In much of equine veterinary medicine, compensation is tightly linked to the revenue produced by the individual for the practice (Fig. 3).

During the first 5 years of employment as an equine veterinarian, women have about 20% lower revenue production than men. This disparity continues and worsens over graduation years. The unusually high production average in the male cohort of 1971 to 1975 is likely to have unrealistically skewed this cohort's data set. Nevertheless, there clearly are real differences in the gross production revenue that is earned by the different genders (Fig. 4).

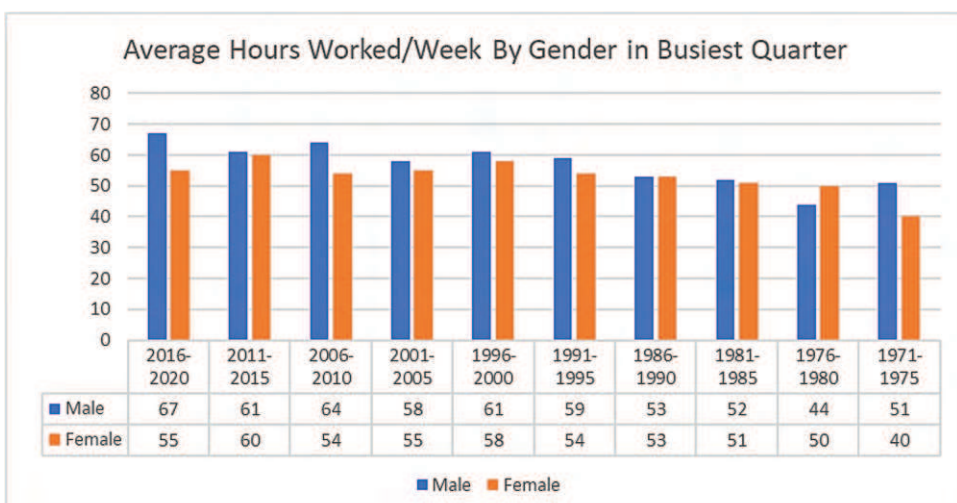


Fig. 5. Average hours worked per week by gender and graduation year cohorts in busiest quarter.

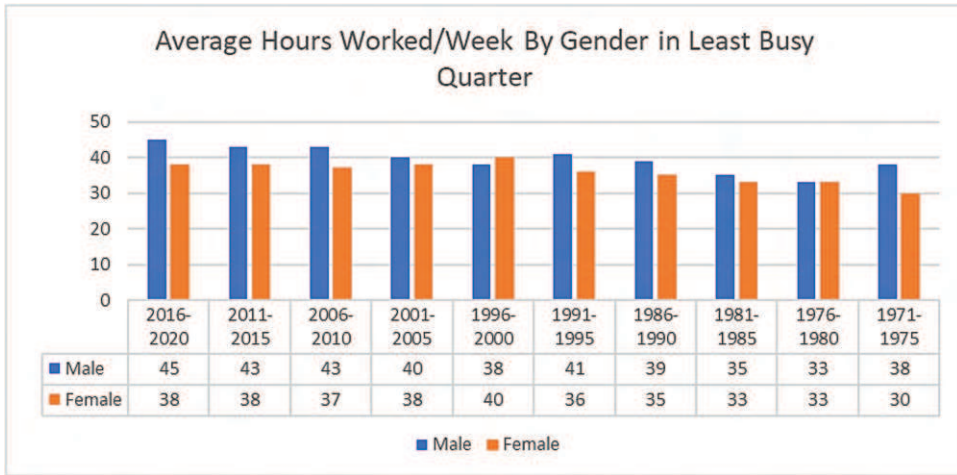


Fig. 6. Average hours worked per week by gender and graduation year cohorts in least busy quarter.

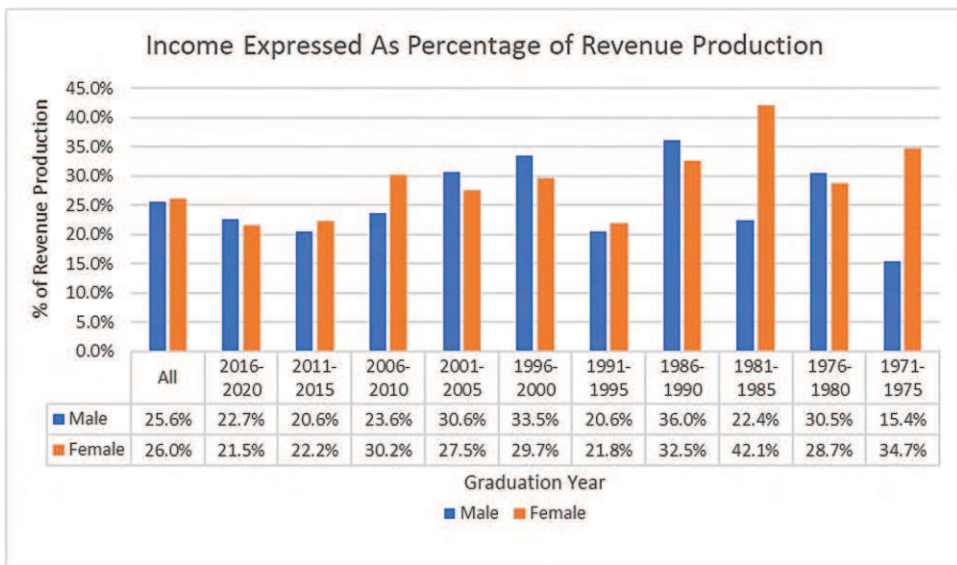


Fig. 7. Income expressed as percentage of revenue production.

One might then wonder if the women are working less hours than the men as a factor in the lower revenue produced. Respondents were asked to report the average number of hours that they worked each week in the busiest quarter of the year and in the least busy quarter of the year (Figs. 5 and 6).

When examining the average number of hours that each graduation cohort worked each week during the busiest and least busy quarters, it is apparent that male and female veterinarians work fairly similar hours, with the exception of the early-career men who graduated between 2016 and 2020 working about 7 to 12 hours per week more than the women and the men who graduated between 2006 and 2010 working about 6 to 10 hours per week more than the women. Over 50 weeks, this difference adds up to about 50 extra days of production, which could explain disparities in revenue production for these graduation year cohorts, but not those of the other cohorts.

In order to explore the disparity in earnings between the genders, the income earned was expressed as a percentage of the gross revenue production for each graduation cohort (Fig. 7).

When looking at all respondents, both men and women reported income that was 25% to 26% of the average revenue production. Small differences are present in the first decade after graduation, after which no pattern emerges to shed light on the gender disparities in revenue production and income previously noted.

In order to examine the hours worked in relation to the wages earned for each gender, the reported W2 income for 2021 was divided by 52 weeks and then divided by the average of the hours worked per week in the busiest and least busy quarters combined (Fig. 8).

In this analysis, it is shocking to discover that those in the first 5 years after graduation (2016–2020) earned an hourly wage just marginally more than

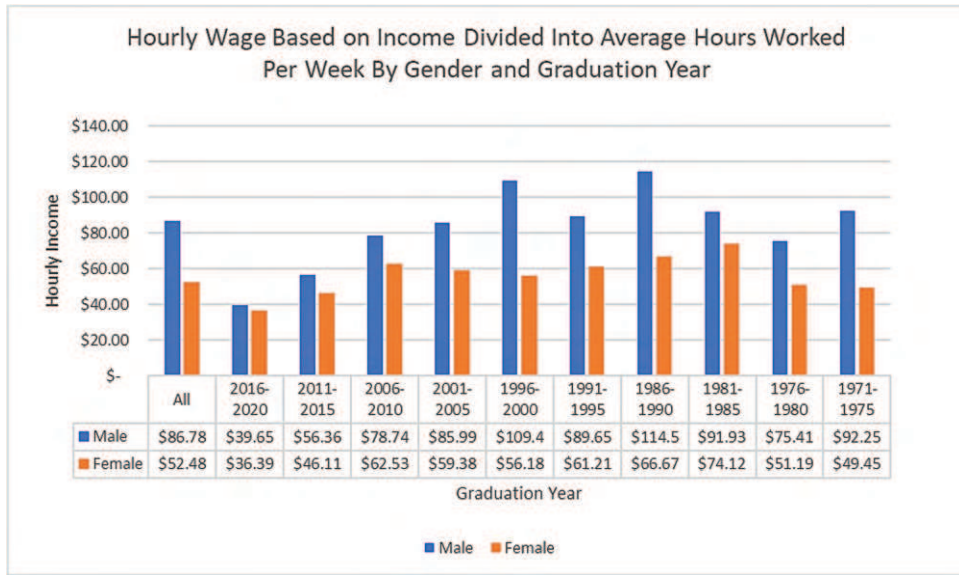


Fig. 8. Hourly wage by gender and graduation year.

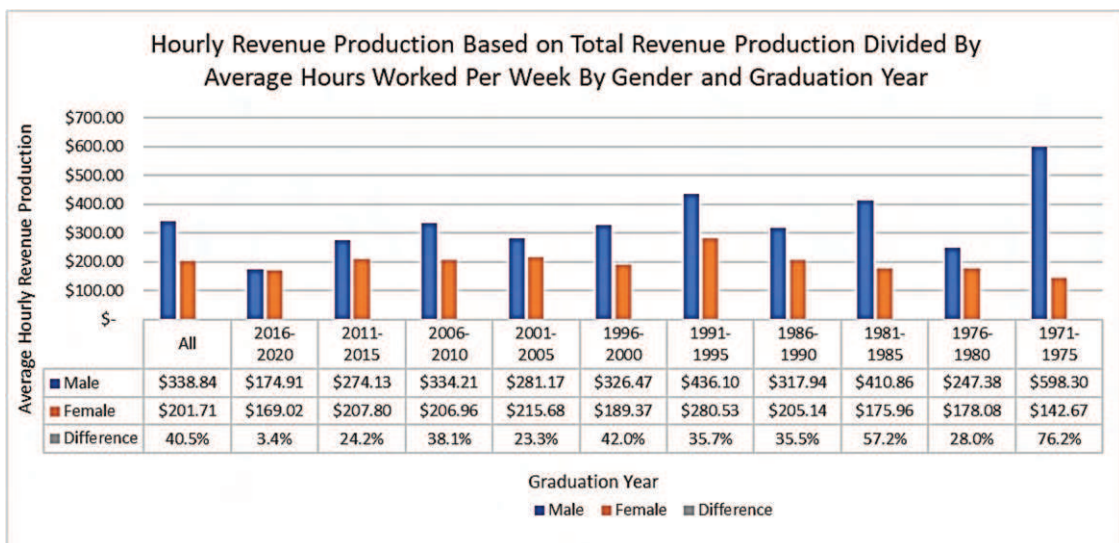


Fig. 9. Hourly revenue production by gender and graduation year.

that of an experienced veterinary technician, but without the benefit of overtime, and for some, including emergency fee compensation. The results also show that the average hourly wage for men is higher than that for women in every graduation year cohort. These results suggest that the women are producing less revenue on an hourly basis—revenue on which their income is based. To illustrate this idea more clearly, hourly revenue production for each gender was calculated by dividing the total revenue production by 52 weeks and then dividing by the average hours worked per week in the busiest and least busy quarters combined (Fig 9).

The results of this analysis show that female respondents produced markedly less revenue per hour worked than the men in all graduation years except the graduation years 2016 to 2020.

Determining the reasons for these disparities was not possible in this study. A time-tracking study has been planned for 2023 by the Compensation Subcommittee to try to elucidate these differences. Hypotheses generated by the members of the subcommittee to explain the difference in revenue produced per hour include communication style differences between genders, increased time spent by female veterinarians to create complete medical records, increased prevalence among women for enjoyment of the connections and relationships with clients, and a decreased confidence in their value/worth that creates a reluctance to charge robustly for their time. In addition, it was suggested that unconscious biases may exist among more senior veterinarians that cause them to prioritize mentoring and sharing of more lucrative work with male associates over female if they have both genders in the practice.

Continued efforts to understand the reasons for the gender differences in compensation and revenue production in equine veterinary medicine are imperative to ensure a bright future for all who embark on this career.

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.

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How to Perform a Point-of-Care Ultrasound of the Cardiorespiratory System (CRASH)

Cris Navas de Solis, LV, PhD, DACVIM

This session will help practitioners learn how to complete a cardiorespiratory assessment with sonography of the horse (CRASH), a protocol to assess the cardiovascular and respiratory system of horses in a goal-oriented, time-sensitive approach. Author's address: University of Pennsylvania, New Bolton Center, 382 West Street Road, Kennett Square, PA 19348; e-mail: navasdes@vet.upenn.edu. © 2023 AAEP.

1. Introduction

The most common point of care ultrasound (POCUS) protocol used in horses is FLASH (fast localized abdominal sonography of horses).[1] This is a protocol with 7 standardized windows for the evaluation of the adult horse with acute colic. Similarly, a POCUS protocol for the evaluation of the thorax in humans and small animals is referred to as TFAST (thoracic fast assessment with sonography of trauma). The concept of having a fixed, tested protocol with known performance and limitations is clinically attractive. For this reason, a protocol to assess the horse with cardiorespiratory disease analogous to FLASH for the horse with colic or to TFAST for small animals has been developed. In the horse, a protocol developed for the evaluation of patients with cardiorespiratory disease was named CRASH: cardiorespiratory assessment with sonography of the horse. This is a POCUS protocol to assess the cardiovascular and respiratory system of horses using a goal-oriented, time-sensitive approach. Echocardiographic windows described for this protocol are standard echocardiographic windows as recently summarized by Schwartzwald.[2] Thoracic windows were chosen based on sonographic location of common respiratory diseases in horses.

2. Materials and Methods

The protocol can be performed on most horses with an unclipped haircoat using alcohol as a coupling agent. A macroconvex probe, a sectorial probe, and many of the POCUS/pocket-sized devices currently on the market are adequate to perform this protocol. A displayed depth of 30 cm is preferred, and 28 cm may be adequate in most horses. See Fig. 1 for standard images of the CRASH.

3. Results

The objective of CRASH is to answer 8 specific questions:

1. Is there increased pleural fluid? This is seen as fluid in the pleural space. Fluid is

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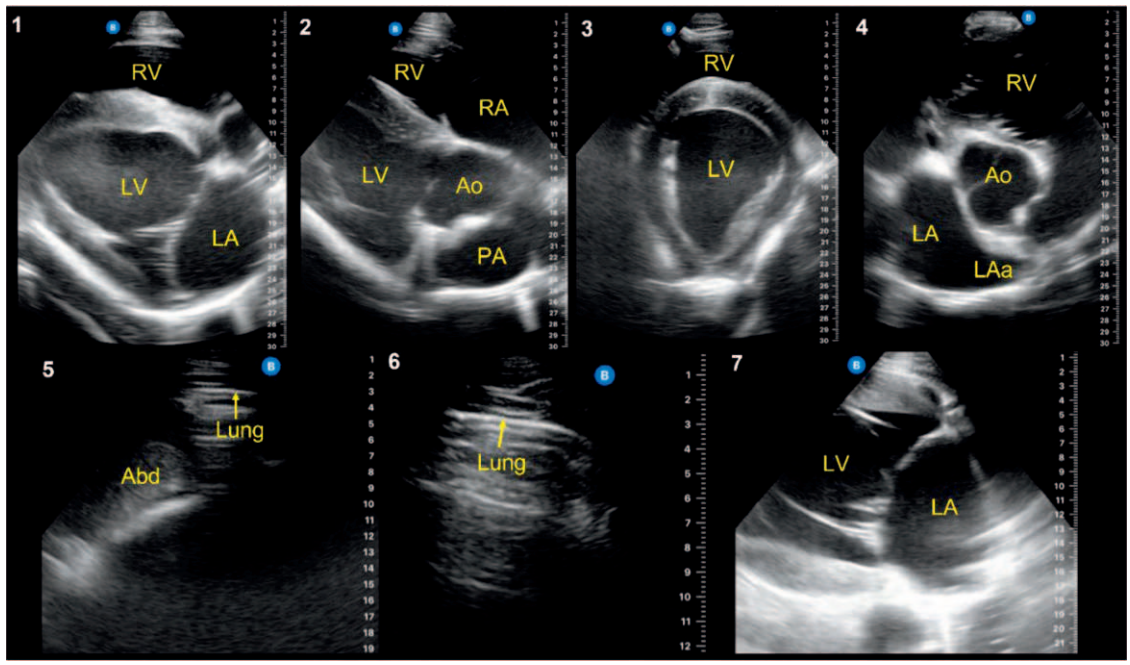


Fig. 1. Standard images of CRASH. 1, Right parasternal long-axis 4-chamber view. The transducer is positioned in the right fourth intercostal space at a level slightly above the olecranon, angled caudally, and rotated clockwise to the 1 o'clock position. The ventricles, atrioventricular valves, and atria are imaged. Imaging the left ventricular (LV) apex is prioritized, and the dorsal aspect of the atria may not be imaged in its entirety in all horses. This view is used to assess the structures and dimensions of the left ventricle and left atrium (LA). RV, right ventricle. 2, Right parasternal long-axis view of the left ventricular outflow tract. Starting from a 4-chamber view, the transducer is angled cranially and rotated to the 2 o'clock position. It is used to assess the structure and dimensions of the aorta (Ao) and the pulmonary artery (PA). Specific attention is paid to the relative size of the pulmonary artery and the aorta as a marker for pulmonary hypertension. RA, right atrium. 3, Right parasternal short-axis view at the level of the chordal attachments. This view is obtained by rotating the transducer clockwise to the 3 to 4 o'clock position from a 4-chamber view. It is used to assess ventricular size. 4, Right parasternal short-axis view at the level of the aorta. This view is obtained by moving the transducer dorsally from the chordal attachments and rotating the probe to the 5 to 6 o'clock position. The aorta is seen centrally with the left atrium and left atrial appendage (LAa) visualized caudally toward the far field. The size of the left atrium can be directly compared with the aorta similarly to the LA:Ao ratio described in small animals. 5, Caudoventral thoracic window (right and left). The caudo-ventral thorax from the right side is viewed in a longitudinal plane over the 7th intercostal space. A hyperchoic echo of lung, A-lines, and gliding respiratory motions are the expected normal appearance. The diaphragm is viewed at the ventral aspect of the window to ensure ventral position. Abd, abdomen. 6, Caudodorsal thoracic window (right and left). The caudodorsal thorax from the right side is viewed in a longitudinal plane over the 15th intercostal space. A hyperechoic echo of lung, A-lines, and gliding respiratory motions are the expected normal appearance. 7, Left parasternal long-axis 2-chamber view. The transducer is positioned in the 5th or 4th left intercostal space slightly above the olecranon. The left ventricle, left atrium, and mitral valve are viewed. Imaging of the left atrium is prioritized, and the apex of the left ventricle may not be viewed. This view has traditionally been used for assessment of left atrium dimensions.

considered relevant to report if it is more voluminous than in the lateral aspect of the most ventral lung tip and more than approximately 1 cm in depth.

2. Is there increased pericardial fluid? This is seen as fluid visible in the pericardial space that is more than a few millimeters in depth.
3. Is there moderate or severe lung pathology, such as consolidation, masses, abscesses, and severe or coalescing B-lines or comet tails? Consolidation is defined as a hypoechoic area of lung with bronchial or vascular markings present. Masses and abscesses are defined as well-circumscribed areas in the lung or pleural space that do not contain normal bronchial or vascular markings. Moderate or severe B-lines or comet tails are defined as interruptions of the smooth and regular hyperechoic echo of lung that merge or create patches.
4. Is there pneumothorax? Pneumothorax is the presence of air in the pleural space. This is visible as a hyperechoic echo of gas free in the pleural space (outside of the lung) with absence of the normal hyperechoic lung margin, which slides dorsally and ventrally with respiratory motions.
5. Is there evidence of moderate or severe pulmonary hypertension? This is evident when a pulmonary artery is larger than the aorta's sinotubular junction or when there is a change in shape of the interventricular septum by becoming concave right to left.
6. Is there evidence of moderate to severe left-sided heart disease? This is supported by a

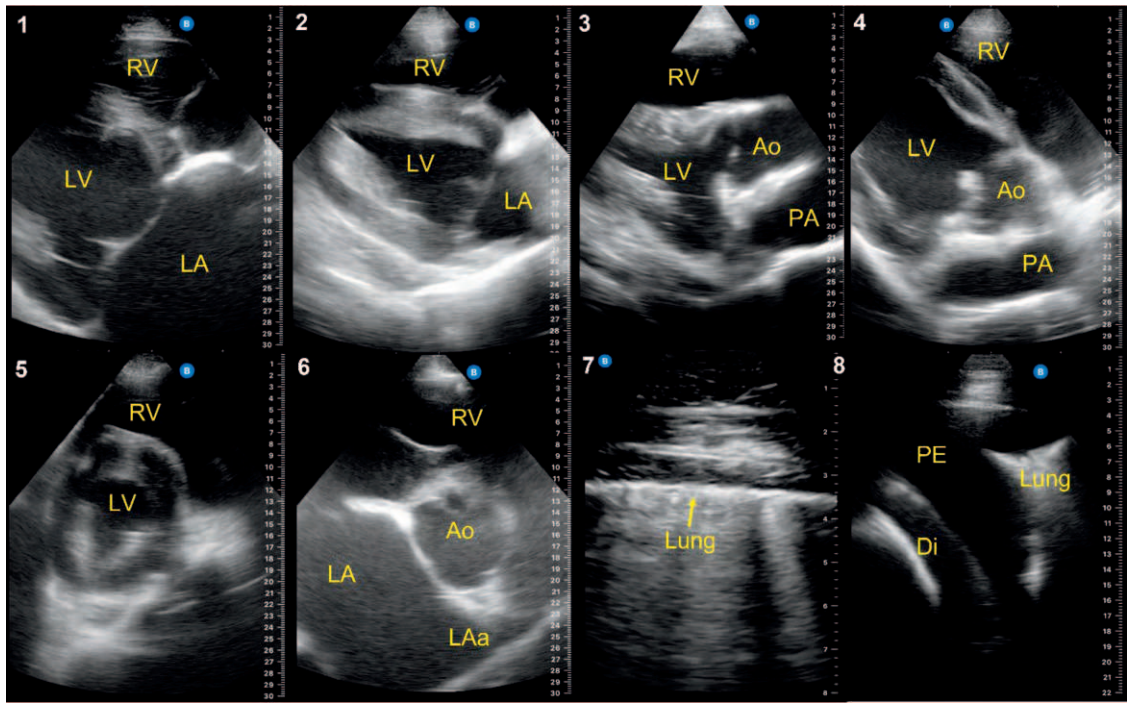


Fig. 2. Images from horses presented for systemic disease and presenting abnormalities visible on the CRASH examination. 1, Right parasternal long-axis 4-chamber view. There is severe left atrial enlargement. The left atrium is rounded, several-fold larger than the right atrium, and expanded beyond the far field of a 30-cm displayed depth. LV, left ventricle; LA, left atrium; RV, right ventricle. 2, Right parasternal long-axis 4-chamber view. The myocardium of the left ventricle is subjectively thickened with an appearance of hypertrophy/pseudohypertrophy. 3, Right parasternal long-axis view of the left ventricular outflow tract. The pulmonary artery is larger than the aorta, and the interventricular septum is flattened convex right to left, suggesting pulmonary hypertension. Ao, aorta; PA, pulmonary artery. 4, Right parasternal long-axis view of the left ventricular outflow tract. The aorta has a large nodular lesion. 5, Right parasternal short-axis view at the level of the chordal attachments. The myocardium of the left ventricle is subjectively thickened with an appearance of hypertrophy/pseudohypertrophy. 6, Right parasternal short-axis view at the level of the aorta. The size of the left atrium is disproportionally large in comparison with the size of the aorta. LAa, left atrial appendage. 7, Caudodorsal (Image 6) thoracic window (right and left). A hyperechoic echo of lung with coalescing B-lines/comet tail artifacts is seen. 8, Caudoventral thoracic (Image 5) window (right and left). There is a large amount of pleural fluid. PE, pleural effusion; Di diaphragm.

left ventricular apex that is rounded and not cone shaped, a severely enlarged left ventricle that is compressing the right ventricle, or a moderate to severely enlarged left atrium that has lost its rectangular shape and is disproportionate to the size of the right atrium.

7. Is there moderate or severe left ventricular hypertrophy or pseudohypertrophy? This is seen as the thickening of the left ventricular wall in relationship to the left ventricular internal diameter. This corresponds to a relative wall thickness larger than 0.55.
8. Is there abnormal echogenicity of the myocardium or valves? This is defined as the presence of hyperechoic, hypoechoic, or nodular areas in the myocardium, mitral, tricuspid, or aortic valves.

Examples of abnormalities detected using CRASH can be seen in Figure 2. Clinical signs that may prompt a CRASH in the author's practice are tachycardia, tachypnea, dehydration or hypotension, respiratory distress, trauma, or fever. Clinical scenarios with characteristic sonographic findings often detected are left-sided congestive heart failure; undifferentiated hypotension (dehydration/volume depletion/endotoxemia/systemic inflammatory response syndrome/sepsis); hypertensive heart disease; pulmonary hypertension, pleuropneumonia, or neoplasia causing pleural effusion; pericarditis or neoplasia causing pericardial effusion; and pneumothorax.

4. Discussion

POCUS is gaining popularity in human medicine, particularly in the emergency setting and in routine assessment of patients as an adjunct to the physical examination. The size, cost, and usability of this technology not only renders it very attractive to both general practitioners and specialists but also provides advantages unique to the equine practitioner.[3] Ambulatory settings can involve lack of electricity, evaluation of immobile animals, and lack of human help or technical assistance. POCUS transducers need to be charged but work with a tablet or a smartphone to display the images, negating the need to transport a larger portable machine. Referral hospitals house critical patients that require frequent monitoring, are occasionally immobile,

and are possibly infectious. POCUS could be invaluable in these situations, with the potential to provide quicker referrals, improved quality medicine, and more targeted treatments.[4]

The difference in equipment cost between pocket-sized and hospital-based ultrasound equipment is approximately 30- to 80-fold, and the difference in the types of images obtained with each device can be significant. The author does not foresee pocket-sized ultrasound replacing hospital-based equipment in the near future. However, pocket-sized ultrasound currently holds an important role in his practice as a stall-side diagnostic and teaching tool. There are controversies about what role POCUS should play in veterinary medicine. Some have enthusiastically adopted this diagnostic modality based on the evidence in human fields and small animal medicine that shows that POCUS can increase diagnostic accuracy of non-specialists and make high-quality care accessible.[5–7] Others consider that the expertise of imaging specialists and the use of POCUS by practitioners should be limited based on the concern that information obtained with a POCUS examination may be falsely perceived as analogous to an ultrasound examination by an expert sonographer, which may lead to the potential for an incorrect diagnosis and lower quality of care.

Trends in medical education favor the use of ultrasound beyond an imaging technique and suggest that it could be a useful tool to "bridge the gap between the classroom and the clinic floor." Some trends in education have referred to POCUS as the stethoscope of the 21st century. There are controversies and lack of high-level evidence to support this, but preliminary evidence and personal experiences make exploration of the advantages of this equipment as an educational tool a worthwhile effort.[8]

It is important to recognize that POCUS protocols are not designed to replace comprehensive sonograms or the work of specialists. They are tools designed to answer specific questions in clinical scenarios in which availability of a prompt stall-side examination can potentially improve outcomes. The development of new POCUS protocols may increase the tools available to the ambulatory veterinarian for triage and to the criticalist for rapid assessment and frequent monitoring, and it may also aid training of students and novice veterinarians. The CRASH protocol may be a useful protocol for many veterinarians and increase the quality of care that is provided to horses.

Acknowledgments

Declaration of Ethics

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

Conflict of Interest

The VLCS Department of Texas A&M, ACVIM, and Butterfly supported a study in which the feasibility and performance of CRASH was evaluated and which has been accepted for publication in *J Vet Int Med*. Drs. Kari Bevevino, Sonya Gordon, Noah Cohen, and Cris Navas are authors of this study.

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How to Perform Ultrasound-Guided Procedures in the Cervical Area: Nerve Roots, Cerebrospinal Fluid Aspirates, and Cervical Facets

Cris Navas de Solis, LV, PhD, DACVIM

This session will help practitioners learn how to complete ultrasound-guided injections in the cervical area. Ultrasound-guided aspiration of cerebrospinal fluid and injections of nerve roots and cervical facets can be performed in horses and have useful clinical applications. Author's address: University of Pennsylvania, New Bolton Center, 382 West Street Road, Kennett Square, PA 19348; e-mail: navasdes@vet.upenn.edu. © 2023 AAEP.

1. Introduction

There are a few principles that are important to remember in order to perform ultrasound-guided injections safely and successfully. The most important one is that the needle must remain in the plane of the ultrasound beam in its entirety. Following an ultrasound plane is an acquired skill that requires practice. It allows the operator to see the probe, the needle, and the ultrasound machine simultaneously. This means planning the positioning of the ultrasound machine and horse so that the ultrasound plane, operator's eyes, and machine are aligned. However, this is not possible for many common injection or biopsy sites. In general, having the same operator hold the probe and the needle is the easiest approach. In many cases, having an assistant control the syringe for injection or the biopsy instrument handle while the sonographer controls the probe and needle and makes sure the needle stays in the appropriate location is helpful. In some cases, a different operator can introduce the needle, and the only job of this person is to follow the ultrasound place dictated by the sonographer. In the author's experience, this second "two brains, two hands approach" is more complicated than the "one brain, two hands approach" unless the two operators are very used to working together and in sync with one another.

2. Materials and Methods

Useful strategies for performing ultrasound-guided procedures are listed below:

- Find the best sonographic window and mark it with typographical correction fluid before preparing the site. As the site of injection needs to be sterile most of the time, 3 to 4 lines far from the injection site that intersect at the site for

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injection are useful. Correction fluid is helpful to create these marks.

- The author prefers to place gel within a sterile glove, place the probe in the glove, and use white tape to fix the glove to the probe tightly. The use of alcohol, rubber bands, or sterile covers is another option, but in the author's experience, the glove and white tape approach provides better contact and better image. The only disadvantage is that the tape is not sterile, so if the operator touches the tape, that hand should be considered "not clean." If the ability to switch the probe between the operator's gloved hands is desired, it is possible to utilize the fingers of the glove covering the probe to tie the glove in a secure position.
- Supplies needed are a large convex or microconvex probe (linear probes may be used is smaller horses), 21- to 18-gauge 1.5- to 3.5-in needles, 3- to 5-mL syringes, ultrasound gel, alcohol, sterile globes, white tape, correction tape, and occasionally 1 to 3 mL of lidocaine in a syringe and 25-gauge needles.
- Gelatin makes a good phantom to practice guided injections. Learning to follow an ultrasound plane with a needle is a skill with a very steep initial learning curve, so practicing with a gelatin phantom has a high return on time invested.

3. Results

Cervical Facet Joints

Injections of the cervical facet joints are common in equine practice. Obtaining images adequate to perform this procedure is technically easy, and the limiting factor is experience in following an ultra sonographic plane. When the technique was first described, a cranial approach was recommended. That is, the injections were made following a plane in the long axis (chair sign, left image). More recently, a transverse (cranial or craniodorsal approach) plane ("Pac-Man" sign; Fig. 1, right image) has been suggested to be more accurate, easier, and safer. In normal horses, the dorsal and craniodorsal approaches have been proven to be equally effective.[1–3]

In Figure 1, the left image shows a long-axis image with the right side of the screen being cranial. The cranial articular process of the caudal vertebra (C6) is the convex hyperechoic echo of bone on the left side of the screen, and the caudal aspect of the vertebra situated cranially (C5) is the convex echo in the middle to right side of the screen (the back of the chair). The image on the right shows the same articulation after rotating the probe approximately 45° to 60° into a transverse orientation so that dorsal is to the right side of the screen. The cranial articular process of the vertebra situated caudally (C6) is ventral (to the left of the image), and the caudal articular process of the vertebra situated cranially (C5) is dorsal (to the right). The articular processes are separated by a small gap (the "mouth" of Pac-Man) that represents the articular space and the target of the injection. The needle is inserted from the craniodorsal aspect (top right of the screen). Synovial fluid may be retrieved. Some clinicians prefer obtaining fluid before each injection, while others accept injections when the needle is clearly observed in the articular space and injectate can consistently be observed distending the synovial space during injection. Cadaveric studies with confirmation of needle placement with dissection or computed tomography have shown that fluid is retrieved in only approximately 50% of successful needle placements after entering the synovial space.[3] In a recent unpublished study using a cranial to craniodorsal approach, fluid was retrieved in 85% of cases. A cranial approach has not been directly compared to a craniodorsal or dorsal approach. The advantage of a cranial approach may be the more frequent retrieval of fluid, and the disadvantage may be the higher risk of penetrating the vertebral canal if the plane is not followed adequately and the needle is placed ventral to the facet joint. The advantage of a cranial or craniodorsal approach may be that it is technically less demanding. An 18- to 20-gauge needle that is 3.5 in long can be used to perform these injections. The skin needs to be prepared aseptically.

Cerebrospinal Fluid Aspiration from the C1-C2 Region

Cerebrospinal fluid can be aspirated from the space between C1 and C2 under ultrasound guidance.[4–5] The spinal cord and subarachnoid space can be imaged easily in this area and fluid aspirated by placing the needle from ventral to dorsal. Accuracy in needle placement is critical for this aspirate to be successful and to avoid serious complications, including inadvertent puncture of the spinal cord itself. This is a technique that should not be performed by an operator that is not proficient in guided procedures. Traditional sedation protocols include detomidine (5 mg/500-kg horse on average IV), with the addition of morphine (0.1 mg/kg IV, administered 3 minutes after detomidine) to decrease the reaction when the dura mater is penetrated. The need for morphine has recently been challenged, and the use of detomidine without morphine can be successful.[6] It may be advisable to avoid sedation with butorphanol in these cases so as to mitigate against the head-twitching movements than can accompany the use of this drug. Some clinicians consider that the lumbosacral space is a better site for cerebrospinal fluid sampling in horses with disease caudal to C1-C2 as cerebrospinal fluid travels from cranial to caudal; however, the relevance of this physiology is uncertain for clinical cases. The main advantage of a C1-C2 aspirate is clear visualization of the spinal cord with ease of sampling when compared to blind or localized aspirates in the lumbosacral region. The primary disadvantage of the

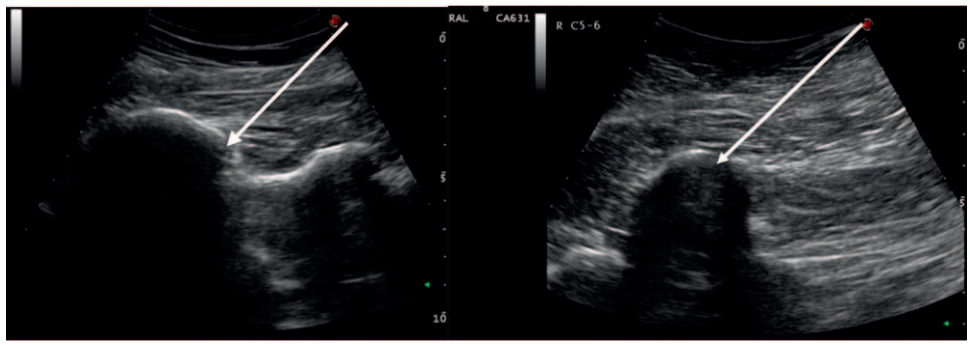


Fig. 1. Longitudinal (left) and transverse (right) images of the cervical facet joint. The white arrows show the direction of the needle from cranial to caudal (left) or dorsal (craniodorsal) to ventral (caudoventral; right).

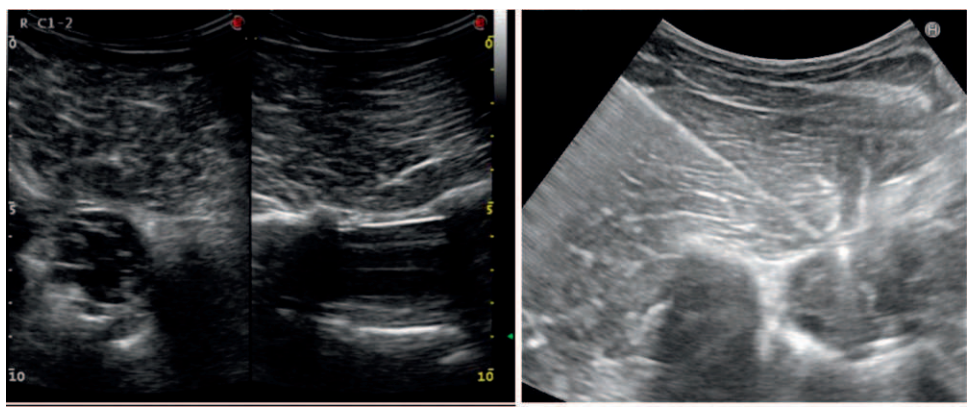


Fig. 2. Transverse image of the sonographic window to obtain a cerebrospinal fluid aspirate in the C1-C2 region (left panel) and longitudinal image in the same region. In the right panel, a needle can be seen with the tip in the subarachnoid space.

technique is the potential for very serious consequences associated with errors in technique.

A 10- to 4-MHz, microconvex curvilinear transducer was used in the original studies[4] describing this procedure, and a large convex probe can also be used successfully. The ultrasound probe is oriented dorsoventrally to obtain a transverse plane (Fig. 2, left image) dorsal to the articular space. The window is caudal to the caudal aspect of the transverse process of C1 and approximately 5 to 8 cm ventral to the dorsal midline of the mane. The subarachnoid space has a striated appearance, which is believed to be due to trabeculae connecting the arachnoid mater and the pia mater, and the normal cerebrospinal fluid is anechoic. An 18- to 20-gauge, 3.5-in needle is advanced in a ventral to dorsal direction until it is seen passing through the dura mater into the subarachnoid space (Fig. 2, right image). This is often (but not always) accompanied by the sensation of a "pop," and fluid can be readily aspirated with application of gentle negative pressure. The ventral approach is critical to mitigating the risk of inadvertent spinal cord puncture in the event of the horse throwing its head upwards. This approach avoids arteries present on either side of the spinal cord, and the operator can slow down the advancement of the needle as they approach the cord and check once they feel they have punctured the dura; negative pressure typically indicates that they are not within the space and can incrementally advance. C1-C2 taps can have rare but serious complications even in horses with normal fluid aspiration and seemingly uneventful taps. Acute worsening of ataxia following a C1-C2 tap and evidence of subarachnoid hemorrhage and axonal degeneration at necropsy at or near the C1-C2 tap site has been described.[7] A dose of nonsteroidal anti-inflammatory drugs is commonly administered at the time of procedure, and some clinicians recommend keeping the head at a neutral plane for a time to reduce risk of complications appreciated in humans.

Cervical Nerve Roots

The technique for ultrasound-guided perineural injection of the cervical nerve roots has recently been described.[8] In this study, guided injection was significantly more likely to result in successful iodinated contrast delivery to the cervical nerve roots (100%) when compared with both intra-articular (0%) and periarticular caudal (33.3%) approaches as evaluated by computed tomography or magnetic resonance imaging. A technique for the guided injection of the ramus ventralis of the 7th and 8th cervical nerves (C6-C7 and C7-T1 areas, respectively) has also been described.[9] The described technique uses a convex probe that is moved caudally and slightly ventrally

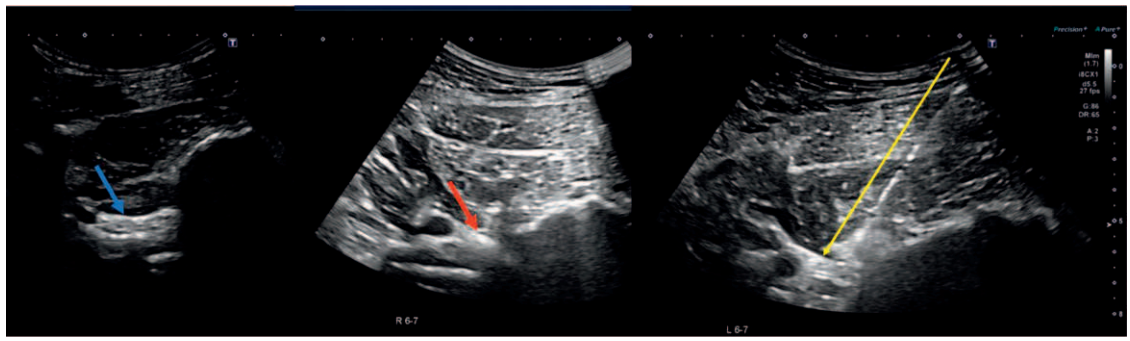


Fig. 3. An image acquired with a large convex (5–8 MHz) transducer shows the ventral branch of the 8th (left image, blue arrow) and 7th (middle image, red arrow) cervical spinal nerve roots crossing obliquely over and immediately dorsal to the vertebral vessels. A 20-gauge, 3.5-in spinal needle is inserted until the tip is visualized approximately 0.5 cm from the nerve (linear echo parallel to the yellow arrow). In all images, dorsal (craniodorsal) is to the right.

from the transverse view of the cervical facet joint described for injection of the cervical facets with a dorsal or craniodorsal approach. A caudoventral rotation (approximately 20° counterclockwise on the left side of the neck, clockwise on the right) has been proposed to allow better identification of the nerve roots, and the nerve can be followed caudally from this position. Injection can be accomplished with a 20-gauge, 3.5-inch needle. In the above reference, the needle was introduced approximately 2 cm caudoventral to the transducer and advanced until it was within 5 mm of the nerve. In the author's practice, the same image is used with the needle being introduced dorsally to the probe as this is an easier approach to avoid the scapula and provides an easier angle to follow the ultrasound plane with the needle. This technique has not yet been reported in clinical cases in the peer-reviewed literature but is frequently used by some clinicians without apparent complications and has received good clinical response in cases of cervical radiculopathy. Identifying the adjacent vascular structures using two-dimensional ultrasound and color Doppler has been suggested to aid this technique.[2,9] The vertebral artery (axial and dorsal relative to the vertebral vein; ventral relative to the cervical nerve root) and vein (ventral and abaxial) can be identified. The 8th nerve root is larger than the more cranial roots (Fig. 3).

4. Discussion

These ultrasound-guided procedures in the cervical area can be performed by equine clinicians and are useful as diagnostic and therapeutic tools. Basic anatomical concepts, good sonographic skills, and proficiency following an ultrasound plane are needed to perform these procedures successfully and safely.

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.

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How to Ultrasound Limb Cellulitis

Kate Chope, VMD, DACVSMR

Cellulitis is commonly seen in equine practice. Ultrasound is an excellent method for evaluating the cellulitic limb, including assessment of possible synovial involvement, abscessation, osteomyelitis, foreign material, or extension into a ligamentous structure. It can be used to obtain fluid samples, guide diagnostic and treatment choices, and monitor response to therapy. Ultrasound can be used in the field or hospital setting to improve management of limb cellulitis. Author's address: University of Pennsylvania, New Bolton Center, 382 West Street Road, Kennett Square, PA 19348; e-mail: kchope@upenn.edu. © 2023 AAEP.

1. Introduction

Limb cellulitis is a condition commonly seen in equine practice. Cellulitis is defined as a diffuse bacterial infection of the dermis and subcutaneous tissues.[1,2] It presents as an acute, painful, diffuse, and often extensive swelling of the affected limb, with hindlimbs more commonly affected than the forelimbs.[1–3] Thoroughbreds are overrepresented in the literature.[1,2] Cause is most often presumed to be due to disruption of the skin barrier secondary to penetrating injury or dermatitis, although cases of cellulitis secondary to limb surgery and limb injections have also been reported.[1] Impairment of the immune or circulatory system giving rise to hematogenous spread has also been proposed.[3] However, in many cases, no known predisposing cause is identified.[1] The most common bacterial organisms cultured are *Staphylococcus aureus* and *Streptococcus species*.[1–3] While many cases of limb cellulitis may respond well to appropriate antibiotic therapy, others require more extensive management and result in more significant secondary complications that can affect morbidity and mortality and become performance limiting. In a retrospective series of 44 horses with limb cellulitis admitted to a veterinary teaching hospital, 67% short-term survival for primary cellulitis and 90% short-term survival for secondary cellulitis were reported.[3] In a separate, earlier retrospective at another teaching hospital, 89% survived to discharge, with 11% euthanized for secondary complications. More recently, Cooper et al. reported septic tendonitis or desmitis as a rare but possible sequelae of limb cellulitis.[2]

Ultrasound is a well-established method for evaluating soft tissues and bony surfaces in the horse. Ultrasound of limb cellulitis is relatively straightforward to perform with practice and can be of assistance in confirming the diagnosis of cellulitis, identification of fluid pockets for sampling, and screening for factors that would alter management or result in reduced prognosis, such as a septic synovitis or septic tendonitis/desmitis.

2. Materials and Methods

Patient Preparation

The full extent of any edematous or thickened area should be examined. Ideally, the region should be

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clipped using a #40 clipper blade. However, clipping should be performed cautiously or judiciously in regions where the skin may be compromised, and care should be taken not to compromise the dermal integrity further. The skin should be cleaned with appropriate antiseptic soap and water and rinsed with alcohol or water. If the skin is irritated or its integrity compromised, water or sterile saline is more appropriate. In cases with chronic thickening or excessively dry skin, hosing the leg or applying warm wet wraps, with or without ultrasound gel, before the scan will improve image quality. Copious coupling gel should be applied. Adequate sedation and restraint are essential as the patient may resent the pressure of the ultrasound probe and move the limb, particularly in abduction (hindlimb) or in a sudden exaggerated fashion.

Equipment Selection

A high-frequency linear probe (greater than 9 MHz) is most appropriate to obtain a high-quality resolution. In cases with significant swelling, chronicity, or large joint effusion, a lower frequency curvilinear or small convex probe (5–8 MHz) is indicated in order to obtain adequate depth of penetration.

Approach

The goal of the scan is to determine 1) the extent of cellulitis and where it appears most marked; 2) the path of any wound or draining tract that may suggest a primary cause, such as foreign material, or specific area requiring further investigation; 3) the presence of fluid pockets or abscesses, which can be sampled for culture and sensitivity; 4) involvement of a synovial structure, whether or not there is a tract or wound present; 5) evidence of a septic tendonitis or desmitis (and any other concomitant tendinous or ligamentous injury); and 6) delineation of regions of edema, vasculitis, or lymphangitis, if possible.

The limb should be evaluated in a systematic and thorough fashion, taking care to ensure that it is evaluated circumferentially from the proximal to the distal extent of the swelling. It is important to review the anatomy of the region prior to the scan to make sure all possible synovial structures have been considered and that basic tendinous and ligamentous anatomy is familiar. While daunting initially, dividing the area of interest into familiar anatomic regions and examining them in a systematic fashion can be helpful (i.e., plantar, plantar medial, medial, lateral, and dorsal). Forming an index of suspicion as to the most significant structures of concern based on history, swelling, regions that are fluctuant or painful on palpation, or location of wound prior to starting the exam is helpful particularly when the operator is evaluating extensive areas. However, in many cases, the diffuse and painful nature of cellulitis precludes straightforward assessment or can be misleading, and one should be careful to perform a complete examination or significant findings can be missed. Lastly, prior to finishing the scan, it is important to consider whether the findings and clinical picture correlate as expected.

For diffuse cellulitis with no overt wound or draining tract, two methods of ultrasound approach can be considered:

Method 1 is starting with the metacarpus or metatarsus and examining the familiar anatomic structures such as the flexor tendons and accessory ligament of the deep digital flexor tendon (inferior check ligament and suspensory ligaments and synovial structures, carpal or tarsal sheath, digital sheath) and gradually progressing toward critical evaluation of the subcutaneous, periligamentous, and perivascular regions. An advantage to this method is that it can be less disorienting. One can use familiar structures for orientation and to evaluate them one step at a time, without becoming distracted by more diffuse superficial abnormalities or focusing on what appears to be the most unusual area and neglecting to complete a full examination. It also aids in identification of the soft tissue landmarks of the tendon sheaths, bursae, and joints.

One can then move distally to the pastern and proximally to the carpus, antebrachium, tarsus, and/or crus if indicated, being sure to evaluate the entire length of any structures that span both regions, such as the digital sheath or any abnormal vessels.

Based on operator experience and as suggested in the literature, structures of the most common concern in the metacarpus and metatarsus are the medial and lateral subcutaneous regions, the deeper periligamentous region surrounding the suspensory ligament, the suspensory ligament itself, the digital sheath, the metacarpal or tarsal-phalangeal joint, and the carpal sheath/tarsal sheath.

In the pastern, at a minimum, the superficial and deep digital flexor tendons, digital sheath, and palmar/plantar digital structures should be evaluated. Other joints or synovial structures should be evaluated as indicated based on swelling, wounds, or radiographs. In all cases of tarsal involvement, the tarso-crural joint and subtendinous, calcaneal and gastrocnemius bursae should be evaluated. The proximal and distal intertarsal joints and tarso-metatarsal joint are less commonly involved in this operator's experience but can be screened and should be evaluated if indicated.

Method 2 is to begin by evaluating the superficial layers and progressing to tendons, ligaments, bones, and synovial structures after an initial superficial scan. This method can be quite helpful when there is significant chronic thickening and time is required for the gel to absorb and aid in beam penetration of deeper structures. It also can appear to give a more rapid result as to the nature of the cellulitis and path of any wounds. However, care should be taken not to abbreviate the exam based on positive findings in one region.

For penetrating wounds or draining tracts, one can likewise begin with the tract and follow in its entirety and then finish the remainder of the scan, or one can use a systematic approach to identify and evaluate

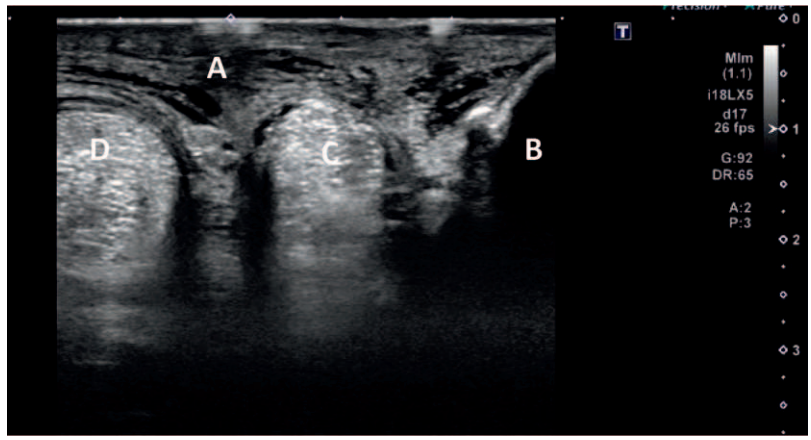


Fig. 1. Transverse image of the lateral aspect of the left forelimb over the proximal suspensory branch region demonstrating acute cellulitis and edema. Marker is dorsal. A, subcutaneous edema; B, bony echo of MC3 and MC4; C, lateral suspensory branch; D, deep digital flexor tendon.

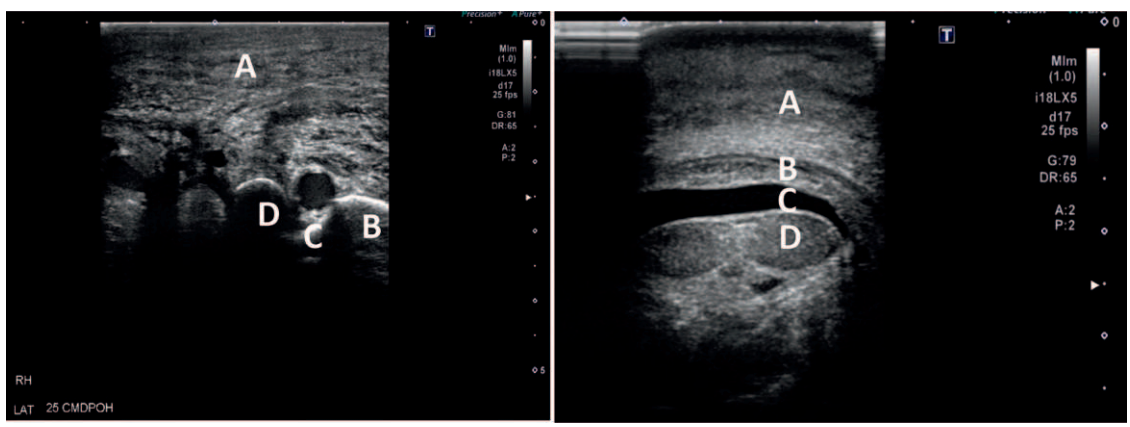


Fig. 2. Left panel, Transverse image of the lateral aspect of the metatarsus at 25 cm distal to the point of the hock in a case of chronic cellulitis. A, thickened subcutaneous tissues; B, third metatarsal; C, vessel D; fourth metatarsal. Right panel, Transverse images of the digital flexor tendon sheath (DFTS) in the same horse with chronic cellulitis demonstrating thickening of the DFTS and hypoechoic fluid consistent with sympathetic effusion with no overt indication of sepsis. A, thickened subcutaneous tissues; B, DFTS; C, anechoic synovial fluid of DFTS; D, deep digital flexor tendon.

nearby structures prior to tracing the tract. In either case, it is important to consider what the tract appears to communicate with and then examine that structure separately for evidence that the communication does or does not exist. Keep in mind that tracts may be tortuous, have more than one path, or travel in unexpected directions. The presence of gas, foreign material, fluid pockets, tracts, and irregular bone should be carefully evaluated and considered.

Normal Appearance

The subcutaneous layers of the distal limb are typically quite thin (roughly 2–3 mm) and homogeneously hypoechoic to mildly echogenic. The normal appearance of each of the tendons and ligaments of the distal limbs are beyond the scope of this discussion and are described elsewhere. However, generally, they should be relatively homogenously echogenic with a dense linear fiber pattern. If in question, the opposite (presumed normal) limb can be evaluated for comparison. Synovial structures should have variable volumes of anechoic fluid with a thin homogeneous hypoechoic lining. Normal bursae such as the calcaneal bursa, subtendinous bursa, and gastrocnemius bursa have minimal detectable fluid and may not be readily apparent sonographically. Bony surfaces will vary depending on structure but should largely present a relatively smooth hyperechoic cortical surface, albeit with variable contour.

Abnormal Findings

Edema

This typically appears as anechoic fluid layers within the subcutaneous tissues often with visible hyperechoic septae. Minimal attenuation of the ultrasound beam occurs. It is usually readily compressible with probe pressure.

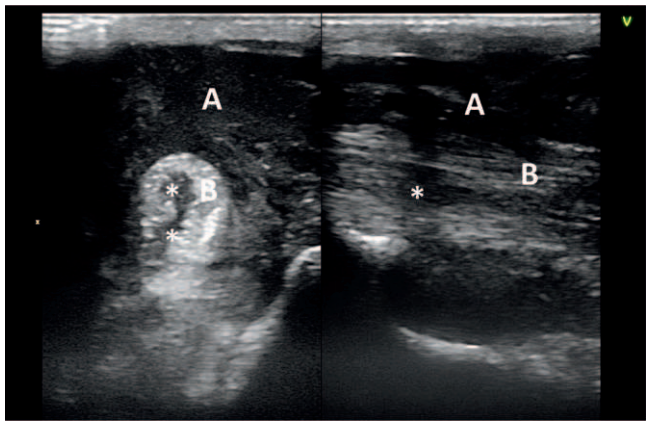


Fig. 3. Transverse (left panel) and longitudinal (right panel) image of a subcutaneous abscess overlying and communicating with the suspensory branch; secondary septic suspensory desmitis. A, heterogeneous abscess fluid; B, suspensory branch. Asterisks indicate septic lesion in the suspensory branch.

Cellulitis

Affected tissue is thickened and has increased echogenicity.[2] Focal hypoechoic to heterogeneous fluid accumulations may be present. In chronic cases, the tissues may have a more densely echogenic appearance that attenuates the ultrasound beam. Increased vessel size or impression of increased vascularity is often present. In more severe cases, isolated pockets of echoic fluid, consistent with abscesses, may be seen.

Septic Synovitis

Synovial fluid has increased echogenicity or heterogeneity, with or without overt increase in volume; synovium may appear thickened and homogeneous or heterogeneous.[4] Free gas echoes or foreign debris may be present. Nonseptic synovitis can be seen in conjunction with localized inflammation such as cellulitis. Often referred to loosely as "sympathetic" effusion, nonseptic synovitis typically appears as an increased anechoic effusion with variable homogenous synovial thickening. If the cell or protein count is increased, however, the fluid may appear somewhat echogenic and complicate interpretation. Ultrasound appearance can be suggestive of septic or nonseptic synovitis but should not replace cytology and culture.

While synoviocentesis may be desired to definitively rule in or out sepsis, it is generally not advised to direct a needle through cellulitic tissue into an underlying synovial structure due to the risk of inoculating an aseptic synovitis with bacteria. In these instances, ultrasound may be helpful to identify synovial recesses remote from regions of cellulitis, although in some cases these may not be present.

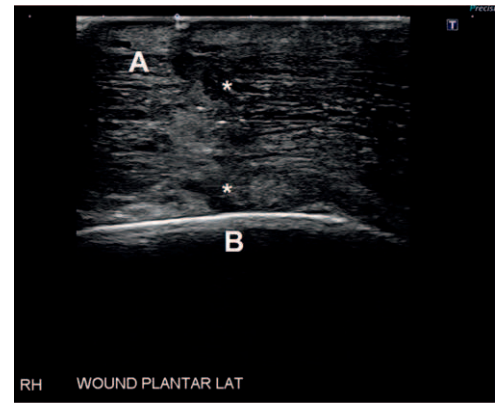


Fig. 5. Plantar lateral wound tract with cellulitis. A, edematous tissue; B, bone. Asterisks indicate draining tract.

Septic Tendonitis or Desmitis

Lesions in septic tendonitis or desmitis have been described to have a fluid-filled mixed echogenicity with marked fiber disruption.[1] Lesions would be expected to be irregular, extend to the margin of the tendon or ligament, and communicate with a fluid-filled tract and abnormal or abscessed periligamentous tissues.[1]

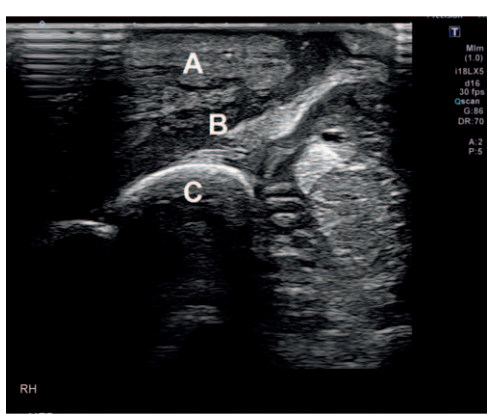


Fig. 4. Transverse image of right hind medial metatarsal region demonstrating draining tract and cellulitis. A, subcutaneous tissues; B, hypoechoic draining tract; C, bone echo.

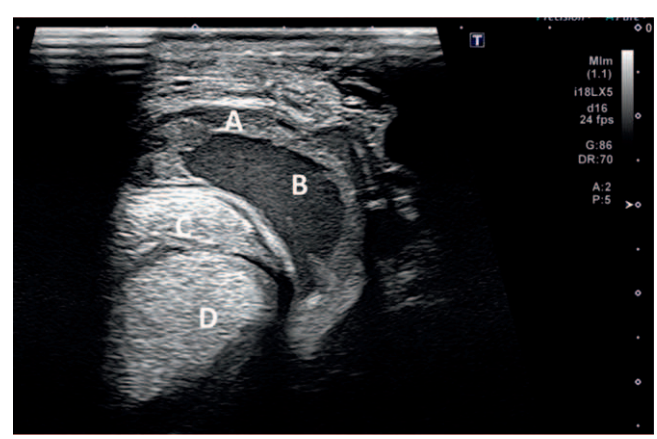


Fig. 6. Septic digital flexor tendon sheath in a horse with chronic cellulitis and no history of wound or recent intrathecal injection. A, thickened synovium; B, echogenic synovial fluid; C, superficial digital flexor tendon; D, deep digital flexor tendon.

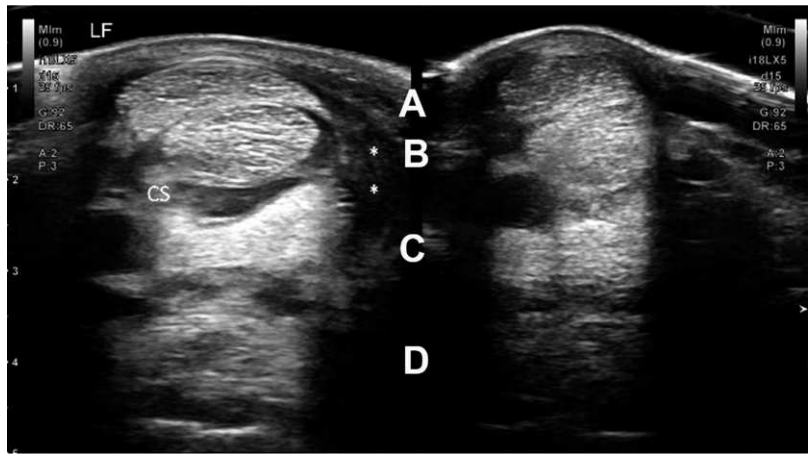


Fig. 7. Bilateral transverse images of the proximal metacarpal region demonstrating a septic carpal sheath and cellulitis (left panel; LF) contrasted with normal (right panel). A, superficial digital flexor tendon; B, deep digital flexor tendon; C, inferior check ligament; D, suspensory ligament; CS, carpal sheath. Note fluid in the left front carpal sheath.

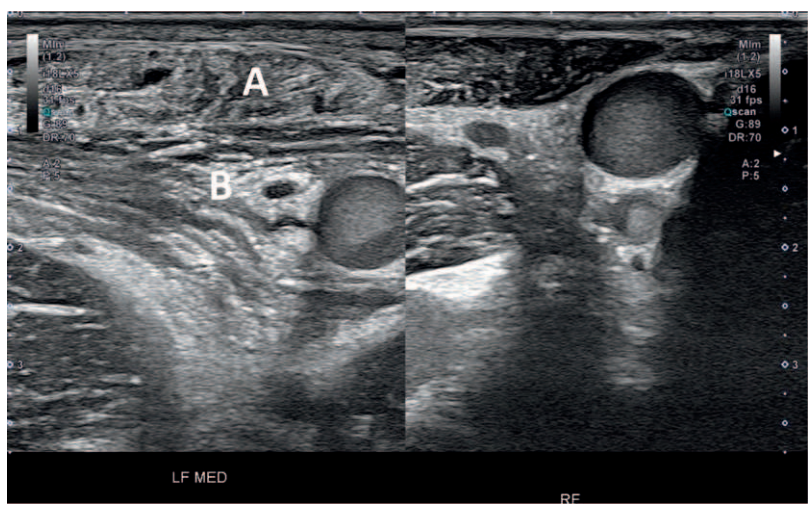


Fig. 8. Transverse ultrasound images of the left front (left panel) and right front (right panel) distal radial regions in a horse with cellulitis and perivasculitis in the left forelimb. A, increased echogenicity of muscle; B, thickened perivascular tissues with layers of edema and increased echogenicity.

Perivasculitis

There will be increased echogenicity of the perivascular tissues. Large vessels (saphenous, cephalic vein) may be screened for thrombi.

Lymphangitis

This is characterized by lymphatic dilatation. Typically, dilated lymphatics appear as tubular structures with a slightly scalloped or irregular contour that have an anechoic or mildly echogenic lumen and no evidence of blood flow on low-flow Doppler interrogation.

Ultrasound images of various findings encountered in examination of primary and secondary cellulitis are seen in Figs. 1 to 10.

3. Results

A total of 79 cellulitis cases were evaluated at the University of Pennsylvania from 2020 to 2022. This represents 2.5% of all equine noncardiac ultrasound examinations performed during this time. An additional 8 recheck evaluations were performed. These numbers represent those seen at a referral hospital and likely underrepresent those seen in primary care settings. Review of case logs suggested identified causes including detection of a wound or skin compromise, detection of foreign material or abscess, presumed primary joint sepsis, and unknown etiology. Presumed secondary extension into a synovial structure or tendon or ligament were seen in association with cellulitis in this population in isolated cases; it was previously identified in 2% of 426 limb cellulitis cases evaluated from 2000 to 2019 at the same institution.[2] Vasculitis was described occasionally, and vascular thrombosis was recorded in at least one case.

4. Discussion

Cellulitis is commonly seen in equine practice. Ultrasound is an excellent method for evaluating the

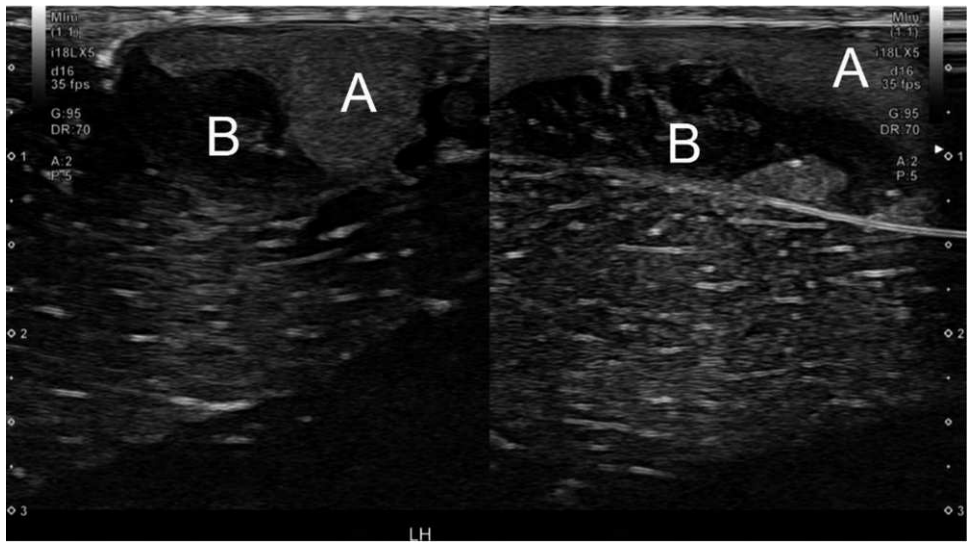


Fig. 9. Transverse (left panel) and longitudinal (right panel) images of a horse with a thrombus in the saphenous vein. A, blood in lumen of the vessel; B, hypoechoic thrombus.

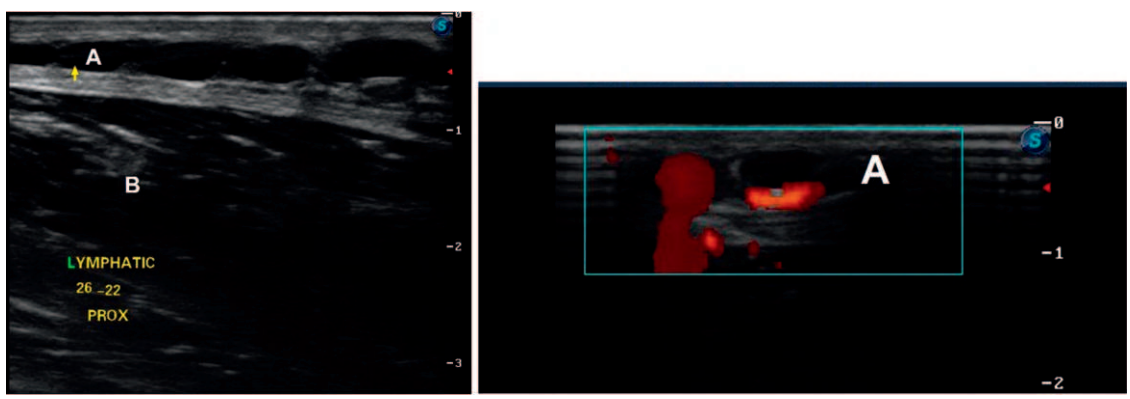


Fig. 10. Left panel, Dilated lymphatic on the proximal medial crus, saphenous region of a horse with lymphangitis/cellulitis. A, lymphatic; B, underlying muscle. Right panel, Cross-section image of vessel and lymphatic demonstrating no red Doppler flow in dilated lymphatic (A; left panel). Note no Doppler flow on cross-sectional image (right panel).

cellulitic limb, determining structures involved, and guiding diagnostic and treatment choices. On initial examination, focal fluid pockets can be identified to obtain fluid for sampling and antibiotic sensitivity, and appropriate antibiotic choices can then be made. Synovial structures can be screened for sepsis. While it does not replace fluid analysis, ultrasonographic findings can be helpful in assessing the risk/benefit ratio of sampling a synovial structure when diffuse cellulitis is present. Extension of the infection into a tendon or more commonly, suspensory ligament can be detected. Other unusual causes or sequela that may require an altered treatment plan can also be detected. Ultrasound can also be used to monitor progression of treatment or identify regions of concern in cases not progressing as expected. With practice, appropriate anatomical knowledge, and a methodical approach, ultrasound is a readily available diagnostic procedure that can improve the diagnosis, treatment, and management of limb cellulitis.

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 has no conflicts of interest.

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How to Ultrasound the Cranial and Caudal Nuchal Bursa: Normal and Bursitis

Kate Chope, VMD, DACVSMR

Nuchal bursitis, although uncommon, can be a cause of significant discomfort and poor performance. Once familiar, clinical signs are readily identifiable. Ultrasound is an excellent method to evaluate the bursae and guide treatment options. The purpose of this paper is to describe how to perform ultrasound of the cranial and caudal nuchal bursa region and to understand the clinical and sonographic presentation of nuchal bursitis. Author's address: University of Pennsylvania, New Bolton Center, 382 West Street Road, Kennett Square, PA 19348; e-mail: kchope@upenn.edu. © 2023 AAEP.

1. Introduction

Nuchal bursitis, colloquially known as poll evil, can be a cause of significant discomfort and poor performance. Clinical signs include swelling in the poll region (Fig. 1), pain on palpation of the poll, altered head carriage (Fig. 2), head shy behavior, and decreased performance or inability to perform as desired. The swelling can be significantly asymmetric in nature (Fig. 3). In more severe cases, the bursa can fistulate into a draining tract, which can be difficult to resolve successfully and create significant cosmetic and management concerns for the owner. Mineralization detected on radiographs dorsal to C1 or C2 can be seen in association with overt nuchal bursitis or as an incidental finding and, as such, can be a confounding finding in survey cervical radiographs (Fig. 4) or on prepurchase evaluations. Recent papers have discussed case presentations and treatment options,[1,2] anatomy and imaging,[3] and potential causative agents.[3] Although remaining uncommon overall, recent literature and anecdotal evidence suggest a possible increase in prevalence or recognition. Additionally, with the increased focus on the poll region as a possible region of discomfort, it is important for practitioners to understand implications of therapies being directed to the region.

Once the characteristic appearance or clinical signs are recognized, diagnosis is relatively straightforward via ultrasound with equipment that is readily available to most equine practitioners and internists. Ultrasound is an excellent method of evaluating the nuchal bursa region and can be performed in the field or a clinic setting with readily available equipment. Ultrasonographic and radiographic evaluation of the poll region provide complementary diagnostic information. Magnetic resonance imaging or computed tomography may provide further information in specific cases. Early diagnosis and critical evaluation can aid in determining prognosis, guiding treatment options, and potentially improving outcome.

2. Materials and Methods

Patient Preparation

For the best image, hair on the neck and the mane is clipped with a number 40 clipper blade from the level

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of the occipital crest to the caudal extent of C1 or C2 (depending on degree of palpable swelling and/or radiographic indications) and to the lateral margins of the wings of the atlas, 8 to 10 cm to each side of midline (Fig. 5). The skin should be cleaned and ultrasound coupling gel applied. Adequate sedation is often required for clipping the poll region, as horses with nuchal bursitis are often quite painful to pressure applied to the region. Ear plugs may also be helpful in horses who resent the sound of clippers near the ear.



Fig. 1. Photograph of asymmetric bilateral enlargement of the cranial nuchal bursa region, viewed from cranial orientation.



Fig. 2. Photograph of clinical presentation of low head, extended head position.

As it is often of cosmetic concern to owners to clip the mane beyond the traditional margins of the bridle path, the mane can be preserved and the midline region assessed from right or left lateral oblique angles; however, this limits assessment of the nuchal ligament and requires more careful assessment of anatomy. In many cases, initial scanning can be done with the mane intact and distal clipping of the mane performed based on findings. In cases where clipping is discouraged altogether, the hair coat can be wet with alcohol or warm water in the direction of hair growth. However, it is important to keep in mind that image quality is lost when the hair coat is not clipped. Veterinarians should be aware that the more subtle clinical cases in which lack of clipping tends to be preferred are often the cases in which higher resolution is most useful, and owners should be cautioned that subtle findings may be missed. Additionally, lack of clipping usually results in increased probe pressure required to obtain an image, which is often resented by the patient and can cause compression of fluid filled structures (making them easier to misinterpret).

Probe Selection

Due to the need for high-resolution assessment of superficial structures and the depth required to fully evaluate the surfaces of C1 and C2, evaluation with both a high-frequency linear "tendon" probe and a mid-range small convex or abdominal convex probe is recommended. This is particularly true in cases that have significant swelling resulting in greater required depth of imaging. Additionally, the wider field of view of a convex probe combined with greater depth aids the practitioner with orientation.

Anatomy

The cranial nuchal bursa is located deep to the funicular portion of the nuchal ligament and dorsal to the dorsal arch of the atlas (C1; Fig 6). Laterally and ventro-laterally, it is framed by the semispinalis capitus muscle and paired tendons of the semispinalis capitus. Directly ventrally, cranial to and overlying the atlas, the rectus capitus is present (Fig. 7).[2,3] The bursa is a bilobed structure with an incomplete septum and a synovial lining (Fig. 8). The nondistended bursa lies over

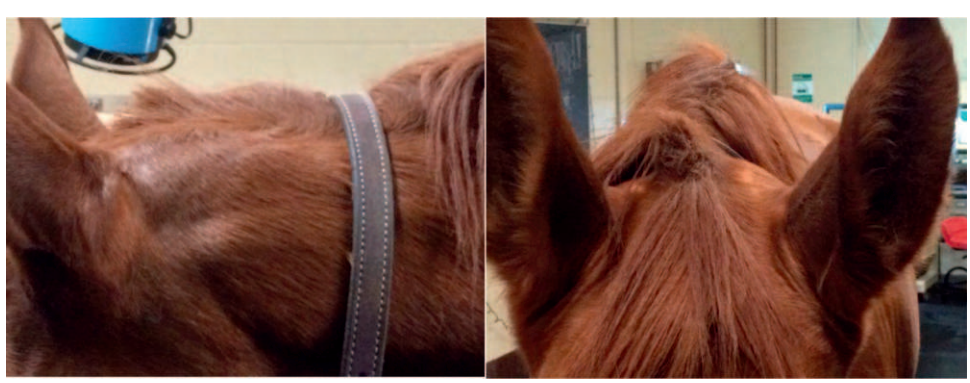


Fig. 3. Photograph from lateral and cranial orientations demonstrating milder asymmetric enlargement of the cranial nuchal bursa.

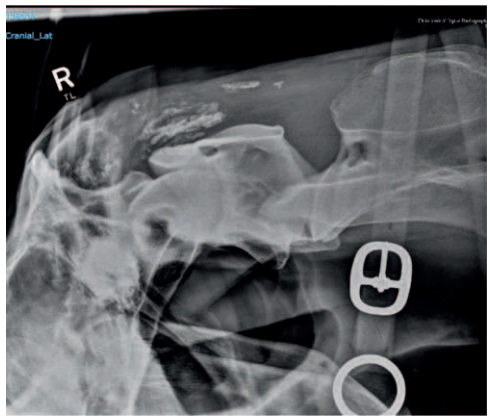


Fig. 4. Standing lateral radiograph of the cranial cervical region demonstrating significant mineralization overlying C1 and occipital condyle, suggestive of mineralization in the cranial nuchal bursa.

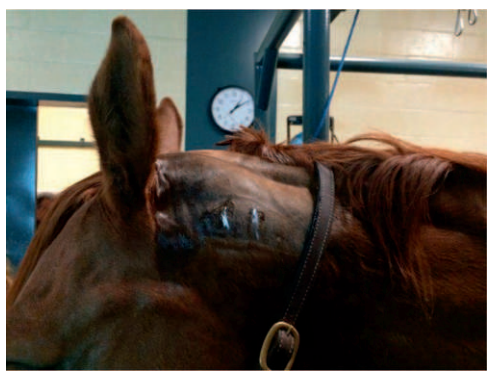


Fig. 5. Photograph of clipping for evaluation of the cranial nuchal bursa. Note mane is clipped overlying C1.

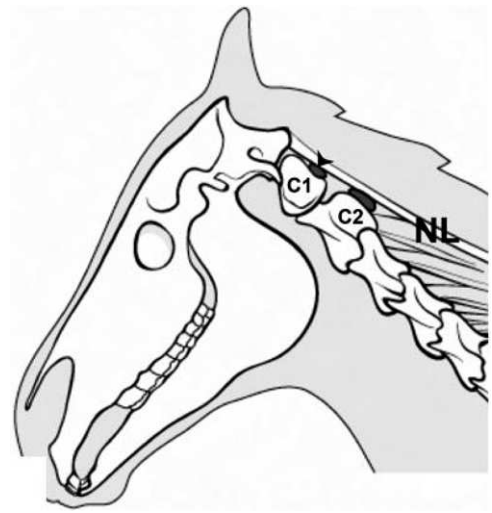


Fig. 6. Schematic line drawing of the cranial and caudal (inconsistent) nuchal bursa. Drawing courtesy of Beth Mellor.

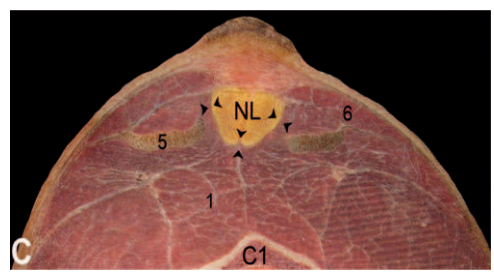


Fig. 7. Cross-sectional anatomic specimen of the nuchal region overlying C1. NL, nuchal ligament; 5, semispinalis capitus; 1, rectus capitus; 6, splenius; C1, atlas. Paired black arrows represent margins of normal nuchal bursa (nondistended). Note the fat and connective tissue overlying the nuchal ligament. Image courtesy of Gustavo Abuja.

the middle and caudal thirds of the dorsal surface of C1 and extends caudally over the articulation between C1 and C2. Based on work by Abuja et al, when distended with 60 mL of saline, the bursa can extend over half the dorsal surface of C1 and beyond the edges of the nuchal ligament (Fig. 9). In cases of bursitis, the clinical and sonographic impression is that the margins are extended. The caudal nuchal bursa is variably present and seen overlying C2 between the funicular portion of the nuchal ligament and the digitation of the lamellar portion attached to the atlas.[4]

Scanning Technique

The left and right parasagittal regions and dorsal midline are evaluated in transverse and longitudinal planes from the occiput to cranial or caudal C2. This operator tends to start on the near (left) side of the horse in horses without marked asymmetry. Beginning longitudinally, place the probe on the caudal aspect of the occipital crest just to the left of midline and slide caudally to the caudal extent of C1, noting the atlanto-occipital space and bony contour of C1 for orientation. The same evaluation can then be performed in a transverse plane. The left side of the neck should then be systematically scanned cranial to caudal in both planes from immediately adjacent to midline to the lateral wing of the atlas. Identification of the tendon of the semispinalis capitus muscle, bony contour of C1, atlanto-occipital articulation, and atlanto-axial articulation should be performed. Once the sonographer is oriented and adequate image quality obtained, evaluation from dorsal midline can be performed. This often requires decreasing the frequency for greater penetration; image quality is often less optimal over dorsal midline. The bilobed nuchal ligament can be identified deep to a superficial layer of fat and loose connective tissue. The right side of the neck from adjacent to midline to the lateral extent of the wing of the atlas should then be evaluated. The region deep to the nuchal ligament or between the tendon of the semispinalis capitus and the nuchal ligament and dorsal to the bony contour of mid-distal C1 represents the expected location of the nuchal bursa. The expected region of the nuchal bursa should be carefully evaluated for presence or absence of fluid distension and synovial thickening. If fluid is present, the character should be evaluated regarding its volume, echogenicity, and homogeneity. Margins of the bursa should be estimated sonographically based on visible landmarks and measured externally. The



Fig. 8. Transverse T2-weighted (turbo spin echo) magnetic resonance images of the cranial nuchal bursa in a cadaver specimen. A, Nondistended cranial bursa. B, Cranial bursa distended with 60 mL saline. 5, Paired tendons of the semispinalis capitus muscle. White arrowheads delineate cranial nuchal bursa. Images courtesy of Dr. Gustavo Abuja.

appearance and thickening of any visible synovial lining should be noted. The presence of intrabursal dystrophic mineralization should also be recorded. If there is clinical or radiographic indication to suggest caudal nuchal bursitis, the exam region should be extended over the length of C2.

If the mane cannot be clipped, the nuchal ligament and bursal region can be evaluated by obliquely angling the probe from left or right toward midline; however, it can be more difficult to critically evaluate the nuchal ligament in its entirety, and this view can become slightly disorienting. As with any oblique ultrasound imaging, care should be taken to ensure documentation of which side of the neck contains the visible structures.

When asymmetry is present (most commonly the case), practitioners who are less familiar with this region may wish to begin on the side with less appreciable swelling to aid in orientating to normal anatomic landmarks. Additionally, the patient may be more tolerant of pressure over the less clinically affected side.

Normal Appearance

The bony contour of the occipital crest is typically smooth. Small irregularities can be seen occasionally. These may represent trauma or enthesopathy, but if they are seen in absence of injury to the nuchal ligament or muscular attachments, they are of questionable clinical significance. The left and right semispinalis capitus tendon presents as a prominent homogeneous echogenic crescent-shaped tendon a few centimeters left or right of midline, with a longitudinal fiber pattern easily identifiable. Care should be taken not to misidentify this tendon as the nuchal ligament. The nuchal ligament is located on midline, deep to a flattened triangular layer of loose connective tissue and fat. It is bilobed and coarsely echogenic with a dense fiber pattern. Deep to the nuchal ligament and dorsal to mid to distal C1 is the potential space of the cranial nuchal bursa (Fig. 10). Variably, in cases that image well, a diffusely mildly echogenic layer can be appreciated that represents the bursa. Fluid is not normally appreciated, as with many normal bursae in the horse. Increased prominence or hyperechogenicity of this layer in the absence of fluid may suggest inflammation but is of unknown significance. Abuja et al.[2] report consistently visualizing the cranial nuchal bursa in cadavers as a 2- to 4-mm anechoic band-like structure deep to the nuchal ligament. The bony contour of C1 should be smooth. The atlanto-occipital joint and atlantoaxial joints can be identified. Distended bursae often extend to immediately adjacent to the joint space.

Abnormal Findings

Sonographic findings in nuchal bursitis can include increased volume of synovial fluid with or without changes in overall echogenicity and homogeneity (Figs. 11, 12); synovial thickening and increased heterogeneity; mineralization within the synovial lining or centrally within the bursa; overlying subcutaneous thickening; and identification of draining tracts. The character of the effusion may range from anechoic to echogenic or heterogeneous in nature. Hypoechoic strands of fibrin may be present, and hyperechoic soft-tissue density material is occasionally seen within the bursa (Fig. 13). Intrasynovial mineralization may be present centrally, and it may appear to be almost deep to the visible bursa/immediately dorsal to C1 or C2 (Figs. 14, 15). The inflamed nuchal bursa is often asymmetric in size and distention grossly and ultrasonographically. It may appear considerably more lateral of midline than expected on one or both sides of the neck; it also may extend more cranially than expected from normal anatomic specimens. Abuja et al. reported that when distended with 60 mL saline, the margins of the bursa extend over half the dorsal surface of the atlas in a craniocaual direction and extend laterally beyond the edges of the nuchal ligament.

The margins of the bursa should be carefully evaluated for the presence of a fistula. Tracts tend to appear as hypoechoic tubular structures with central fluid of varying echogenicity, typically extending toward the skin surface. If the bursa has opened and is draining or iatrogenic exploration has been performed,

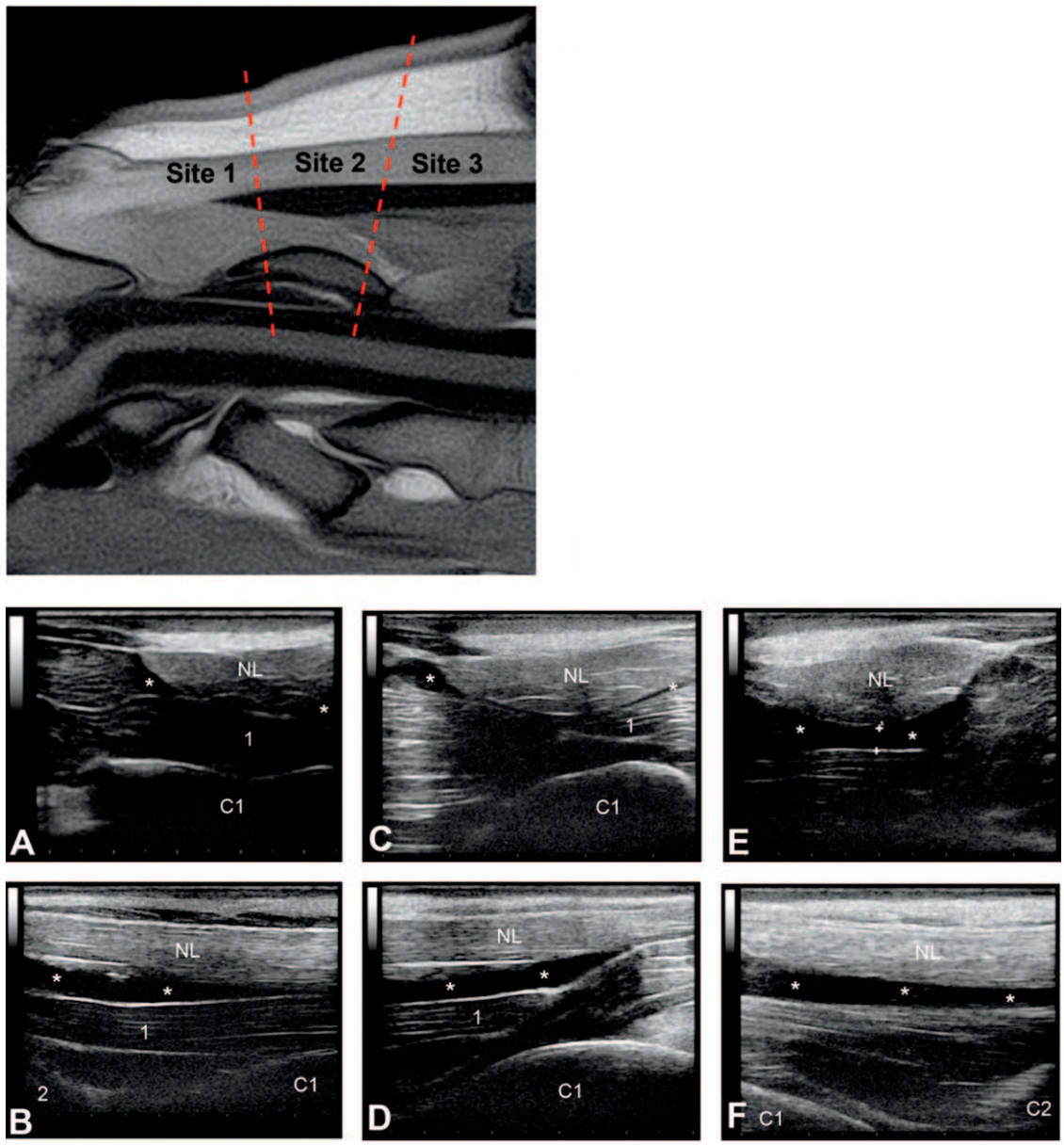


Fig. 9. Magnetic resonance and ultrasound images of the cranial nuchal bursa of a cadaver distended with 60 mL of saline. A and B represent transverse and longitudinal ultrasound images taken at Site 1 on the magnetic resonance image. Images C and D were obtained at Site 2. Images E and F were obtained at Site 3. C1 and C2 represent 1st and 2nd cervical vertebrae. NL, nuchal ligament; Asterisk, cranial nuchal bursa.

hyperechoic specks of gas may be seen within the tract or the bursa itself. The overlying soft tissue can be edematous or have an appearance consistent with chronic inflammation. Differentiation of septic versus nonseptic processes is particularly difficult in the nuchal bursae given the large degree of heterogeneity that can be seen in the absence of positive bacterial culture results. As with ultrasound of any synovial structure, increased echogenicity of the synovial fluid suggests an increased cell or protein count, and a large amount of fluid or synovial heterogeneity raises concern for sepsis. However, based on most cases described by Bergren et al.[2] being inflammatory as opposed to septic, an inflammatory or nonbacterial cause should be considered. The enlarged bursa is often quite easily apparent sonographically. Identifying landmarks and fluid character of bursal contents can be more difficult.

3. Results

Ultrasound of the poll region was performed in 60 cases of poll pain or suspected nuchal bursitis at Tufts University from 2013 to 2022. Eight out of 60 horses had no significant findings, and 52/60 had a diagnosis of cranial nuchal bursitis. This represents 0.8% of the noncardiac ultrasound caseload for that time period. A total of 32/52 horses had repeat evaluations as part of their management. From 2020 to 2022, 13 horses at

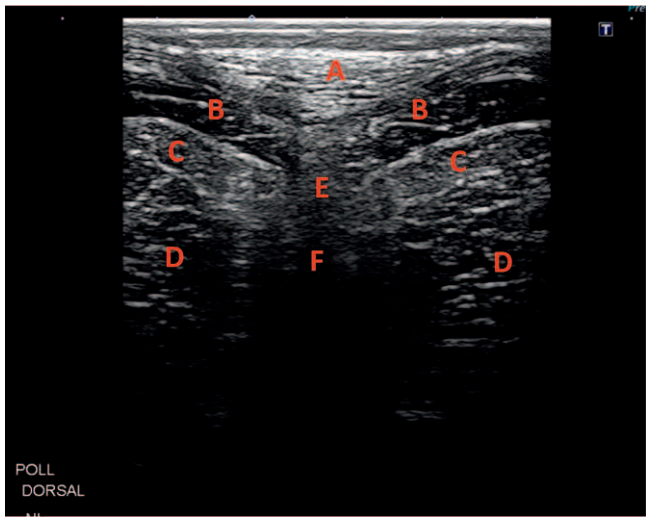


Fig. 10. Transverse image of the dorsal aspect of the poll imaged with a tendon linear probe, demonstrating the subcutaneous fat (A), splenius (B), paired tendons of the semispinalis capitus (C), rectus capitus (D), and region of the nuchal ligament (less apparent) (E) and expected nuchal bursa (F) "T" marker is to the left.

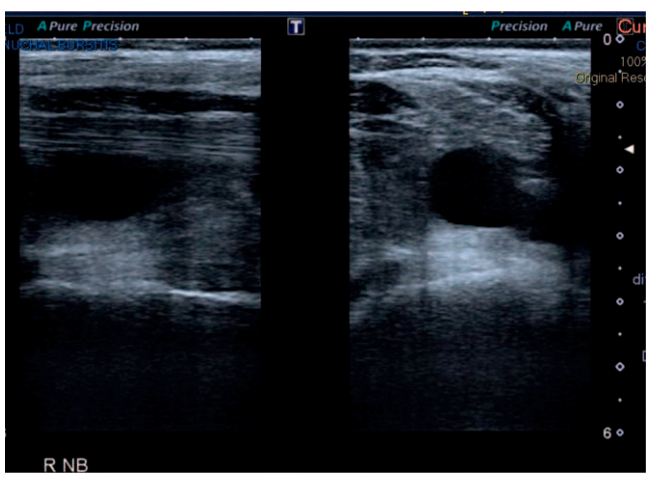


Fig. 11. Anechoic cranial nuchal bursa effusion deep to the tendon of the right semispinalis capitus muscle.

the University of Pennsylvania had a diagnosis of primary nuchal bursitis. This represents 0.3% of the noncardiac ultrasound caseload at this institution. An additional 12 recheck evaluations were performed.

In 2010, Garcia-Lopez et al. described the diagnosis and management of cranial and caudal bursitis in 4 horses,[1] including the use of ultrasound to diagnose, obtain synovial fluid, and guide placement of arthroscopic portals. Building on that work, in 2018, Bergren et al. described the diagnosis, treatment, and outcome of 30 cases of cranial nuchal bursitis from 1990 to 2014 in 2 referral centers.[2] The median age was 13 years (range 5–22 years), and follow-up time was 12 to 108 months. Breed distribution was largely Warmbloods with a few other breeds. The most recorded use was dressage, hunter/jumper, or pleasure, reflecting the hospital case populations. The mean

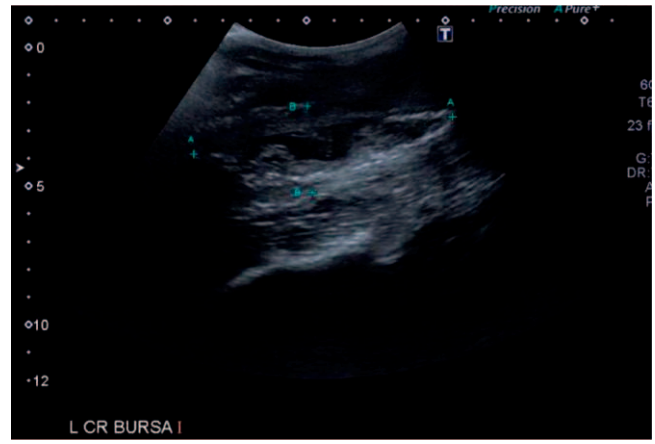


Fig. 12. Longitudinal image of the left side of the cranial nuchal bursa with synovitis and effusion.

duration of signs prior to presentation was 22.4 weeks (1 week to 3 years). A total of 27/30 horses were radiographed, with 22% having significant radiographic changes. All horses were examined ultrasonographically. Synovial effusion was detected in 98%, synovial proliferation in 26.7%, and presence of fibrin or cellular debris in 23.3%.

Five of 13 horses treated conservatively with intrabursal anti-inflammatory therapy responded favorably long term. A total of 21 of 26 horses responded favorably to surgical management (bursoscopy), with 2 horses requiring a second surgery. Complications included fistulous tracts through the ports and persistent poll swelling. Synovial fluid cytology was available for 8 horses, with 5/8 having neutrophilic inflammation and 3/8 having eosinophilic/acellular proteinaceous material. Two horses underwent serologic testing for *Brucella abortus*, and both were negative. Two horses underwent polymerase chain reaction of synovial fluid for *Borrelia burgdorferi*, and both were negative. Aerobic and anaerobic cultures were performed in 12/30 horses. Fifty percent had positive bacterial cultures that grew a variety of Gram-positive and Gram-negative organisms. Based on nucleated cell count and total protein concentration, in 8/30 cases, definitive determination of sepsis versus inflammation was not achieved. Overall, the authors concluded that bursitis may respond to medical or surgical management, with a trend toward worsened prognosis in cases that had surgery following failed medical management. The percentage of horses that returned to work was 66.7%, and they had a fair overall prognosis. *B. burgdorferi*-associated nuchal bursitis was described as a case report in 2021 by Guarino et al.[4]

4. Discussion

Nuchal bursitis, particularly cranial nuchal bursitis, is an uncommon but important differential for head and neck pain, swelling in the poll region, and poor performance. Ultrasound is an excellent method to diagnose and assess the cranial and caudal bursae and associated structures, as well as obtain synovial

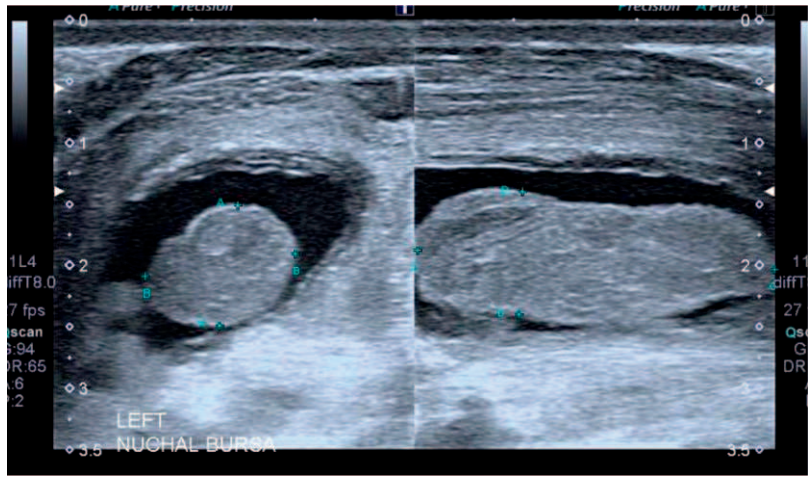


Fig. 13. Echogenic "raft" of soft tissue density material within the lumen of cranial nuchal bursa.

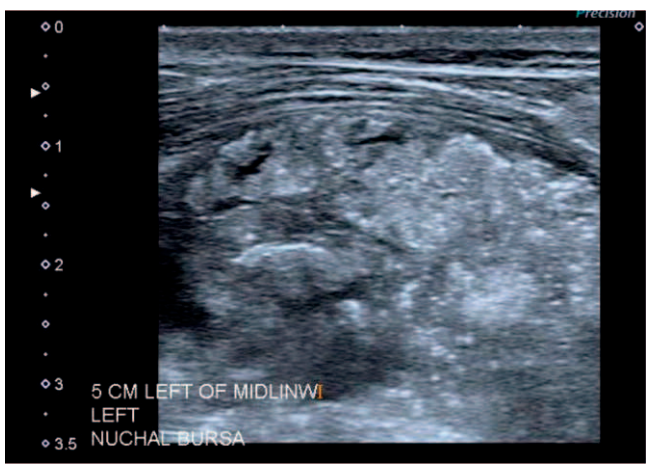


Fig. 14. Heterogeneous contents within the cranial nuchal bursa.

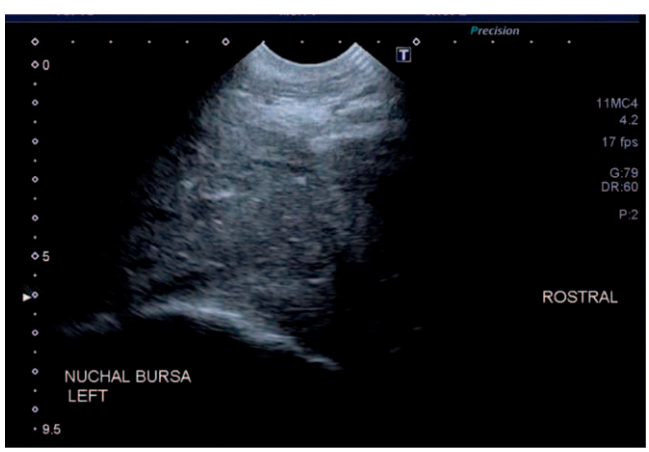


Fig. 15. Longitudinal image of the left aspect of the cranial nuchal bursa; the tendon of semispinalis capitus is visible in near field. Severely thickened synovium; minimal effusion seen.

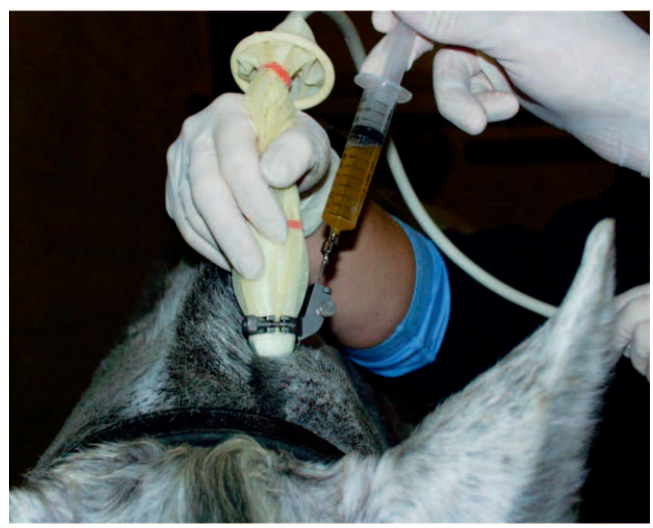


Fig. 16. Ultrasound-guided synovial fluid aspirate of the cranial nuchal bursa. The photo depicts use of a biopsy guide, although free-hand ultrasound-guided sampling can also be performed.

fluid aspirates (Fig. 16). With anatomic review and practice, the enlarged nuchal bursa is readily identifiable and assessed; in horses with significant disease, adequate sedation and analgesia is essential for patient comfort and a diagnostic scan. Infectious causes should be investigated, although differentiation of septic versus nonseptic bursitis using synovial fluid aspirates from cases in which no positive culture was obtained appears to be difficult.

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 has no conflicts of interest.

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How to Get the Most from Sonographic Evaluation of Pleuropneumonia

JoAnn Slack, DVM, MS, DACVIM

This session will benefit practitioners who wish to gain information beyond pleural fluid volume and character and apply that information to the formulation of a treatment plan and prognosis. Author's address: University of Pennsylvania, New Bolton Center, 382 West Street Road, Kennett Square, PA 19348; e-mail: slackj@vet.upenn.edu. © 2023 AAEP.

1. Introduction

Thoracic ultrasonography is ideal for investigating several of the features of equine pleuropneumonia, including the location, volume, and character of pleural effusion; pulmonary pathologies; pneumothorax; pleural abscesses; adhesions; and extension of infection into the pericardial space. Sonographic evaluation can also raise early suspicion for anaerobic infections.[1] Ultrasound can be used to identify the best location for pleural drainage and monitor for reaccumulation of fluid as well as overall progression of the disease process.

2. Materials and Methods

Patient preparation consists of clipping the hair over the entire thoracic region with a #40 blade, cleansing and rinsing the skin with mild soap and water, and applying coupling gel to cleansed skin. In winter, it may be necessary to start with a #10 blade or even bathe some horses. Alcohol can be applied to the hair coat of horses with short, clean summer coats or body clips rather than clipping. The thorax is examined from the 17th intercostal space (ICS) to the 2nd or 3rd ICS, beginning dorsally in the 17th and scanning dorsal to ventral, between the ribs, from caudal to cranial. In areas of normal or near-normal aeration, the lung and pleura can be evaluated with a high-frequency (7.5–14 MHz) transducer at 5 to 6 cm of depth. A-lines (reverberation artifact) and gliding motion (visceral pleura sliding against parietal pleura) are normal findings, as is a small amount of anechoic pleural fluid at the tip of the lung just behind the heart. A few scattered B-lines are also normal in most patients. In patients with extensive consolidation and/or effusive pleuropneumonia, a lower-frequency (2.5–5.0 MHZ) transducer is needed for deeper penetration into the thoracic cavity (30 cm or more). The rib spaces are used as anatomic markers for lung pathology, whereas a horizontal line drawn from the point of the shoulder is used to measure height of the pleural fluid.

Cranial to the heart, the thorax can be scanned with a low-frequency transducer either through the triceps muscle or by placing the transducer under the triceps muscle. The latter is facilitated by having the horse stand with its forelimb well forward. In

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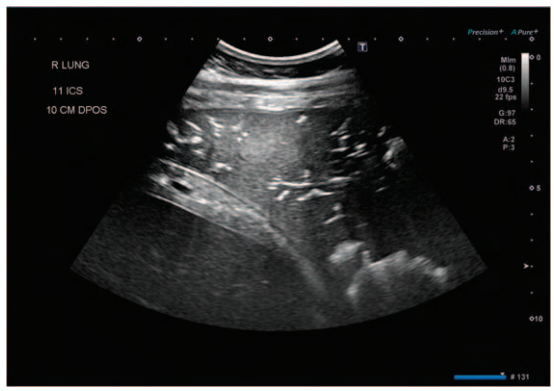


Fig. 1. Hepatized lung with hyperechoic, linear air bronchograms. Note that all ultrasound images shown in this paper are oriented with dorsal to the right of the image. ICS, intercostal space; DPOS, dorsal to point of shoulder.

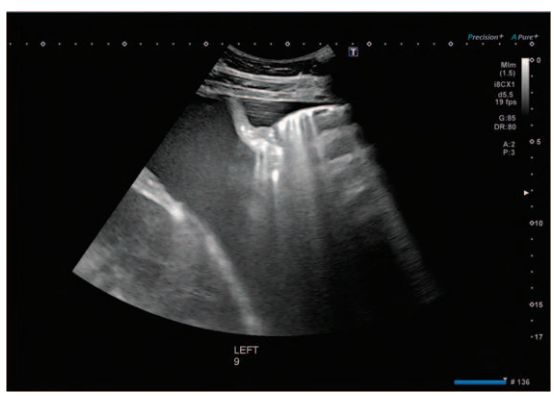


Fig. 2. Large echoic nonfibrinous pleural effusion and atelectatic tip of lung. In real time, tip of lung can be seen to "wave" in fluid. B-lines are present in more dorsal lung.



Fig. 3. Heteroechoic, bulging pulmonary parenchyma consistent with necrosis. Small volume pleural effusion.

normal horses, the mediastinal septum (where the left and right pleural reflections meet) and dorsal mediastinal contents are not seen. Instead, the normal aeration and gliding motion of the right cranial lung lobe is seen filling the pleural space in the right 2nd and 3rd ICS. The cranial-most aspect of the left lung is normally obscured by positioning of the heart. Caudal to the heart, the normal pericardial diaphragmatic ligament, accessory lobe of the right lung, and caudal vena cava with its plica are not seen unless there is marked pleural effusion. Variable amounts of pericardial fat can be present and should not be mistaken for fibrin or a mass.

3. Results

Pulmonary Pathology

Dorsal to any pleural fluid line, normally aerated peripheral lung is hyperechoic, and the visceral pleura will glide smoothly if there are no fibrinous attachments. Rare B-lines may be seen. The dorsal and approximately half of the caudal lung fields typically have this appearance in cases of pleuropneumonia. As fluid and cellular debris accumulate and push air out of the alveoli, multiple scattered and coalescing B-lines become visible, usually starting at the midthoracic level. As more fluid and debris accumulate and larger portions of the alveoli lack air, hypoechoic pulmonary parenchyma becomes visible at the lung periphery, representing pulmonary consolidation. As the sonographer progresses cranially and ventrally along the thorax, larger areas of consolidation typically become visible. Air bronchograms (Fig. 1), fluid bronchograms, and/or blood vessels become visible in these larger areas, giving the lung a hepatized look. The tip of the caudoventral lung (in the few intercostal spaces just behind the heart) usually contains the largest area of consolidation. This wedge of firm, consolidated lung typically sits below the pleural fluid line and moves as a single unit within the fluid (nonundulating). This contrasts with atelectasis of the lung tip where air is compressed out of the smaller airways, resulting in a homogenous, hypoechoic lung tip (Fig. 2) that undulates in the pleural fluid (moves like an elephant's trunk).

Liquefactive pulmonary necrosis is a component of most pleuropneumonias. It occurs secondary to the release of both bacterial and (leukocytic) lysosomal hydrolytic enzymes. Initially, necrosis appears similar to consolidation on a brief ultrasound scan, but careful inspection with higher resolution demonstrates a heteroechoic parenchyma with a bulging surface to the wedge of lung (Fig. 3). The lung may appear gelatinous as it moves within the pleural fluid in association with respiratory or cardiac motion. As liquefactive necrosis progresses, it leads to cavitation with asymmetric air accumulation just outside the smaller airways but within the pulmonary parenchyma. A hypoechoic halo can be seen at the periphery of these air accumulations. As neutrophils, fluid, and necrotic debris accumulate and become walled off from the remaining parenchyma, more discrete pulmonary abscesses with thick walls become evident. Dorsal gas caps may be seen within an abscess if it communicates with an airway or if anaerobic bacteria are present. More commonly, though, anaerobic pulmonary infection appears as numerous hyperechoic pinpoints distributed haphazardly within the pulmonary parenchyma, rather than accumulating in a focal area of necrosis or within linear airways.

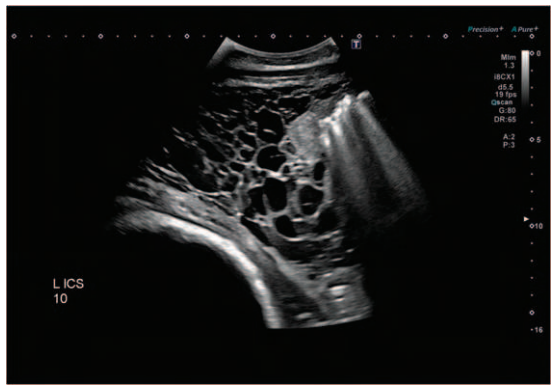


Fig. 4. Loculated pleural fibrin and fluid. Tip of lung is adhered onto its own axial surface. ICS, intercostal space.



Fig. 6. Large cranial pleural effusion seen on both sides of the echoic mediastinum. Mediastinum should not be mistaken for fibrin.

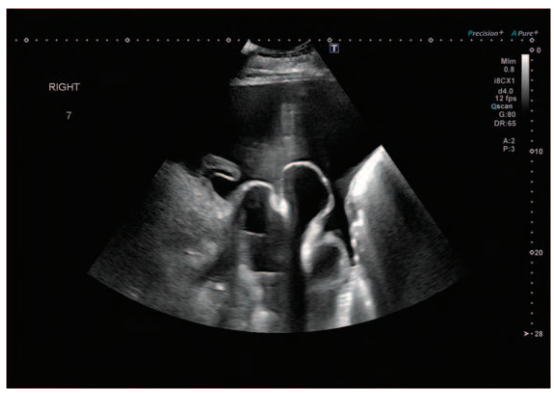


Fig. 5. Large hypoechoic pleural effusion with pericardial diaphragmatic ligament floating in fluid. Ligament should not be mistaken for fibrin.



Fig. 7. Organizing, encapsulated right cranial pleural abscess. POS, point of shoulder.

Coagulative necrosis secondary to pulmonary infarction is less commonly seen on ultrasound. If a larger, more proximal blood vessel is occluded, there may be a very sharp demarcation between consolidated and more hypoechoic necrotic lung. Color Doppler can be applied to the pulmonary vasculature in hopes of seeing this change in blood flow; movement from respiration often interferes with this diagnostic approach, however.

Pleural Pathology

In the early exudative stages of pleural inflammation, pleural effusion is anechoic to hypoechoic and lacks fibrin strands. It is in this early stage that application of a drain to one side of the thorax may result in drainage of both sides. This stage typically lasts 1 to 2 days before the fibrinoeffusive stage takes over, with increasing echogenicity of the pleural effusion and formation of hypoechoic, fibrinous strands (Fig. 4). By this point, the two hemithoraces typically need separate drainage as any fenestrations in the mediastinal pleural reflections become plugged with fibrin. It is important to recognize normal pericardial fat and the normal pericardiodiaphragmatic ligament (Fig. 5) and normal mediastinum (Fig. 6) so as not to confuse these with fibrin.

As the disease progresses, fibrin becomes organized and loculated, with adhesions developing between the parietal pleura and visceral pleura (visible fibrin strands and/or reduced lung gliding). A mature, thick, hypoechoic layer of fibrin (pleural peel) may be seen along most pleural surfaces by 2 to 4 weeks. As fibrinous loculations become more compartmentalized, multiple sites of pleural drainage may be required. While this can happen anywhere in the pleural cavity, the cranial pleural space on either side of the cranial mediastinum is commonly affected (Fig. 7). This is problematic because access for drainage may require general anesthesia and lateral recumbency. Furthermore, compartmentalized fluid pockets may progress to mature pleural abscesses, with thick purulent debris and fibrin that is not amenable to simple chest tube drainage but rather requires a surgical approach and debridement.

Pericardial Pathology

Local extension of infection is the most likely cause of pericardial exudate and fibrin accumulation, although hematogenous spread cannot be ruled out. Recognition of this complication is important, as it adds significantly to the cost of treatment and has the potential to cause cardiac tamponade. Small effusions may respond to antibiotic treatment, but moderate to large fibrinous effusions require drainage and lavage.

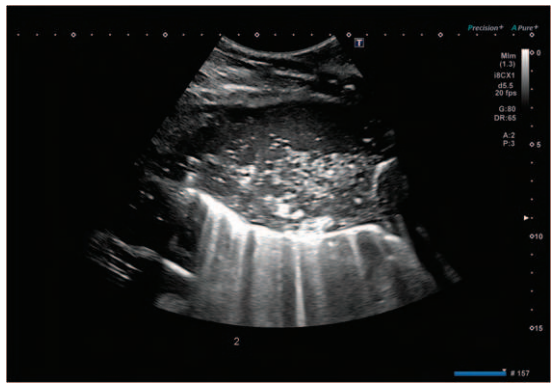


Fig. 8. Gas trapped in pleural fibrin and fluid.

Other

Pneumothorax is usually due to bronchopleural fistula or secondary to thoracocentesis. When free air in the pleural cavity is dorsal to the pulmonary parenchyma and dorsal to any pleural fluid line, it can be seen as a nonmoving hyperechoic line that casts a dirty shadow and does not have B-lines. At the junction of free air and aerated lung, the lung appears to glide "underneath" the free air. More recently, M-mode has been proposed for diagnosing pneumothorax, with a "sand on the beach" sign for normal lung and a "barcode" or "stratosphere" sign for the pneumothorax. Ultrasound can be used to identify a dorsal site for drainage of the pneumothorax. Polymicrobullous fluid (Fig. 8) is seen when air is mixed into the pleural effusion rather than residing dorsal to the lung (hydropneumothorax). Both a dorsal pneumothorax and polymicrobullous fluid can be seen at the same time.

Not all pleuropneumonias produce effusion. Dry pleuritis is best recognized by an absent or reduced gliding sign. Fibrin can frequently be seen between the visceral and parietal pleural surfaces, especially if using a high-frequency transducer.

Sonographic Planning for Thoracic Procedures

Ultrasound is very useful for selecting sites for thoracocentesis and chest tube placement. If fluid sampling is to be done without placement of a chest tube (small volume effusion), then any fluid pocket with minimal fibrin that is remote from the heart and lung can be selected. If effusion is very small, real-time ultrasound guidance may be needed. For chest tube placement, the goal is to select the most ventral site that communicates with the largest volume of fluid but avoids or reduces the risk of cardiac penetration. This is typically in the right and left 7th intercostal spaces. If the pleuropneumonia is acute and there is little to no fibrin, placement of a chest tube on one side may drain both hemithoraces. If there is a lot of fibrin loculation, drainage may be slow and tubes may become clogged. Installation of fibrinolytics can be considered in these cases. In chronic cases, pleural abscesses may require surgical drainage. Ultrasound is then used to identify the abscess margins and relationship to the thoracic wall. Ideally, the abscess will be adhered to the thoracic wall, and the surgical approach can be performed without further respiratory compromise.[2]

4. Discussion

Sonographic evaluation of the thorax provides critical information for managing pleuropneumonia. Horses with simple consolidation, minimal fluid accumulation/reaccumulation, and no fibrin production are thought to have the best prognosis and the lowest overall (hospitalization and beyond) cost of treatment,[3,4] although one study did not find any differences in cost of hospitalization between fibrinous and nonfibrinous pleuropneumonia.[5] Extensive fibrin loculation can lead to pleural abscess formation and the need for surgical debridement, fibrinolytics, and multiple thoracic drains. Cranial thoracic pleural abscesses are troublesome to access for drainage, if they can be reached at all. Identification of pulmonary necrosis makes cavitation and abscessation more likely, potentially increasing the overall treatment duration and cost. Necrosis can also lead to bronchopleural fistula formation and subsequent hydropneumothorax, pneumothorax, or tension pneumothorax. While little is known about bronchopleural fistulas in horses and the definitive diagnosis is rarely made premortem, they are associated with prolonged hospitalization and mortality in human patients postpneumonectomy.[6] Although unusual, fibrinoeffusive pericarditis as a sequela to pleuropneumonia is difficult to resolve. Horses may show signs of poor cardiac filling and output secondary to increased intrapericardial pressure and cardiac compression.

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.

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How to Ultrasound the Equine Lower Urinary Tract

JoAnn Slack, DVM, MS, DACVIM

This session will benefit practitioners who wish to learn the normal imaging anatomy of the lower urinary tract, identify sonographic abnormalities of the lower urinary tract, and distinguish urinary structures from the accessory sex glands of male horses. Author's address: University of Pennsylvania, New Bolton Center, 382 West Street Road, Kennett Square, PA 19348; e-mail: slackj@vet.upenn.edu. © 2023 AAEP.

1. Introduction

Sonographic examination of the lower urinary tract is useful in the diagnosis of urolithiasis, cystitis, urinary tract obstruction, trauma, neoplasia, and other masses. Horses with renal lithiasis benefit from examination of the lower urinary tract for prognostication, particularly if surgical intervention is planned. Pyelonephritis may also be associated with ureterolithiasis, ureteritis, cystitis, or neoplasia of the lower urinary tract. Birthing trauma has the potential to affect the lower urinary tract structures, as do perirectal or peripelvic trauma and abscesses from other causes. The information that is gained from the sonographic appearance of various abnormalities of the lower urinary tract adds to the overall diagnostic and treatment plans as well as to the prognosis. Because portions of the lower urinary tract are anatomically related to the genital tract, it is also helpful to know the normal relative anatomic locations and sonographic appearance of not only the female reproductive tract but also the accessory sex glands in stallions and geldings.[1]

2. Materials and Methods

The lower urinary tract is primarily examined per rectum with two exceptions: the urinary bladder and the proximal ureters as they exit the kidneys. These structures can frequently be seen from transcutaneous windows using a low-frequency (approximately 2–5 MHz) convex transducer. If the bladder is moderately to markedly distended, it can be seen from the caudoventral abdominal windows or even from the lateral flank regions. The right ureter is easier to see than the left owing to its more superficial location in the right 17th to 15th intercostal spaces. The left ureter is more deeply positioned but in smaller or leaner horses can still be seen transcutaneously in the left paralumbar fossa to the level of the left 16th intercostal space. With patience, the ureters can be seen to distend with anechoic urine and then contract and often have a small amount of hyperechoic fat surrounding them. Power Doppler can be used to distinguish the renal vessels from the ureters.

For examining structures per rectum, both a standard linear "reproductive" transducer and a microconvex transducer (approximately 4–8 MHz) ideally should be

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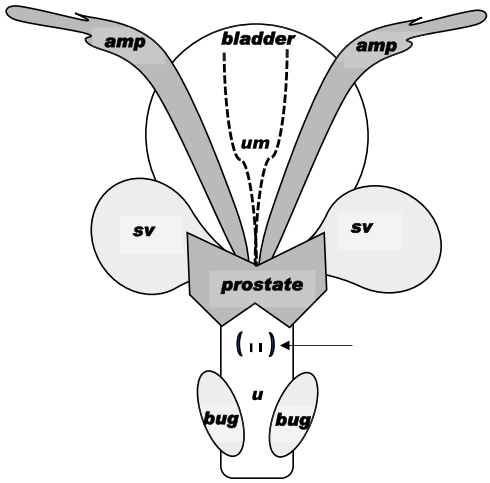


Fig. 1. The normal relative relationships of the lower urinary tract and the accessory sex glands of the male horse. Amp, ampullae of ductus deferens; sv, seminal vesicle; bug, bulbourethral gland along dorsolateral distal urethra (u); um/dashed lines, uterus masculinus. The arrow points to convergence of ampullae (inner lines) and seminal vesicles (outer crescents) at the seminal colliculus.

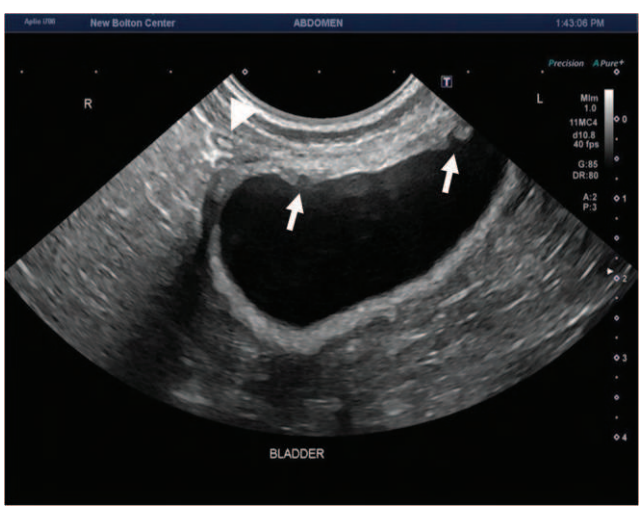


Fig. 2. Transrectal sonogram showing small intrapelvic bladder at level of the trigone containing hypoechoic urine. Normal ureteral openings (arrows) and right ampulla of the ductus deferens (arrowhead) visible.

used to examine all structures to the maximal depth and highest resolution, in both transverse and longitudinal planes. Depth, gain, and focal position should all be adjusted to optimize image quality. Sedation, intravenous hyoscine butylbromide, and lidocaine per rectum may each facilitate examination. Because gas will be introduced by cystoscopy and potentially obscure sonographic imaging, it is recommended that sonographic examination occur beforehand.

3. Normal Structures Visualized per Rectum

Ureters

Paired ureters exit the hilus of the right and left renal pelvic regions, curve caudally and medially, and run

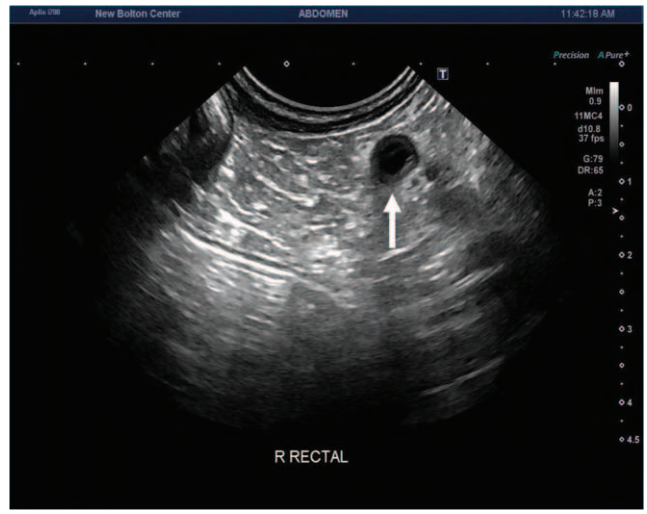


Fig. 3. Transrectal sonogram showing normal right ureter, mid-contraction, between bladder and right kidney. Notice thin, hypoechoic, smooth wall and anechoic urine.



Fig. 4. Transcutaneous sonogram showing normal ureter at level of right renal pelvis surrounded by fat.

laterally alongside the aorta (left) and caudal vena cava (right). They then run in the retroperitoneal tissues along the roof of the abdominal cavity, ventral to the psoas major and minor muscles, crossing the external iliac vessels and entering the pelvic cavity. Once in the pelvic region, the ureters move medially within the broad ligament of the female or move medially in the urogenital fold and cross the ampullae of the ductus deferens in the male. The ureters then enter the dorsolateral surface of the bladder and run a short distance within the bladder wall before opening into the bladder lumen at the level of the bladder trigone. In males, the ureteral openings (ostia) are located either just ventral to the ampullae or medial to the ampullae of the ductus deferens and to the seminal vesicles. The seminal vesicles and ampullae of the ductus deferens continue caudally to the seminal colliculus of the urethra where they join and form the 2 ejaculatory ducts.[2] Pulsatile contractions of the

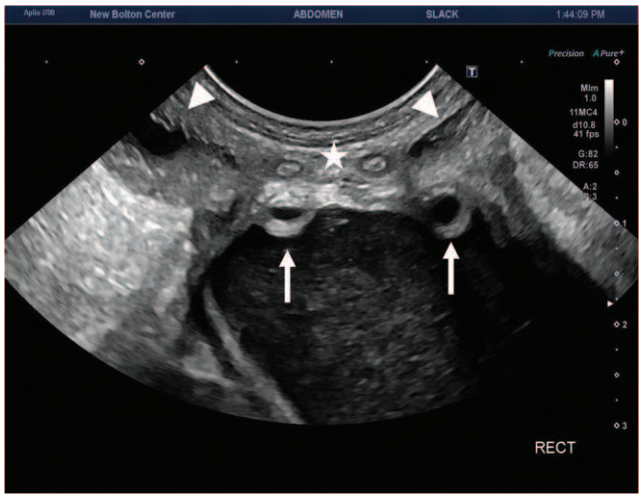


Fig. 5. Transrectal sonogram showing normal ureters (arrows) just cranial to ostia. Fluid-distended seminal vesicles of gelding (arrowheads). Normal ampullae of the ductus deferens dorsal to bladder and ureters (on either side of star).

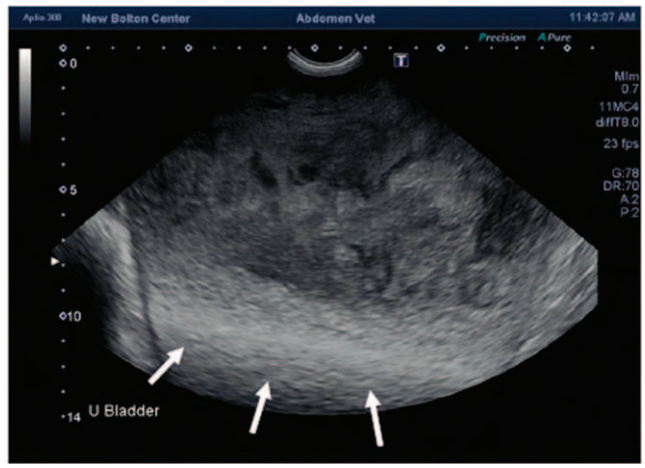


Fig. 7. Transrectal view of bladder showing ventral sedimentation of calcium carbonate crystals. When ballotting the bladder, the sediment stays along the ventral aspect. Findings are typical of sabulous cystitis. Image obtained from gelding with history of urine dribbling.

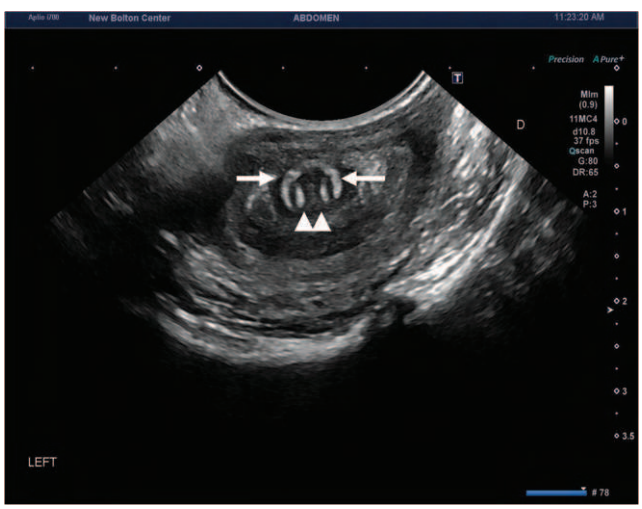


Fig. 6. Normal male pelvic urethra at level of seminal colliculus. Seminal vesicles (arrows) and ampullae of ductus deferens (arrowheads) nearing their termination on the ejaculatory ducts. The uterus masculinus terminates between the ampullae of the ductus deferens and is barely visible in this transrectal image.

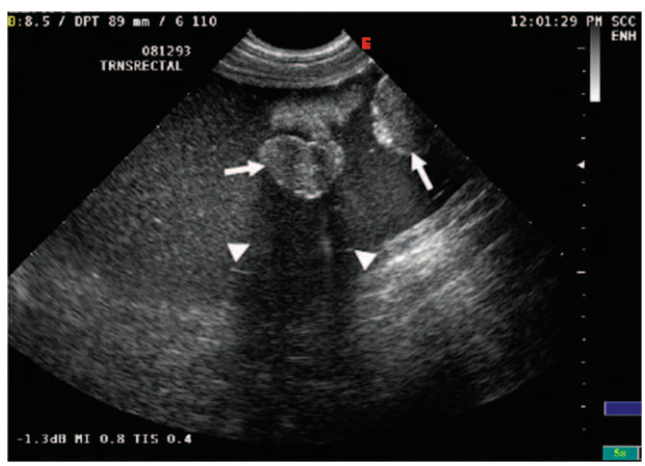


Fig. 8. Bladder polyps: masses appear as ovoid homogenous masses (arrows) that cast a weak acoustic shadow (arrowheads) from the far surface.

ureters are normally seen along their lengths and at the ostia when urine empties into the bladder.

It is typically easiest to identify the ureters at the level of the bladder, either at the ostia or slightly cranial (proximal) to this location. The left ureter can be followed cranially and laterally all the way to the left kidney in all but the largest horses. The right kidney is not typically palpable/reachable, so the right ureter is followed as far toward the kidney as possible. The diameter of the normal ureter is between 2.9 and 18.5 mm, depending on state of distension, whereas the ureteral walls measure up to 2.4 mm in thickness regardless of state of distension.[3] In intact males, the ampullae of the ductus deferens are quite echogenic and large (up to 18 mm in diameter) and easily distinguished from the ureters.[4] In geldings, the distinction is more difficult, as the ampullae are much smaller (up to 4 mm in diameter).[1] The seminal vesicles (SVs) can also be seen alongside the bladder in the region of the ampullae and ureters in all male horses. Anechoic to hypoechoic fluid is normal in the SVs of both stallions (2–39 mm in diameter depending on when last ejaculated) and geldings (up to 9.5 mm in diameter).[1] Geldings may also have flattened SVs with no visible/measurable fluid. Both seminal vesicles and ampullae can be distinguished from the ureters by following each structure to its termination into the bladder or urethra.

Bladder

The bladder appears as a round or ovoid structure containing anechoic, hypoechoic, or heteroechoic, sometimes layered fluid. The echogenicity and



Fig. 9. Large hyperechoic curvilinear structure casting strong acoustic shadow consistent with bladder stone. Transrectal image.

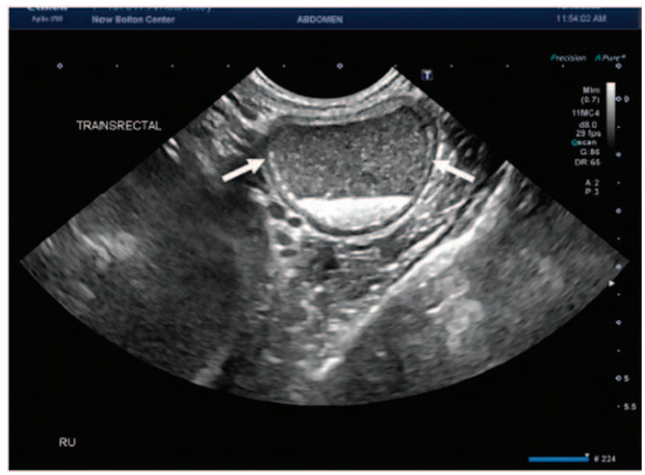


Fig. 11. Markedly distended ureter with normal wall thickness and layered urine. Same horse as Fig. 7. A cystolith was obstructing the ostia of the right ureter, causing urine backup and distension of the ureter (hydroureter). Transrectal image.



Fig. 10. Hyperechoic spiculated curvilinear echo (arrow) casting a strong acoustic shadow within the bladder (bladder stone). The urine is heteroechoic and layered consistent with mucus and sedimentation of crystals (arrowheads).

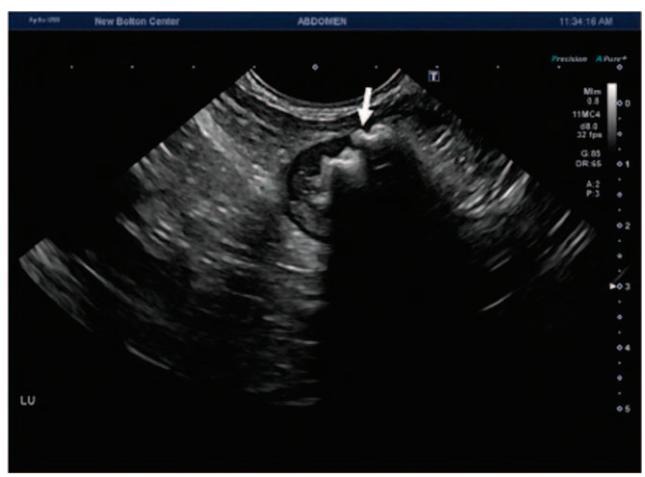


Fig. 12. Ureterolith in lumen and wall of the left ureter. Irregular hyperechoic surface with strong acoustic shadow originating from surface of stone. Transrectal image.

layering of the fluid depend on the relative contents of mucus and calcium carbonate crystals. The bladder wall is smooth and echoic and measures up to 5 mm in thickness.[3] The bladder can be completely intrapelvic or large enough to extend into the abdomen and can be visible transcutaneously via a caudoventral abdominal approach.

Pelvic Urethra

The male urethra can be followed per rectum from the neck of the bladder, externally to the level of the glans penis. It passes over the pelvic floor to the ischial arch then cranially, enclosed in the corpus spongiosum of the penis. The pelvic portion is approximately 10 to 12 cm in length and surrounded by the urethralis muscle except at its most cranial aspect.[2] The prostate lobes and isthmus are visible dorsal and lateral to the proximal pelvic urethra, while the bulbourethral glands are located laterally alongside the more caudal urethra. The internal obturator muscle is ventral to the urethra. The region of the seminal colliculus is visible along the dorsal midline of the urethral wall, approximately 5 cm caudal to the junction of bladder and urethra.[2] The seminal vesicles and ampullae of the ductus deferens can be followed to the seminal colliculus where their combined openings (ejaculatory ducts) are visible. The uterus masculinus (a fetal remnant) can sometimes be seen as a small anechoic fluid-filled structure along midline between the ampullae of the ductus deferens in both stallions and geldings. Prostatic, bulbourethral gland, and urethral gland ducts are not typically visible sonographically. The female urethra is approximately 5 to 8 cm in length and is encircled by the urethralis muscle.[2] It



Fig. 13. Sedimentation of calcium carbonate crystals (arrow) in distended ureter. Notice weaker shadow originating deeper within sediment (arrowheads) indicating lack of solid stone formation. Ureter is dilated with heteroechoic urine and mucus.

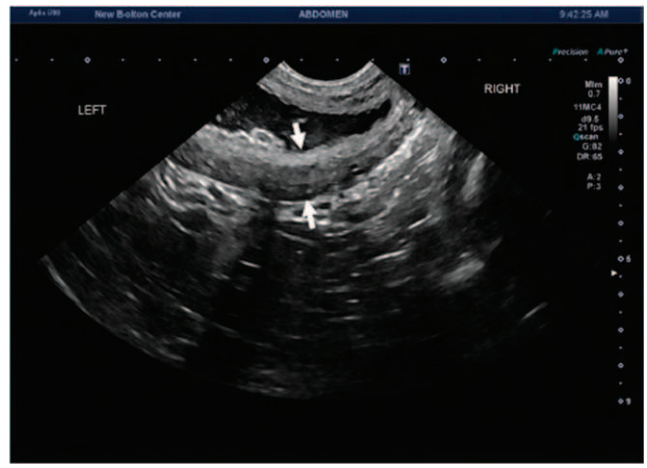


Fig. 15. Thickened (1.5 cm), heteroechoic bladder wall in a gelding with cystitis. Transrectal image.

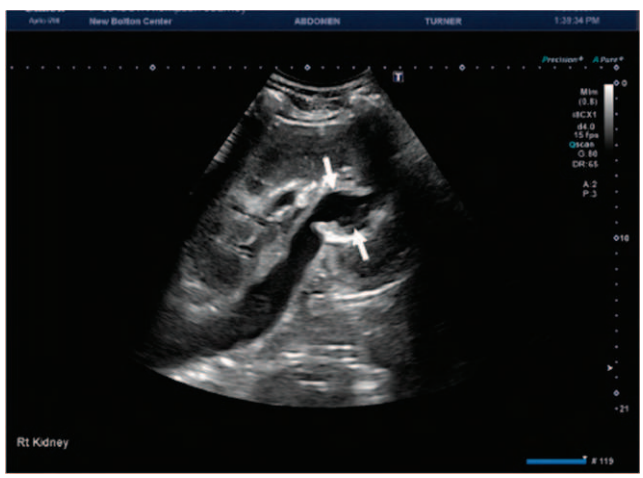


Fig. 14. Distended proximal ureter of right kidney secondary to distal obstruction by ureterolith. Transcutaneous image.

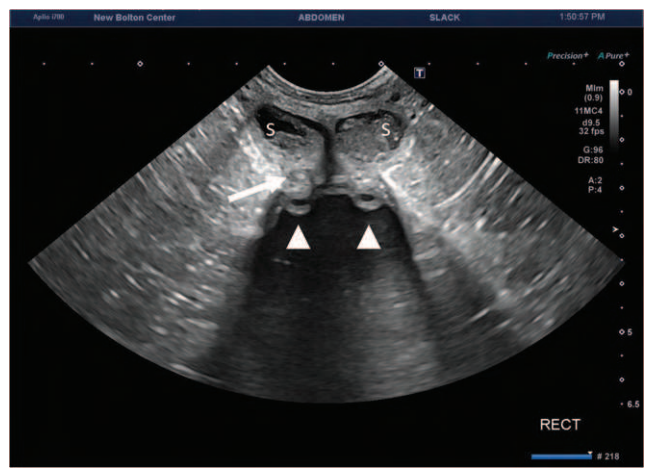


Fig. 16. Heteroechoic fluid and mucus within seminal vesicles (S) of a gelding. Not to be confused with dilated ureters. Normal ureters (arrowheads). Ampulla of ductus deferens (arrow). Transrectal image.

lies ventral to the vagina and empties into the vaginal vestibule.

4. Results

Examples of normal sonographic anatomy can be seen in Figs. 1–6. Abnormal sonographic findings are shown in Figs. 7–16. The most common abnormal findings on sonographic examination of the lower urinary tract in the author's practice are uroliths (bladder, ureter, urethra), sabulous cystitis, bacterial cystitis, ureteritis, and perirectal abscesses that involve some portion of the urinary (± genital) tract. Traumatic injury postfoaling and broad ligament hematomas are occasionally seen obstructing the ureters. Bladder polyps and neoplasia are rare.

Figure 1 shows the normal relative relationships of the lower urinary tract and the accessory sex glands of the male horse. The normal uterus masculinus is barely visible unless cystic.[5] The seminal vesicles are often asymmetrical. The ampullae, seminal vesicles, and uterus masculinus all travel deep to the prostate before inserting into the dorsal wall of the urethra.

5. Discussion

Sonographic evaluation of the lower urinary tract is a relatively noninvasive, low-cost option for evaluating adult horses with signs referable to the urinary tract. Evaluation per rectum gives diagnostic and prognostic information for common problems, including urine dribbling, hematuria, urinary causes of colic symptoms and masses palpated per rectum. Importantly, ultrasound allows for identification of uroliths in various parts of the urinary tract and is particularly useful for identifying ureteral abnormalities that can affect prognosis and treatment. The author's practice strongly believes that identification of any urolith should prompt thorough examination of the remaining parts

of the urinary tract (upper and lower). Surgical planning is enhanced with knowledge of the size and location of uroliths and peri-urinary masses. A transducer with medium frequency and a small footprint (microconvex) is needed to perform a comprehensive evaluation that includes deeper structures. The ureters are also easier to follow in a transverse plane with a microconvex transducer rather than a linear rectal transducer. Knowledge of the relevant anatomy is critical to avoid misidentification of certain urinary structures. With practice, all lower urinary structures can be visualized by ultrasound per rectum except the most proximal part of the right ureter.

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.

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Ultrasonographic Findings in Horses with Gastric Impaction

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Transabdominal ultrasound can be utilized to identify gastric impaction and provides adjunctive information to gastroscopy or can stand alone in practices without access to endoscopic equipment. Ultrasonographic abnormalities suggestive of gastric impaction include a large radius of curvature of the stomach, stomach extending to ventral midline, and ventral displacement of the spleen. Serial ultrasound monitoring can provide noninvasive evidence of response/resolution, decreasing the need for serial gastroscopy. Authors' address: University of California – Davis, School of Veterinary Medicine, One Garrod Drive, Davis, CA 95616; e-mail: mevaughan@ucdavis.edu. *Corresponding and presenting author. © 2023 AAEP.

1. Introduction

Gastric impaction in horses is an uncommon, poorly elucidated, and frustrating clinical entity characterized by dehydrated ingested material remaining within the stomach despite fasting or inappetence of 16 hours or greater.[1–5] Gastric impactions that occur in the absence of other gastrointestinal abnormalities are considered primary impactions, while those associated with other intra-abdominal disease such as displacements, volvulus, or liver disease are considered secondary.[3] The diagnosis is generally made via direct visualization of the impaction via gastroscopy or direct palpation of the impaction at exploratory laparotomy.[1–5] The magnitude of gastric distention via gastroscopy can be difficult to assess.[4] Clinical signs and presenting complaints are broad and nonspecific, ranging from mild changes in behavior to moderate abdominal discomfort. Patients rarely present in distress, often with normal to mild derangements in heart rate and respiratory rate. Nasogastric intubation may be unrewarding, and difficulty passing the tube, foul-smelling gastric contents, and/or thick, difficult to siphon feed material have also been reported.[1–5] Caudal displacement of the spleen has been encountered on rectal palpation.[1–2] Abnormalities on complete blood count and serum chemistry are commonly mild and nonspecific. Both medical and surgical management of gastric impaction have been reported, with medical management yielding a better prognosis, likely due in part to the difficult surgical access to the equine stomach.[2–3] Serial gastric lavages are the cornerstone of medical therapy, though treatment is often protracted. The addition of diet cola is thought to improve dissolution of the impaction, although the mechanism remains poorly understood.[2–4]

The utility of transcutaneous abdominal ultrasound (AUS) in the diagnostic workup of horses presenting with abdominal discomfort is well established. A

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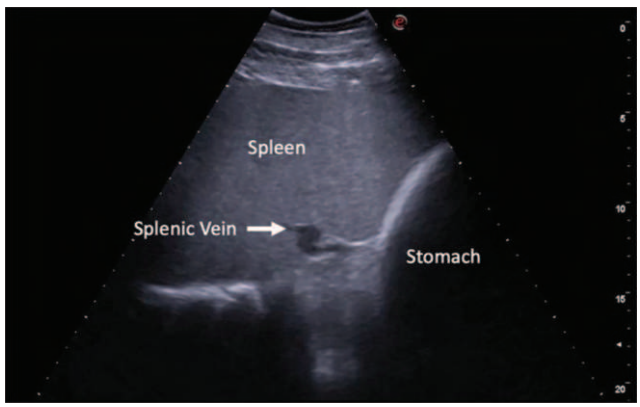


Fig. 1. Reference image of a normal stomach taken in the left 11th ICS. Image obtained at 21 cm of depth using a 5.0-MHz curvilinear transducer. Dorsal is to the right.

recent PubMed search for "abdominal ultrasound horse" yielded over 4,000 references. This large existing body of scientific literature is both overwhelming and sometimes contradictory, leaving the equine practitioner without clear guidance about what is considered "normal" and "abnormal." This is especially true of ultrasonographic evaluation of the stomach where the existing literature is inconsistent with regard to normal anatomic location and size. The normal equine stomach is visualized in the left intercostal spaces (ICS), ventral to the lung and dorsal to the spleen, adjacent to the splenic vein (Fig. 1). Normal cranial to caudal margins range from the 10th to the 15th ICS and span 4 to 7 ICS depending on the reference.[6–10] Recent work has better characterized the effects enteral fluids, fasting, and nasogastric intubation have on ultrasonographic visualization of the stomach in normal horses, with visualization ranging from the 6th to 15th ICS in unfed and 6th to 16th ICS in fed horses, spanning up to 9 ICS.[11–12] Normal gastric wall thickness ranges from 4 to 7 mm.[6–10] A minority of previous retrospective analyses of gastric impaction include limited descriptions of ultrasound findings that predominantly focused on the number of intercostal spaces in which the stomach was visualized.[1–2] The purpose of this study is to review the ultrasonographic technique to evaluate the equine stomach and report the ultrasonographic findings associated with gastric impaction in the horse.

2. Materials and Methods

Medical records were reviewed for all patients presenting to the Large Animal Ultrasound Service at the UC Davis William R. Pritchard Veterinary Medical Teaching Hospital for AUS between September 1, 2000, and September 1, 2022. Horses were included in the study if they were diagnosed with gastric impaction and underwent complete AUS performed by the Large Animal Ultrasound Service and gastroscopy performed by the Equine Emergency and Critical Care Service or the Equine Internal Medicine Service.

Data collected included signalment, history, physical exam findings, gastroscopy findings, ultrasonographic findings, treatment, and outcome. Outcome was determined based on review of the medical record or email and/or telephone conversation with the owner. AUS was performed using a low-frequency curvilinear transducer and one of the following ultrasound machines: GE Vingmed System 5,[a] Esaote Biosound Technos,[b] or Esaote Biosound Twice.[c] Complete AUS exam included evaluation of the right and left kidneys, right and left liver lobes, spleen, stomach, descending duodenum, small intestine, cecum, cecal mesentery, and large colon. The caudal and cranial-most intercostal space where the stomach was visualized and the arc of the radius of the greater curvature of the stomach were recorded. The stomach was considered normal if it demonstrated a subjectively normal radius of curvature with wall thickness less than 7.0 mm. Horses were placed in standing stocks and lightly sedated with detomidine hydrochloride[d] (0.004–0.015 mg/kg IV). Gastroscopy was performed using a variety of endoscopy towers given the long study period, the most recent being the 3.25-m Storz Vet Video Endoscope PV-G 34-325.[e]

3. Results

Signalment

Sixteen horses met the inclusion criteria, including 9 geldings and 7 mares with a mean age of 12.8 years (range 6 months to 23 years). Breeds represented included 6 Warmbloods, 2 Belgians, and 1 each of the following: Gypsy Vanner, Friesian, Paint, Morgan, Rocky Mountain Horse, Mustang, Irish Sport Horse, and Thoroughbred/Appaloosa. Use was recorded for 6/16 horses and included dressage (2), hunter/jumper (1), show (1), retired (1), and juvenile (1). Housing was available for 5/16 horses and included stall (3) or paddock (2). Diet was recorded in 6/16 horses and included grass hay only (3), alfalfa hay only (1), grass/alfalfa mix (1), and grass/equine senior/pellets (1).

Clinical Signs

Inappetence (7/16) was the most common presenting complaint, followed by one or more of the following: chronic/intermittent colic (4/16), acute colic (3/16), fever (3/16), hypersalivation (3/16), weight loss (2/16), malpositioning/enlargement of the spleen on rectal exam (2/16), and 1 horse with squamous cell carcinoma of her vulva presented for abdominal ultrasound as a metastasis check. Presenting complaint for 3/16 horses was listed as "gastroscopy" with no further explanation of the clinical signs that prompted referral in the medical record. Duration of symptoms in patients with clinical signs ranged from 24 hours to 6 months. Nasogastric intubation was performed at presentation in 10 horses and yielded one or more of the following: no reflux (4/10), feed (4/10), foul-smelling gastric contents (3/10), reflux (≥ 2 L; 2/10), and

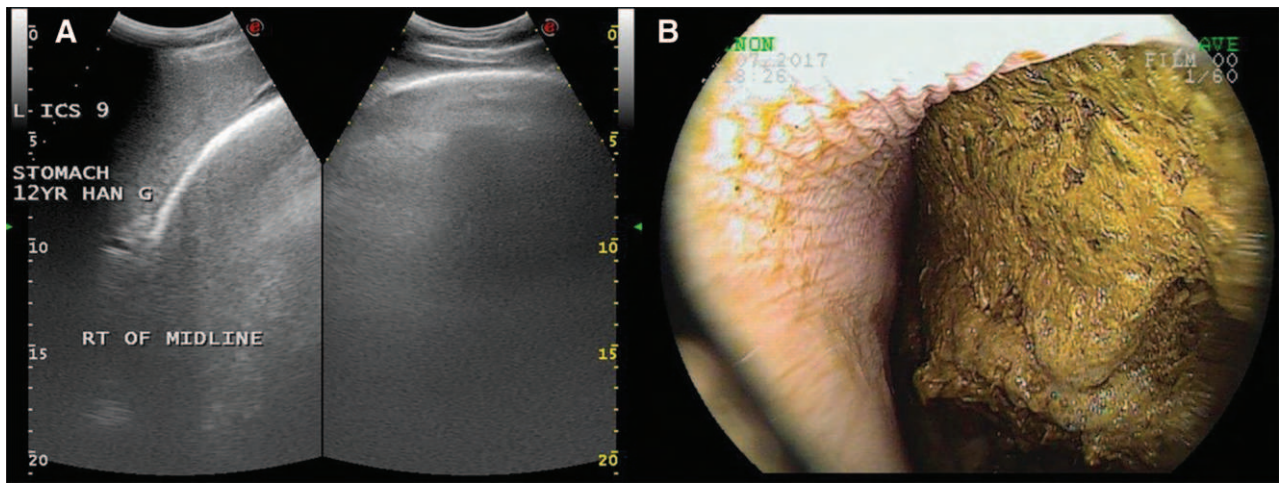


Fig. 2. A, Composite image of a very large radius of curvature obtained in the ventral abdomen at the level of the 9th ICS in a 12-year-old Hanoverian gelding with gastric impaction. B, The gastric impaction. The ventral gastric margin extends to the right of ventral midline. Image obtained at 21 cm of depth using a 3.5-MHz curvilinear transducer. Dorsal is to the right.

failure to advance the nasogastric tube into the stomach (2/10).

Ultrasound Findings

Complete AUS was performed prior to gastroscopy in 7 horses and prompted gastroscopy in all cases. Four horses underwent AUS the day of presentation and 3 during the first 24 hours of hospitalization. The remaining 9 were examined 3 to 5 days after admission during treatment. Of these 9, AUS was undertaken in 3 horses that had completely resolved their impaction 24 to 72 hours prior to further characterize gastric size, position, and wall thickness and to rule out other abdominal comorbidities. The stomach was considered within normal limits in 2 horses after resolution of impaction. Gastric wall thickening seen in the remaining horse is described below.

The number of intercostal spaces the stomach occupied was 7–13 (mean 12.8, median 13), ranging from the level of the 6th ICS to the paralumbar fossa region. The stomach was visible in the paralumbar fossa region in 5/16 horses and the 17th ICS in 1 horse. Nine of 16 horses demonstrated a subjectively large radius of curvature (Fig. 2), with the stomach extending to or beyond ventral midline in 5/9 horses. The spleen was ventrally displaced in 9/16 horses (Fig. 3). Gastric contents were gaseous in all cases with no fluid or ingesta visualized. Seven of 16 horses demonstrated gastric wall thickening, 2 graded as mild (7.1–9.0 mm), 1 graded as moderate (9.1–11.0 mm), and 4 graded as severe (> 11.1 mm; Fig. 4). Only 2/7 horses with gastric wall thickening demonstrated a normal radius of curvature, one graded as mild and one as severe. The one abnormal horse whose impaction had resolved prior to ultrasound examination demonstrated severe gastric wall thickening (up to 22.0 mm) with an irregular mucosal surface (Fig. 5) and moderate duodenal wall thickening.

One horse demonstrated an irregularly marginated, ill-defined mass-like structure containing gas echoes

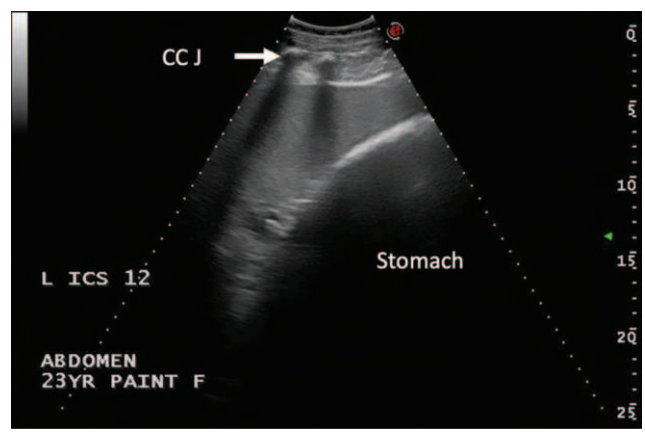


Fig. 3. The spleen is displaced ventral to the costochondral junctions (CCJ) by the severe gastric distention causing a large radius of curvature in this 23-year-old Paint mare who presented for elective ultrasound as a metastasis check for squamous cell carcinoma of her vulva. Image obtained at a depth of 27 cm using a 3.5-MHz curvilinear transducer. Dorsal is to the right.

between the spleen and gastric region strongly suggestive of anaerobic abscessation associated with partial/previous gastric tear or rupture (Fig. 6). Gastrosplenic (1) and cecal (1) lymphadenopathy were seen in 2/16 horses. Clinically relevant ultrasonographic findings were confined to the stomach in all but 1 horse with elevated liver enzymes that demonstrated right-sided hepatomegaly and a splenic mass diagnosed via ultrasound-guided aspirate as a hematoma. Focal mild to moderate small and/or large intestinal thickening (3.5–5.0 mm) deemed of limited clinical relevance was seen in 2/16 horses.

Two horses underwent recheck specialty AUS examination. The first horse was examined 6 days after ultrasonographic and gastroscopic diagnosis (during the course of hospitalization), and ultrasound revealed an unchanged/persistently severely enlarged stomach. The second horse underwent a recheck exam 39 days

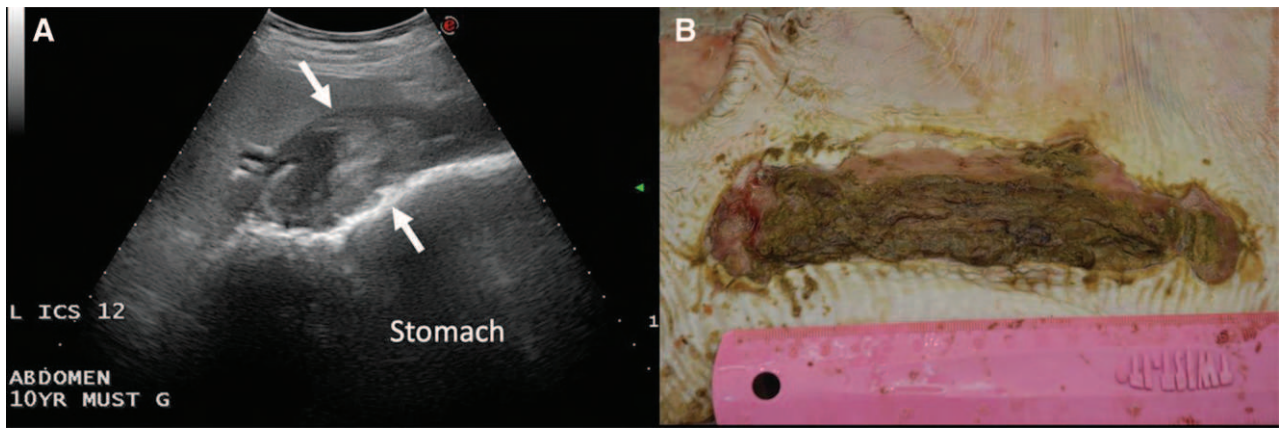


Fig. 4. A, Severe, irregularly marginated gastric wall thickening (arrows) in a 10-year-old Mustang with inappetence, chronic colic and weight loss. Image obtained at a depth of 17 cm using a 3.5-MHz curvilinear transducer. Dorsal is to the right. B, Necropsy revealed chronic gastric impaction with severe chronic multifocal ulcerations with infiltration of neutrophils, lymphocytes, plasma cells, and granulation tissue.

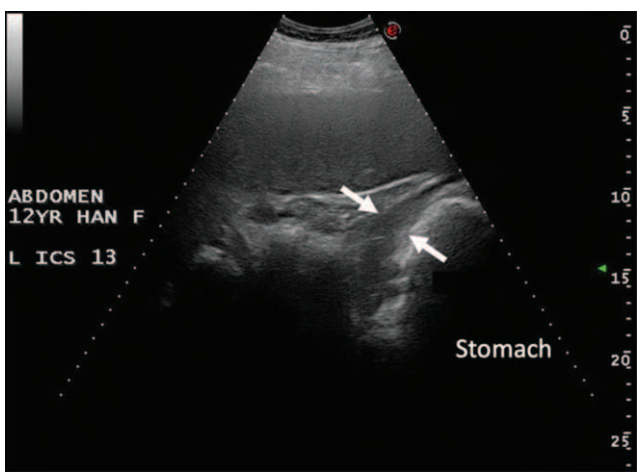


Fig. 5. Severe gastric wall thickening (22 mm) with irregularity of the mucosal layer in a 12-year-old Hanoverian undergoing abdominal ultrasound after resolution of gastric impaction. The stomach is not distended. Image obtained at a depth of 28 cm using a 3.5-MHz curvilinear transducer. Dorsal is to the right.

after initial diagnosis, and ultrasound revealed improved but persistent gastric distention. Ultrasonographic monitoring via point-of-care ultrasound was performed in 7 horses and found to be instrumental in providing information regarding stomach size and position resulting in a decrease in number of recheck gastroscopies required.

Gastroscopy Findings

Gastroscopy was performed prior to ultrasound in 9 horses. Initial gastroscopy revealed a large feed impaction in 15/16 horses that obscured visualization of the margo plicatus in 12 and involved the distal esophagus in 2 horses, 1 of which was suspected to have megaesophagus. Gastroscopy was not performed until resolution of the impaction in the remaining horse. This horse was diagnosed with gastric impaction based on dense malodorous ingesta obtained per nasogastric intubation as well as during subsequent gastric lavage and severe gastric distention and moderate wall thickening on AUS. Recheck gastroscopies (1–7 procedures) were performed in 13 horses to monitor resolution of the impaction during the initial hospitalization and revealed gastric ulceration in 7 and hyperkeratosis in 3 after the gastric impaction had resolved. Five horses returned for recheck gastroscopy postdischarge, 2 of which had recurrent impaction on one occasion and 1 of which had one recurrent impaction and was ultimately euthanized at a subsequent visit for gastric rupture. The remaining 2 horses were diagnosed with ulcers and/or hyperkeratosis at recheck exams.

Treatment and Outcome

All horses were hospitalized, and 15/16 were treated with gastric lavage via nasogastric tube. Four horses underwent 1 lavage, and 11 horses were treated with a minimum of 2 to 5 lavages. Cola (500 mL to 1 L), Epsom salts (0.25–1 g/kg), and/or dicotyl sodium sulfosuccinate (DSS) (10–20 mg/kg) were added to the lavage solution at least once throughout treatment in 12 horses. Time to resolution of impaction ranged from 1 to 13 days (mean 4.5 days, median 4 days). One horse deteriorated clinically while hospitalized and underwent exploratory celiotomy, which revealed gas-distended large and small intestines and a large accumulation of impacted feed within the stomach. The small and large intestines were decompressed, and the gastric impaction was gently massaged in an effort to break up the impaction. One horse was euthanized after the first lavage due to the severity of gastric distention and severe gastric wall thickening on ultrasound and financial constraints of the owner. Necropsy revealed severe gastric impaction with severe chronic multifocal ulcerations with infiltration of neutrophils, lymphocytes, plasma cells, and granulation tissue. Two horses were euthanized after 5 and 7 days of hospitalization, respectively, one with the gastric abscessation associated with the chronic partial gastric wall tear previously described. The other

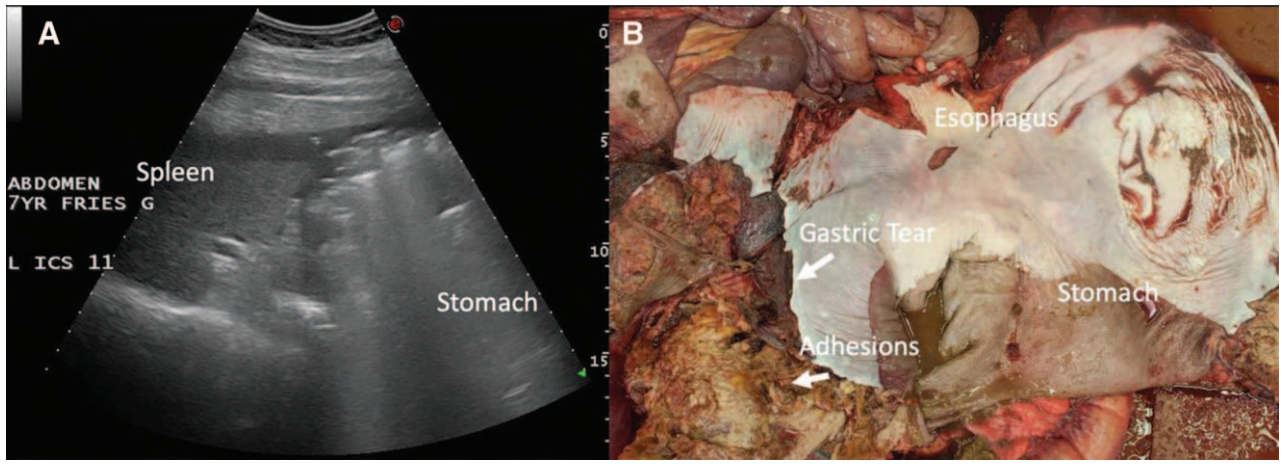


Fig. 6. A, Irregularly marginated gas echoes between the stomach and spleen in a 7-year-old Friesian gelding with gastric tear/rupture walled off by adhesions between the stomach, spleen, and diaphragm. Image obtained at a depth of 20 cm using a 5.0-MHz curvilinear transducer. Dorsal is to the right. B, Necropsy findings illustrate the severe gastric enlargement associated with the chronic gastric impaction.

horse deteriorated due to severe colic signs and was euthanized. This horse also demonstrated severe gastric wall thickening on AUS. A large colon volvulus was found at necropsy in addition to the unresolved gastric impaction and severe chronic multifocal lymphoplasmacytic, neutrophilic necrotizing ulcerative gastritis.

Overall, 13/16 (81%) horses survived to discharge, and follow-up was available for 10. One horse was euthanized 10 months postdischarge for gastric rupture associated with recurrent gastric impaction. Follow-up for the remaining 9 horses ranged from 8 to 95 months. Three horses had at least one more episode of gastric impaction, 3 had recurrent colic, and 3 had at least one subsequent diagnosis of gastric ulceration. Three horses were lost to follow-up.

4. Discussion

Although gastric impaction occurs infrequently, it can be difficult to recognize due largely to the vague and varied clinical signs. The differential list for more subtle clinical presentations such as intermittent colic, weight loss, and/or inappetence is exhaustive and makes narrowing down appropriate diagnostic tests challenging.[1–5] In the current study, inappetence was the most common presenting complaint, with only 3 horses presented for acute colic and at least 1 horse presented asymptomatically. This finding is similar to previous retrospective studies in which inappetence and chronic intermittent colic were the most common presentations.[1–3] The varied nature of clinical signs and presenting complaints highlights the choice to perform AUS prior to gastroscopy in 44% (7/16) of horses in this study and emphasizes the importance of recognizing ultrasonographic abnormalities associated with gastric impaction that can then be followed up with gastroscopy. The diagnosis of gastric impaction in previous studies was made based on gastroscopy and surgical findings with AUS only performed in a subset of horses.[1–5] The description of ultrasound findings in these studies is brief and consists of visualization of the stomach across a greater number of intercostal spaces than expected and ventral or caudal displacement of the spleen.[1–2] In the authors' group of horses, the large radius of curvature of the stomach (equating to an expanded dorsal to ventral window) was the most striking and consistent finding and has only briefly been mentioned in the literature associated with gastric impaction.[1,6,10] It is important to note that evidence of gastric distention on AUS can also be seen with ileus or obstruction and the sensitivity and specificity of the ultrasonographic diagnosis of gastric impaction was not determined in this study. Ventral displacement of the spleen has been previously described and was also seen in the majority of horses reported herein. Importantly, ventral displacement of the spleen may be noticed prior to the large gastric radius of curvature, especially if the stomach is initially mistaken for the large colon in the caudal left abdomen. While gastric wall thickening has been described postmortem,[2] the ultrasonographic finding of gastric wall thickening associated with gastric impaction has not previously been described. Of the horses with moderate to severe gastric wall thickening on ultrasound in this case series, 2 survived and 2 were euthanized. One of the survivors was diagnosed with severe gastric ulcers upon resolution of the impaction, was successfully treated with gastroprotectants, and recovered, and one was taken to surgery due to persistent abdominal pain despite medical therapy. At surgery, the gastric impaction was softened with manual massage. The 2 nonsurvivors were euthanized due to poor prognosis and/or poor response to treatment, and severe chronic ulcerative gastritis/gastric ulceration was diagnosed at necropsy. Interestingly, one of these horses was also diagnosed with a large colon volvulus at necropsy, a condition which has been linked to gastric impaction either as a cause or sequelae

in two studies.[13–14] While the numbers are too small to draw significant conclusions, the authors' findings suggest that gastric impactions in horses with ultrasound findings of moderate to severe gastric wall thickening and severe gastric distention may be longstanding, more difficult to resolve, and have a more guarded prognosis. Primary gastric ruptures were caused by gastric impactions in 87% of horses in one study,[15] so it is not surprising that 2 horses included here were ultimately euthanized for gastric tear or rupture secondary to their gastric impactions.

Gastric impaction, though uncommon, represents a serious condition in horses that has only a fair long-term prognosis even with appropriate therapy. In this case series, although ~80% of horses survived to discharge, a significant portion of these had long-term complications including recurrent impaction, colic, and even gastric rupture. When managing these cases, abdominal ultrasound with an emphasis on evaluation of the stomach offers additional information to that obtained via gastroscopy and should be performed in horses with gastric impaction both to further characterize the status of the stomach with regard to degree of distention and presence of wall thickening and to monitor response to treatment. Furthermore, while many equine practitioners do not have the capability to perform gastroscopy in the field setting, most have portable ultrasound equipment with a low-frequency curvilinear transducer available, offering the ability to diagnose and successfully monitor the treatment of gastric impactions in equine practice.

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.

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[a]Vingmed System 5, GE Medical Systems, Milwaukee, WI 53219.
[b]Biosound Technos, Universal Ultrasound, Bedford Hills, NY 10507.
[c]Biosound Twice, Vetel Diagnostics, San Luis Obispo, CA 93401.
[d]Dormosedan, Orion Corporation, Espoo, Finland.
[e]Karl Storz Endoscopy-America, Inc., El Segundo, CA 90245-5017.

How to Manage Refractory Equine Glandular Gastric Disease

Ben Sykes, BSc, BVMS, MS, MBA, DACVIM, PhD, FHEA

Refractory equine glandular gastric disease is a challenging problem commonly encountered in equine practice. This paper describes the management of these frustrating cases by taking a logical, stepwise approach to alleviating the disease itself, associated clinical signs, and behavioral factors. Author's address: Massey University, Equine Clinic, Palmerston North, 4410 NZ; e-mail: b.sykes@massey.ac.nz. © 2023 AAEP.

1. Introduction

The therapeutic response of equine glandular gastric disease (EGGD) is often poor, with refractory or nonresponder cases commonly encountered in equine practice. Reported healing rates for EGGD vary from approximately 25% for oral omeprazole monotherapy[1–3] to 20% to 62% for oral omeprazole/sucralfate combinations[4,5] to 72% for misoprostol.[4] This contrasts with an overall 77% response rate for equine squamous gastric disease (ESGD) with oral omeprazole.[6] To date, little has been described regarding the management of EGGD cases that fail to respond to primary treatment.

The objective of this presentation is to describe the author's management of these common and challenging cases.

2. Materials & Methods

The author takes a stepwise approach to the management of refractory EGGD as described below. Importantly, the approach utilizes a holistic approach to EGGD management rather than being solely focused on the endoscopic appearance of the stomach.

1. *Look to confirm the relevance of the disease in the primary presentation*.
   a. Assigning clinical relevance to EGGD can be clinically challenging, and it is important, prior to continuing to spend significant client time and resources, that an attempt is made to assign clinical significance to the endoscopic lesion. The author does this primarily by:
      i. *Evaluating if a clinical response has been observed with treatment to date.* Where this has been observed, it supports the argument that the EGGD is clinically significant. In contrast, where no clinical response to treatment has been observed, other differentials should be strongly considered (even if treatment for EGGD is ongoing). Conversely, and challengingly, it should be recognized that a "treatment threshold" appears to exist, wherein clinical improvement is not seen until complete EGGD lesion

NOTES

healing occurs. As such, a failure of clinical signs to respond to the initial treatment does not preclude EGGD being clinically relevant, but, in the author's opinion, it does increase the likelihood that other disease processes might be contributing, in whole or in part, to the clinical signs observed.

ii. *Ruling out concurrent or complex disease*. Musculoskeletal disease,[7] sand enteropathy,[8] inflammatory bowel disease,[9] and dental disease[10,11] have been shown to mimic the clinical signs commonly ascribed to equine gastric ulcer syndrome and should be ruled out. Concurrent disease can also be contributed to EGGD development via pain- induced behavioral stress (i.e., nongastric pain can drive a behavioral stress response and contribute to EGGD risk, but it can also mimic the clinical signs commonly ascribed to EGGD). As such, evaluation of refractory EGGD (nonhealing lesions on endoscopy) should include a complete lameness examination and consideration of nongastric gastrointestinal differentials including sand enteropathy, inflammatory bowel disease, and dental disease.

2. *Address any identified risk factors and optimize management*. Current key recommendations for EGGD prevention include:
   a. Ensuring at least 2, and ideally 3, rest days per week.
   b. Focusing on the behavioral aspects of disease as a means of reducing behavioral stress, increasing pain threshold, and addressing learned behavior. These interventions include:
      i. Cohabitation with a suitable equid companion.
      ii. Positive reinforcement/behavior modification during trigger events (i.e., pre-exercise and transport) including the following:
         1. Pre-exercise feeding (as well as having clear benefits for ESGD risk reduction).[12]
         2. Massage and music therapy.[13,14]
         3. Additional behavioral enrichment techniques.[15]
3. *Switch therapy*. Specifically, when a treatment response has not been seen within 8 weeks of treatment with one pharmaceutical modality (typically either omeprazole 4 mg/kg PO q 24 hr + sucralfate 15–20 mg/kg PO q 8–12 hr or misoprostol 5 μg/kg PO q 8 hr ± sucralfate 15–20 mg/kg PO q 8 hr), then trying an alternative modality is logical. The author typically tries 4 weeks of alternate therapy before reassessing. Unfortunately, it can be difficult to predict which lesion type will respond to a specific pharmaceutical therapy. Further, there appears to be geographical differences in treatment responses to the different pharmaceuticals.
4. *If a positive clinical response has been seen to omeprazole/sucralfate but lesion healing has not occurred, then the factors contributing to ensuring a prolonged intraday duration of acid suppression with omeprazole therapy should be investigated*. This primarily relates to ensuring that omeprazole is administered after an appropriate overnight enforced fast to optimize efficacy.[16] Importantly, a positive clinical response can be observed even with suboptimal acid suppression for healing. This can occur when a short window of potent acid suppression provides resolution of clinical signs, especially during the day when the horse is most commonly observed/ridden, but the duration of acid suppression is not adequate for healing to occur (which requires a more prolonged period of acid suppression, thus the need for an optimized response).
5. *Ensure that the lesion is not an adenomatous polyp*.[17] The clinical significance of this is questionable in many cases (especially in the absence of mucosal lesions). Definitive diagnosis of these can be challenging, and transendoscopic biopsy, which has been shown to correlate poorly with full- thickness biopsy,[18] is typically unrewarding. As such, the diagnosis is typically presumptive based on the characteristic appearance of the lesions. If an adenomatous polyp is suspected, the author's approach is to focus on any mucosal lesion with appropriate pharmaceutical therapy, primarily using omeprazole/sucralfate. However, once the mucosal lesion has healed, management is then focused on the 3-tier approach described below.
6. *Where the endoscopic lesion is refractory to the steps described above, or is a true adenomatous polyp, the author's approach is to change tack and focus on management of the clinical signs, rather than on the endoscopic appearance*. This is done by a 3-tier stepwise approach including:
   a. The use of evidence-backed "alkaline slime"[19] (pectin/lecithin/buffer combinations) or coating supplements[20] for enhanced mucosal barrier protection. This, in addition to management changes, is the author's frontline approach to the management of EGGD-associated clinical signs in refractory cases. In the context of managing refractory EGGD, the primary outcome of success is clinical response, and as such different supplements can be

tried if the initial selection does not work. Alternatively, sucralfate can be used long term if a positive clinical response is observed.

b. When the previous tier provides some but not complete resolution of clinical signs, the targeted use (rather than interval feeding) of long-acting gastric buffers[21] during high-risk/impact periods such as exercise and transport is added.
c. Lastly, when the previous 2 tiers are either ineffective or partially effective, intermittent therapy with omeprazole is used either instead of or alongside the approach described in the previous 2 tiers.
    i. There is no evidence to support the use of long-term, low-dose omeprazole for the prevention of EGGD (in contrast to its validated use in ESGD). Further, published pharmacodynamic work has shown that low-dose omeprazole is unlikely to consistently induce adequate acid suppression to be protective at the level of the glandular mucosa.[16] As such, the focus of omeprazole therapy in this context shifts from the goal of preventing lesion occurrence to the goal of simply controlling clinical signs. In doing this, it is recommended that, where possible, the horse be exercised in the morning shortly after omeprazole administration when its acid- suppressive effects are maximized.[16]
    ii. The specific dose at which this can be achieved can be determined for each by trial and error based on clinical response (as this is the primary goal). The author typically starts at 2 mg/kg and adjusts up or down to affect. Further, the onset of acid suppression is rapid when conditions for absorption are optimized (i.e., good acid suppression is achieved following the first dose),[16] meaning that omeprazole can be used in an "as required" manner with dosing only on the days when needed, rather than requiring the traditional 3- to 5-day wind-up period previously advocated.

3. Results

The author has routinely applied this approach to the management of refractory EGGD in clinical practice for the past 2 years with good results overall. Clinically, most horses can be successfully managed with an acceptable to good outcome. Owner compliance is high, and most owners appreciate the shift in approach to being centered on the horse's welfare and focused on their primary presenting complaint, rather than the more technical approach of being lesion focused.

4. Discussion

Several key aspects are important to the successful implementation of the above approach. Firstly, it requires a shift from a focus on the endoscopic lesion, which veterinary medicine has traditionally focused on, to a more holistic animal-centered approach. This is particularly relevant in the context of EGGD as gross appearance correlates poorly with underlying pathology and clinical response often correlates poorly with endoscopic healing.[18] As such, assigning clinical significance to endoscopic lesions is challenging at best. Further, the approach requires consideration as to the potential impact of behavior on disease predisposition, pain thresholds, and ongoing expression of clinical signs via learned behavior. This approach might require the consultation of a behavioral specialist for optimal outcome.

The primary downside of the approach is that it can be time-consuming and cost-intensive to work through the range of differentials that potentially contribute to clinical signs or disease risk. However, in the author's experience, it is typically favored by owners over extended courses of pharmaceutical treatment. Case selection is important, and early recognition of refractory cases within 8 weeks of treatment initiation is preferred over a shift in treatment focus later in the treatment process.

Acknowledgments

Declaration of Ethics

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

Conflict of Interest

Professor Ben Sykes works as a consultant to Kelato (AUS/USA), Health Food Symmetry (AUS), A-Vet (AUS), Mayo Animal Health (IRE), and Fluxergy (USA). He has previously provided paid educational services for Purina (USA) and Virbac (AUS) and consultancy services to Boehringer Ingelheim (GER), Bova (AUS/UK), Abbey Laboratories (AUS), Equestra/Troy (AUS), and Luoda (AUS) all of whom have products in the gastrointestinal space.

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Evaluation of the Effects of Medium-Term (57-Day) Omeprazole Administration and Omeprazole Discontinuation on Serum Gastrin and Serum Chromogranin A Concentrations in the Horse

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The findings of the present study do not support tapering following medium-term omeprazole treatment in horses. Authors' address: School of Veterinary Sciences, Massey University, University Avenue, Fitzherbert, Palmerston North, Manawatu, NZ 4474; e-mail: a.lovett@massey.ac.nz. *Corresponding and presenting author. © 2023 AAEP.

1. Introduction

Rebound gastric hyperacidity secondary to hypergastrinemia has been suggested to contribute to the rapid recurrence of equine squamous gastric disease following the discontinuation of omeprazole. This study aims to evaluate changes in serum gastrin and chromogranin A (CgA) concentrations in response to medium-term (57-day) omeprazole treatment and after discontinuation.

2. Materials and Methods

Fourteen Thoroughbred racehorses in simulated race training received omeprazole[1] (4.4–5.3 mg/kg, q 24 hr, PO) over 61 days, excluding withholding periods where treatment was stopped as part of a concurrent study. Serum samples were collected on day 0 before treatment, on day 1 of each week of the treatment period, and for a further five weeks post-discontinuation of treatment. Serum gastrin and CgA concentrations were analyzed using radioimmunoassay (RIA) analysis and ELISA, respectively.

3. Results

Median serum gastrin concentrations had a 2.5-fold increase from baseline to day 7 ($p < .0005$) but did not increase further during the omeprazole treatment period. Median serum gastrin concentrations returned to baseline within 2–4 days after administration of the last dose of omeprazole. No effect of treatment or discontinuation was seen in serum CgA concentrations.

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4. Discussion

Serum gastrin concentrations increased in response to omeprazole treatment, but hypergastrinemia was short-lived, returning to baseline within 2-4 days after the last dose of omeprazole. Additionally, the lack of an effect on serum CgA concentrations suggests that enterochromaffin-like cell proliferation does not occur. These findings do not support tapering periods after medium-duration omeprazole treatment in the horse.

Acknowledgments

Funding Sources

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Declaration of Ethics

This study was performed under Hong Kong Jockey Club's Animal Ethics Committee permit number ERC/031/2021.

Conflict of Interest

Dr. Sykes has commercial relationships with Kelato, Equestra Australia, and Abbey Labs Australia, all of whom have EGUS products in their portfolios. None of these companies had any input into the study design, execution, or reporting. None of the other authors have any conflicts of interest.

How to Perform Intra-Ligamental Anesthesia for Exodontia in the Horse

Olivia James, BVSc (hons), CMAVA, MANZCVS (Eq Dentistry), DICEVO, DAVDC (Eq)

Intra-ligamental anesthesia is an effective method to provide anesthesia for exodontia (tooth extraction) in horses, providing more targeted and efficient anesthesia than traditional regional nerve blocks. The procedure requires a solid understanding of the anatomy of the mouth and proficient technical skills to administer the anesthetic solution directly into the periodontal ligament in the standing, sedated horse. Veterinarians should consider using intra-ligamental anesthesia as a primary method of anesthesia for tooth extraction in horses or in addition to traditional regional nerve blocks to provide anesthesia for exodontia. Author's address: The Veterinary Dental Company, 27 Bellevue Trace, Clayfield, QLD 4011, Australia; e-mail: dr.olivia.james@gmail.com. © 2023 AAEP.

1. Introduction

Equine dentistry is an important aspect of comprehensive horse health care, with regular oral examinations, diagnosis, and treatment of disease being essential to maintain optimal oral health. The traditional method of anesthesia for exodontia in horses involves the utilization of regional nerve blocks.[1] However, a growing trend in equine dentistry involves the increasing popularity of intra-ligamental anesthesia, either as an alternative to or in conjunction with regional nerve blocks.[2]

2. Materials and Methods

A 40-cm dental aspirating syringe with thumb rings (Fig. 1) (source: https://theedgeequine.com/collections/surgical/products/nerve-block-syringe-40cm) is utilized along with 1.8-mL local anesthetic cartridges (e.g., prilocaine 4%) without epinephrine (source: https://www.net32.com/ec/citanest-plain-4-local-anesthetic-without-vasoconstrictor-d-118328). Epinephrine is not routinely used as an additive to local anesthetic solution in the horse, as in the case of dental surgery, vasoconstriction is less desirable as the bleeding produced by breaking down the periodontal ligament can aid in further loosening of the tooth. The handle of the aspirating syringe is retracted to insert the cartridge, and long 27-gauge dental needles (source: https://www.net32.com/ec/orabloc-plastic-hub-nerve-block-needle-27g-d-173409) are used. These dental needles screw onto the syringe and penetrate the local anesthetic cartridge, enabling the practitioner to administer injections under pressure in areas where there is minimal dead space.

The needle is bent at the hub to a 45° angle, and with a speculum in place and the horse adequately sedated, the needle is inserted on the buccal and palatal or lingual aspect of the tooth and local anesthetic injected under pressure (Fig. 2). This is more easily achieved in the canine, premolar, or molar teeth than the incisor tooth. In many cases, it is also possible to

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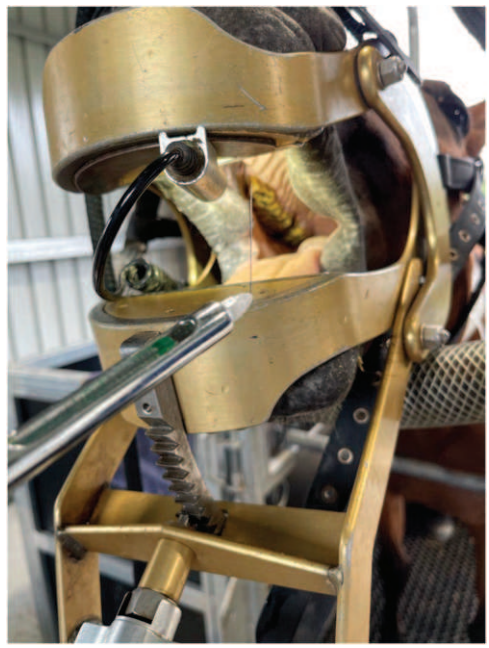


Fig. 1. A dental aspirating syringe with a 1.5" 27-gauge dental needle bent at 45°.

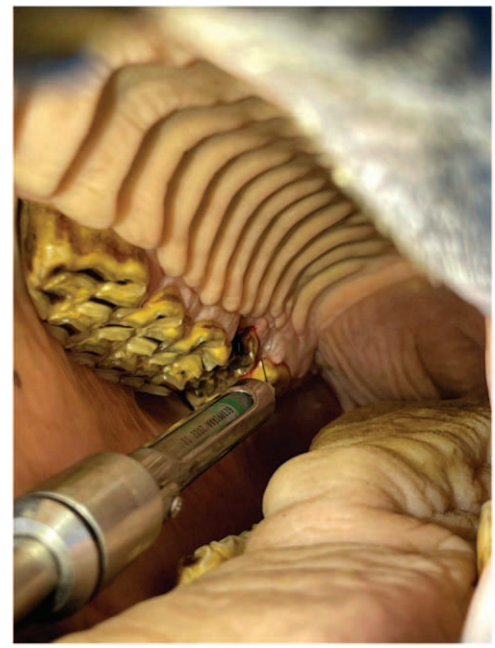


Fig. 2. The needle is shown inserted into the periodontal ligament on the palatal aspect of tooth 109.

inject local anesthetic solution in the interdental spaces. It is more challenging to place the needle on the buccal aspect distal to the 09 maxillary cheek teeth (the 4th maxillary cheek teeth) due to the curve of the maxillary arcade. It can be beneficial to use a Gunther speculum with the mandible offset to increase the space available when blocking the same side on the maxillary arcade. Generally, patients are accepting of this procedure, and light to moderate sedation is recommended.

This technique may be particularly useful should the practitioner wish to avoid the potential complications of regional nerve blocks, such as hemorrhage, soft tissue swelling, lingual self-trauma, and neuropraxia.[3–7] The 27-gauge needle is able to curve to conform to the periodontal ligament space with minimal discomfort, and excellent anesthesia is achievable both as a standalone procedure and in combination with regional nerve blocks.

3. Results

Scientific studies have shown that intra-ligamental anesthesia provides more targeted and efficient anesthesia than traditional regional nerve blocks for tooth extraction in horses.[3] It can be used as a primary method of anesthesia for exodontia in horses, particularly in cases where regional nerve blocks are difficult to perform. Difficulties may arise due to large eruption bumps hindering entry into the infra-orbital foramen or an exaggerated reaction to an infra-orbital or mental nerve block.

Several studies have compared the efficacy of intra-ligamental anesthesia and regional nerve blocks for tooth extraction in horses. In a study by Polyak et al,[2] horses were randomly assigned to receive either intra-ligamental anesthesia or a combination of regional nerve blocks for tooth extraction. The study found that horses receiving intra-ligamental anesthesia had significantly shorter induction times and required fewer additional injections of anesthetic agents compared to those receiving regional nerve blocks.[2]

In a study conducted by Verstraete et al, researchers investigated the efficacy of intra-ligamental anesthesia with regional nerve blocks for extraction of maxillary cheek teeth. The results showed that intra-ligamental anesthesia provided more reliable and consistent anesthesia compared to regional nerve blocks. Based on their findings, the authors concluded that intra-ligamental anesthesia should be considered as a primary method of anesthesia for extraction of maxillary cheek teeth in horses.[3]

Similarly, another study conducted by Archer et al[4] focused on comparing the efficacy of intra-ligamental anesthesia to regional nerve blocks for extraction of mandibular cheek teeth. The results revealed that intra-ligamental anesthesia provided more rapid and complete anesthesia than regional nerve blocks and that it was associated with fewer complications. The authors concluded that intra-ligamental anesthesia is a safe and effective method of anesthesia for extraction of mandibular cheek teeth in horses.[4]

4. Discussion

Regional nerve blocks are a standard method of anesthesia for tooth extraction in horses. This technique involves the administration of local anesthetic agents into or around the nerves that supply the area of the oral cavity where the tooth to be extracted is located.[1] There are several types of regional nerve blocks that can be used for tooth extraction, including infraorbital,

caudal maxillary, inferior alveolar, and mental nerve blocks as well as local infiltration.[5–8]

Intra-ligamental anesthesia has several advantages over traditional regional nerve blocks for tooth extraction in horses. These benefits include more precise and efficient anesthesia and use of a smaller dose and volume of local anesthetic solution. A significant advantage of intra-ligamental nerve blocks is the rapid onset of action as compared to regional nerve blocks, which is beneficial in reducing the overall surgery time and may lessen the duration that the horse's mouth needs to be held open in the speculum. Additionally, intra-ligamental anesthesia can also provide varying degrees of anesthesia to the gingiva of the oral cavity; this is not always achieved via regional nerve blocks. Some regional nerve blocks carry the risk of an extreme, painful reaction during needle insertion (e.g., infra-orbital nerve block) or may pose the risk of damage or infection to sensitive structures (e.g., a caudal maxillary nerve block).[2–4]

However, it also has some disadvantages, including the need for a skilled veterinarian to administer the anesthetic agent directly into the periodontal ligament surrounding the tooth, necessitating some technical proficiency. Equine-specific dental aspirating syringe instrumentation is required; however, these are low cost and readily transportable. Intra-ligamental anesthesia can be used in addition to regional nerve blocks to improve their effectiveness in cases where they are not providing adequate anesthesia and, in some cases, can be considered as an alternative to regional nerve blocks.

5. Conclusion

Intra-ligamental anesthesia is a valuable addition to the tool kit of anesthesia techniques for exodontia in horses. It provides a highly targeted and efficient anesthesia compared to regional nerve blocks and can be used in addition to regional nerve blocks to increase patient comfort during dental procedures. However, it requires a good understanding of the anatomy of the mouth and technical skills to administer the anesthetic agent directly into the periodontal ligament surrounding the tooth.

Veterinarians should consider employing intra-ligamental anesthesia as a primary method of anesthesia for exodontia in horses, particularly in cases where regional nerve blocks prove insufficient or challenging to perform. Further studies are needed to evaluate the long-term effects and potential complications of intra-ligamental anesthesia in horses. By judiciously incorporating intra-ligamental anesthesia into their practice, veterinarians can elevate the standard of dental care for horses, ensuring optimal pain management to increase the success rate of dental procedures.

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.

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A Survey of Oral Examination Practices During Prepurchase Examination

Tracy Tinsley, DVM*; and Jack Easley, DVM, MS, DABVP/Eq, DAVDC (Equine)

A complete oral examination is not commonly performed during the prepurchase exam process. Buyers should be offered a complete examination using sedation, a full mouth speculum, and a mirror or be advised of the limitations of an incomplete exam. Authors' addresses: Elite Equine Mobile Dentistry, 5409 Leopards Bane Court, Holly Springs, NC 27540 (Tinsley); Equine Veterinary Practice LLC, PO Box 1075, Shelbyville, KY 40066 (Easley); e-mail: tracytinsleydvm@gmail.com. *Corresponding and presenting author. © 2023 AAEP.

1. Introduction

Dental disease is a common and potentially debilitating condition in the horse but is frequently asymptomatic and difficult to detect without a detailed examination. It is hypothesized that the oral cavity is not routinely and completely examined during the majority of prepurchase examinations. The objective of the study was to determine common practices for examining the oral cavity during a prepurchase examination.

2. Materials and Methods

A 10-question survey was sent to equine practitioners using the Facebook platform to groups restricted to veterinarians. Responses were analyzed using Google Forms.

3. Results

Two hundred ninety-six responses were recorded. Two hundred ninety-two respondents completed the entire survey. In those that do perform exams, 75% are done without sedation or the aid of a full mouth speculum, mirror, or oroscope. In the comments, there were 14 practitioners that indicated the inability to sedate the horse affected their ability to thoroughly examine the oral cavity. Thirty percent of respondents indicated that an oral exam is a part of every prepurchase examination. Fifty-nine percent of practitioners indicated they do not perform an oral exam or perform an abbreviated oral exam. Seventy-five percent of these exams are performed with the patient unsedated and without the use of a full mouth speculum.

4. Discussion

Inclusion of an oral exam during the prepurchase examination is often not done or done in a limited capacity. Dental disease can be performance limiting/ending, require expensive surgical procedures, lead to extensive time out of work and rarely, euthanasia. Potential purchasers should

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be informed of the limits of an unsedated, abbreviated oral exam.

Acknowledgments

The authors would like to thank the practitioners that participated in the survey.

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 Retrospective Survey of Behavioral and Physical Changes in Equine Patients After Complete Extraction of All Incisors Due to EOTRH

William Rainbow, DVM

Horse owners reported statistically significant improvements of weight, behavior, and overall happiness after complete extraction of all incisors. Owners felt that total incisor extraction improved the quality of life for their horses and would elect to have the procedure performed again on another horse if necessary. Author's address: Equine Veterinary Practice, LLC, PO Box 1075, Shelbyville, KY 40066; e-mail: william.rainbow@gmail.com. © 2023 AAEP.

1. Introduction

Equine Odontoclastic Tooth Resorption with Hypercementosis (EOTRH) is a poorly understood syndrome that is often treated with extraction of all incisors.

The purpose of this study was to determine if horses who are diagnosed with EOTRH experience a statistically significant improvement in the quality of their lives after surgical extraction of all incisors and to determine if owners are satisfied with the results of the surgery.

2. Materials and Methods

A retrospective web-based survey was sent out to owners of horses diagnosed with EOTRH who had undergone complete extraction of all incisors in the previous 3 years. Forty-eight surveys were completed, and the answers examined for statistical significance.

3. Results

Statistically significant differences were found in horses' body condition, dropping of hay, speed of eating, general behavior, resistance to bridling, and headshaking. In addition, owners perceived that horses were happier after surgery, and total extraction improved quality and extended the life of their horse. Over 90% of owners would also elect to have the procedure performed on another horse in the future.

4. Discussion

Owners were highly satisfied with complete extraction of all incisors as a treatment for horses affected by EOTRH. Survey results showed that post extraction horses had improved body condition and exhibited better bridling and eating behaviors, which are consistent with a decrease in dental pain. Owners felt that their horse was happier and that the surgery had improved the horse's quality of life.

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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.

Effect of Fluorescence Biomodulation on Dermal Healing in an Equine Experimental Wound Model

Avery F. Loyd, DVM, CF*; Fred Caldwell, DVM, MS, DACVS, DACVSMR; Lindsey Boone, DVM, PhD, DACVS-LA; and Amelia White, DVM, MS, DACVD

The use of fluorescence biomodulation was studied in experimentally induced wounds of equine distal limbs. There were no differences from control group in healing parameters of wounds healing by second intention, but no detrimental effects were observed. Authors' address: Auburn University, 1500 Wire Road, Auburn, AL 36832; e-mail: afl0020@auburn.edu. *Corresponding and presenting author. © 2023 AAEP.

1. Introduction

Distal limb injuries can result in significant tissue loss necessitating healing by second intention. Additionally, exuberant granulation tissue formation can complicate wound healing. Fluorescence biomodulation (FBM) can penetrate skin and stimulate healing. Fluorescence biomodulation has been used in a variety of clinical dermatological conditions in humans and dogs. The objectives were to determine safety and evaluate macroscopic/microscopic effects of FBM on experimentally induced, full-thickness wounds in horses.

2. Materials and Methods

Six healthy adult mares were used for dorsal metacarpal full-thickness wound models. Two wounds were created on the dorsum of each metacarpus. One forelimb received FBM, and the contralateral limb served as control. Prior to treatments, one wound per limb was used to grade granulation tissue by two blinded observers and photographed for digital wound area measurements over time. The second wound was used to obtain biopsies for histopathologic scoring to evaluate angiogenesis, inflammatory reaction, fibrosis, and epithelialization. Treatment was performed as recommended by the manufacturer: two sequential treatments for a total of four minutes/treatment day, beginning three days following wound creation and continuing every seven days, for a total of four treatments.

Data collected were normally distributed. Statistical analyses were performed using a linear mixed model, generalized linear mixed models, and the Satterthwaite degrees of freedom method. Significance was set as $p < 0.05$.

3. Results

No statistically significant differences were found between treatment/control groups on wound area, granulation tissue grading, or histopathology scoring.

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One horse produced exuberant granulation tissue of all four wounds regardless of treatment and required debridement following the study.

4. Discussion

FBM did not have any statistically significant effects on wound healing. However, it did not appear to have adverse effects on experimentally created equine distal limb wounds. Future studies with larger numbers are warranted for specific clinical applications such as chronic and infected wounds in horses.

Acknowledgments

Funding Source

This study was funded by Vetoquinol SA.

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 Treat Wounds with Fluorescence Biomodulation

Fred Caldwell, DVM, MS, DACVS, DACVSMR

This paper will describe how practitioners can use fluorescence biomodulation in the treatment of equine wounds. It will briefly review the physiology of fluorescence biomodulation in wound healing, describe the treatment procedure, and report the results on its use in the management of a variety of wound types in 10 horses. Author's address: Auburn University, College of Veterinary Medicine, 1130 Wire Road, Auburn, AL 36849; e-mail: caldwfj@auburn.edu. © 2023 AAEP.

1. Introduction

Injuries to the distal limbs in horses are commonly encountered in equine practice. In many instances, these injuries can result in significant tissue loss leading to the need for them to heal by second intention. Wounds on horses' extremities are plagued by the formation of excessive granulation tissue formation (proud flesh) as a consequence of tissue loss, contamination, motion, hypoxia, and an extended inflammatory phase.[1,2] These injuries are costly to manage, slow to heal, require significant time commitment by owners, frequently result in a poor cosmetic outcome, and in some cases can result in the horses' inability to return to performance or even humane destruction.

Photobiomodulation is a process that harnesses the energy of light in the form of a light-emitting diode (LED) to induce transduction pathways by the activation of cellular or tissue photoacceptors.[3] Fluorescence biomodulation is a form of photobiomodulation that relies on light-absorbing molecules to convert light from LED sources to fluorescent light energy that can penetrate skin and stimulate healing.[3] Previous work has demonstrated improved re-epithelialization, decreased inflammation, and improved matrix formation via regulation of epidermal growth factor, tumor necrosis factor alpha, and factor VIII in canine incisional wounds treated with fluorescence biomodulation.[4] In humans, tissues treated with fluorescence biomodulation have shown decreased levels of inflammation through the downregulation of the proinflammatory cytokines tumor necrosis factor alpha and interleukin 6, and it also induces mitochondria biogenesis.[5–7] Therefore, the key to these beneficial effects on healing of dermal wounds may lie in the conversion of the light by the absorbing molecules or chromophores.

Fluorescent light therapy consists of an LED (blue light) -emitting device and a topically applied photoconverter gel (chromophore). The chromophore gel absorbs the incoming LED light and converts it into a broad spectrum of fluorescent light energy (Fig. 1) with wavelengths capable of penetrating skin at various depths. The shorter wavelengths (blue) will penetrate more superficial depths where it exerts an antimicrobial and anti-inflammatory effect. Longer

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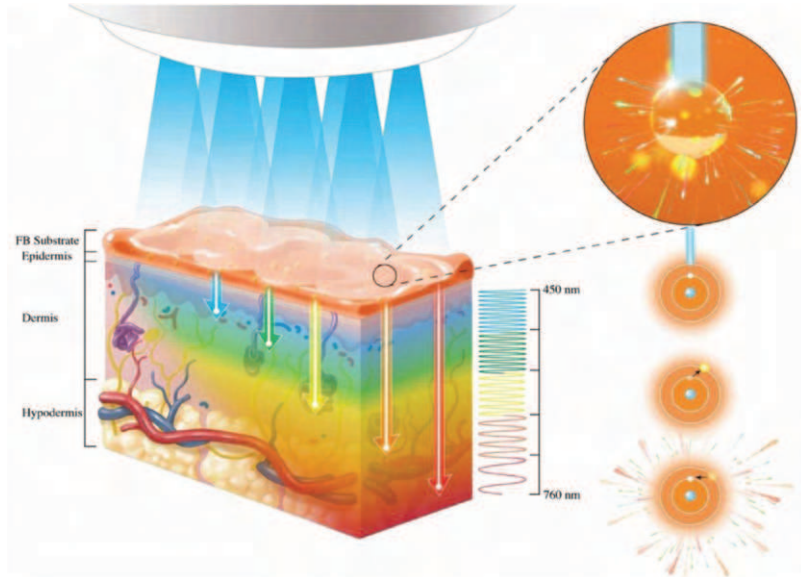


Fig. 1. Chromophore gel applied to the wound and illuminated with LED light, creating fluorescent light energy capable of penetrating and exerting beneficial effects on dermal healing at various depths. FB, fluorescence biomodulation.

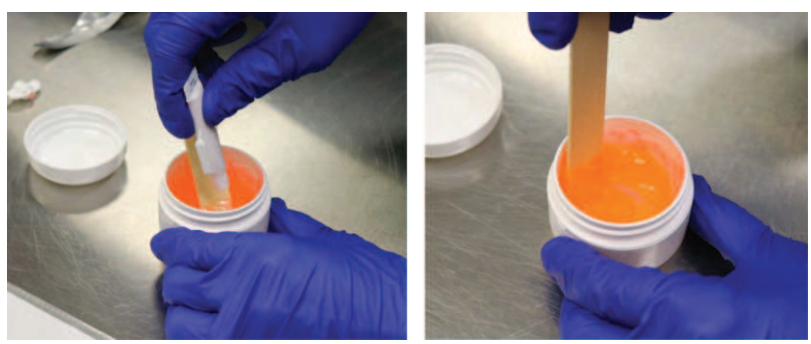


Fig. 2. Mixing of ampule containing chromophore gel into carrier gel.

wavelengths (green, yellow, orange/red) penetrate deeper into the dermis and hypodermis/subcutaneous tissues to stimulate multiple effects including the induction of fibroblast and keratinocyte proliferation, initiation of angiogenesis, stimulation of mitochondrial activity, reduction of inflammation, and regulation of collagen production. Fluorescence biomodulation has been shown to improve re-epithelialization and matrix formation and reduce dermal inflammation in a prospective, blinded, incisional wound-healing controlled clinical trial in dogs.[8] The purpose of this submission is to describe the technique for wound treatment with fluorescence biomodulation and present a summary of the results of its use in various wound types in 10 horses.

2. Materials and Methods

Horses are either restrained in stocks and/or sedated with xylazine (0.3 mg/kg IV) or detomidine hydrochloride (0.01 mg/kg IV). The surrounding hair is clipped if not already, and the area surrounding the wound is cleaned with sterile saline. The contents of the ampule containing the chromophore gel[a] are mixed into the pot of carrier gel immediately prior to application (Fig. 2). A 2-mm layer of gel is applied to the wound, and protective eye wear is worn by all personnel. The LED light is positioned at a fixed working distance of 5 cm from the area and activated (Fig. 3). An audible beep will be emitted, the light will illuminate, and a 2-minute timer will be initiated. The light will automatically turn off after 2 minutes. The gel is wiped from the wound with sterile gauze soaked in saline, and a second treatment is initiated within 5 minutes by reapplication of gel and activation with another 2-minute light treatment cycle. The wound is then maintained under a bandage or managed without a bandage according to clinician preference and wound location. Wounds typically are treated with a double application (two 2-minute applications, with one immediately following the other) once weekly as needed until healed. Wounds are monitored for any evidence of excessive redness, irritation, swelling, or pain.

3. Results

Horses were under the care of an attending veterinarian throughout the duration of wound healing. All



Fig. 3. Application of fluorescent light energy to horse wound over dorsal metacarpus.

wounds healed well with good cosmetic results and no evidence of fibrosis or excessive scar tissue formation. The fluorescence biomodulation treatments were well tolerated with no adverse reactions or complications. Signalment, type of injury, duration of treatment, and treatment results are listed in Table 1. Increased dermal vasodilation was apparent following treatment in two horses (cases 5 and 6) as evidenced by increased pink coloration to the site posttreatment. Fluorescence biomodulation did not appear to promote the development of excessive granulation tissue, as none was observed during the healing process in any horses. Epithelialization seemed to develop more rapidly in treated wounds than would be expected with conservative management of similarly sized wounds.

4. Discussion

Fluorescence biomodulation is easy to perform, is noninvasive, and only requires the photoconverter gel,[a] LED lamp, and protective eyewear for personnel. The LED lamp is rechargeable, which makes it easy to use

Table 1. Results of Fluorescence Biomodulation Therapy in a Variety of Equine Wounds

Case	Signalment	Wound Description	Number/Duration of Treatment	Outcome
1	1-year-old Arabian cross filly	Full thickness dermal laceration over dorsal radius	10 double application treatments once weekly	Excellent healing response with minimal residual scar tissue formation
2	3-year-old Thoroughbred filly	Chronic horizontal dermal cracks bilateral palmar pasterns	Single treatment on day 1 and 3	Near complete healing within 8 days of initiating treatment
3	3-year-old Morgan mare	Laceration exposing bone over the proximal right metatarsus	Two double applications once weekly	Rapid improvement in wound appearance, good healing response with minimal residual scar tissue formation
4	5-year-old American Quarter Horse Paint stallion	Deep abrasions of medial carpus bilaterally from breeding phantom	Two double application treatments per wound 1 week apart	Significant reduction in inflammation and healing time, healthy wound appearance, 60% epithelialization
5	6-year-old American Quarter Horse mare	Deep right pectoral/antebrachial laceration from barbed wire	Single application treatments daily for 5 days	Rapid wound improvement in appearance, good healing result ultimately with minimal scarring and excellent cosmetic result
6	8-year-old Thoroughbred gelding	Deep right hind lateral heel bulb laceration from trailer accident	Two double application treatments 13 days apart	Rapid epithelialization with complete healing within 5 weeks of initiating treatment
7	10- year-old American Quarter Horse mare	Right front palmar metacarpal laceration from trailer accident	Primary suture repair, then two double application treatments 1 week apart	Excellent healing response evident at time of suture removal 12 days postinjury
8	15-year-old Appaloosa gelding	Right shoulder trauma/laceration	Five double applications 1 week apart	Immediate wound contraction response, good outcome
9	19-year-old Dutch Warmblood mare	Facial bone sequestrum from frontonasal sinusotomy/multidrug-resistant incisional infection	Two double application treatments 4 days apart	Rapid improvement in wound appearance, reduced swelling and drainage following the second treatment
10	20-year-old Thoroughbred gelding	Chronic full thickness dermal laceration over dorsal carpus	Double application treatments once weekly for 6 weeks	Good healing response with minimal residual scar tissue formation



Fig. 4. Initial images of lateral heel bulb laceration (case 6) prior to treatment (A) and 5 weeks later following two fluorescence biomodulation treatments 13 weeks apart (B).



Fig. 5. Initial images of dorsal carpal wound (case 10) prior to treatment (A) and following once weekly fluorescence biomodulation treatments for 6 weeks (B).

in the field setting. Wounds in horses can be problematic for equine practitioners to manage. Proud flesh production can be a common complication, especially in wounds over areas of high motion or where tissue loss is present. Fluorescence biomodulation has been shown to reduce dermal infection and speed healing in other species.[8–10]

The use of fluorescence biomodulation in the treatment of a mixture of wound types in 10 horses was beneficial to the rate and quality of healing. Following treatment, wound appearance quickly improved, and the initiation of epithelialization occurred rapidly. Classically, wounds over areas of high motion on the extremities can experience delayed healing. Horses in this study (cases 1, 3, 5, 7, and 10) that had wounds in high-motion areas demonstrated evidence of rapid tissue restitution and epithelialization. Case 9 involved a postoperative sinusotomy that experienced dehiscence related to a multidrug-resistant infection. Following initiation of fluorescence biomodulation treatment in this case, incisional drainage was greatly reduced, and the wound promptly showed signs of inflammation reduction and early epithelialization.

As demonstrated in the 10 cases in this study, fluorescence biomodulation can be used in the treatment of a variety of wound types in horses such as on the extremities over high-motion areas, the chest and body, or even on the head (Figs. 4 and 5). Treatment consists of cleaning the wound area, topical application of the photoconverter gel, activation with the LED lamp for 2 minutes, cleaning the gel from the wound, and repeating the process for a second treatment. In the initial use of this therapy in the cases included in this study, variation in the number of treatments existed (Table 1). Since this time, the current treatment recommendation is a double application once weekly until healed. No complications were observed during the treatment of any cases in this study. Slight orange staining of the tissue occurs following treatment but is absent within 24 hours. Advantages of this technique observed in other species include the reduction of inflammation, bacterial colonization control, stimulation of angiogenesis, epithelialization, and fibroplasia, all of which enhance wound healing.[8–10] The variety of wounds observed in the 10 horses in this case study all healed well with

no proud flesh formation, minimal residual scar tissue formation, and a good overall cosmetic result.

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

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Mechanical Nociceptive Thresholds of the Hoof of Horses Submitted to Anesthetic Infiltration of the Digital Flexor Tendon Sheath

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Anesthetic infiltration of the digital flexor tendon sheath does not desensitize the hoof in healthy horses.
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1. Introduction

The specificity of diagnostic block of the digital flexor tendon sheath (DFTS) in horses is controverse, and additional desensitization of heel bulbs has been reported.[1] This study aims to verify if the anesthetic infiltration of the DFTS enables the increase of mechanical nociceptive threshold (MNT) of the dorsal lamellar stratus, sole, coronary band, and heel bulbs of the hoof.

2. Materials and Methods

This study included 6 horses free of hoof abnormalities. Thoracic limbs were randomly assigned to a control group (8 mL of Lactated Ringer's solution) and their contralateral limbs to the treated group (8 mL of lidocaine 2%). All injections were confirmed by contrast tenography (4 mL of iohexol). The MNT was measured through a pressure dynamometer in 10 regions of the hoof. Measurements were made before and 5, 10, 15, 20, 30, 60, 90, and 120 minutes after injection. Comparisons were assessed through the Friedman and Wilcoxon tests ($p < 0.05$).

3. Results

No significant differences were found in MNT during the evaluation follow-up or between groups ($p > 0.05$). Rare measurements of the MNT exceeded 1 kg of force. The median of both groups oscillated in 0.5 kg of force. No signs of analgesia[1,2] were found.

Research Abstract—for more information, contact the corresponding author

NOTES

4. Discussion

The absence of changes in MNT indicates that anesthetic block of the DFTS does not promote analgesia of the dorsal lamellar stratum, the sole, the coronary band, and the heel bulbs of the hoof. Therefore, results demonstrate that the diagnostic analgesia of the DFTS is selective to its adjacent structures, not affecting the distal portion of the equine digit.

Acknowledgments

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Declaration of Ethics

This experiment was approved by the Ethics Committee on Animal Use of the Universidade Federal de Minas Gerais (Approval No. 360, February 27, 2018) and adheres to the AVMA Principles of Veterinary Medical Ethics.

Conflict of Interest

The authors have no conflicts of interest.

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The Effect of Various Perineural Diagnostic Analgesia Techniques on Decreasing Induced Lameness of the Equine Metacarpophalangeal Joint

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Metacarpophalangeal joint lameness is most reliably improved following a low-4-point nerve block but, in some horses, can improve with more distal nerve blocks. Authors' address: Colorado State University, 300 West Drake Road, Fort Collins, CO 80523; e-mail: hannah.patterson906@gmail.com. *Corresponding and presenting author. © 2023 AAEP.

1. Introduction

Nerve blocks are an important diagnostic tool in equine lameness but are not always specific. This study investigated the ability of various nerve blocks to alleviate metacarpophalangeal joint (MCPJ) lameness in an induced synovitis model.

2. Materials and Methods

Eight horses had one MCPJ injected with 75 ng recombinant equine interleukin-1β (reIL-1β). Once lame, horses had palmar digital followed by abaxial sesamoidean nerve blocks or palmar metacarpal followed by palmar nerve blocks (low 4-point nerve block) performed with 2 mL 2% mepivacaine hydrochloride at each site. Lameness was evaluated subjectively (AAEP Grade 0-5) and objectively five and ten minutes following each block. After a one-week washout, lameness was induced in the opposite MCPJ, and horses had the opposite blocking pattern performed. A mixed model analysis was performed.

3. Results

Mean lameness post reIL-1β injection was grade 3.2 and was not significantly improved following palmar digital or abaxial sesamoidean nerve blocks but did improve substantially in two horses. Mean lameness significantly decreased following palmar metacarpal (grade 2.7 5- and 2.2 10-minutes post-block; $p \leq 0.02$) and palmar nerve blocks (grade 1.5 5- and 1.2 10-minutes post-block; $p < 0.0001$). Objective lameness scores followed a similar pattern. Mepivacaine was detected in the MCPJ of three horses following blocking, all of which were in the low 4-point nerve block group.

Research Abstract—for more information, contact the corresponding author

NOTES

4. Discussion

Not surprisingly, MCPJ lameness is most reliably improved following a low-4-point nerve block; however, clinicians should not rule out MCPJ pain as a source of lameness when improvements are noted from palmar digital or abaxial sesamoidean nerve blocks.

Acknowledgments

The authors would like to thank Dr. Ann Hess and Cameryn Manley for their assistance with statistical analysis; Dr. Myra Barrett for allowing us to use the horses in this study; Jennifer Daniels, Natalie Lombard, and Ryan Shelton of the Equine Orthopaedic Research Center for their assistance in this study; and Colorado State University's CVMBS Department of Clinical Sciences for their partial funding of this study through a faculty 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.

Multi-Center Results for Diagnosis and Treatment of Equine Caudal Cervical Pathologic Processes

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Caudal cervical spine pathologic lesions are a common cause of pain, lameness, ataxia, poor performance, or any mixture of these clinical signs. Combined radiographic and computed tomography myelography imaging of the caudal cervical spine is imperative when spinal cord compression, nerve root compression, and/or intervertebral disc disease is suspected. Surgical arthrodesis (ventral interbody fusion) of the C7–T1 articulation can be performed successfully, and it is important for veterinarians to be aware that treatment at this level is possible. Authors' addresses: San Luis Rey Equine Hospital, 4211 Bonsall, CA 92003-7106 (Grant, Huggons); Brazos Valley Equine Hospitals – Salado, 1920 FM 2268, Salado, TX 76571 (Janicek); Rood and Riddle Equine Hospital, PO Box 12070, Lexington, KY 40580-2070 (Woodie, Reed); Equine Care Group, Lummen, Belgium (Mariën); Gartenstraße 14, 85609 Aschheim, Germany (Kasparek, Waselau); Alte Landstraße 104, 22941 Bargteheide, Germany (Jahn, Lorenz); Evidensia Djursjukvård AB, Östhammarsgaten 74, SE-115 28 Stockholm, Sweden (Kristoffersen); Rainbow Equine Hospital, Rainbow Farm, Rainbow Ln, Old Malton, Malton YO17 6SG, UK (Anderson); e-mail: john.janicek@bveh.com. *Corresponding and presenting author. © 2023 AAEP.

1. Introduction

Caudal cervical vertebrae are a source of pathological conditions that clinically result in pain, lameness, ataxia, poor performance, or any combination of these clinical signs.[1] The cervical spine is becoming a more common point of interest in horses. A complete neurological examination is warranted in cases suspected of any cervical spine pathologic lesion followed by diagnostics. Diagnostic modalities used in cases localized to the caudal cervical spine include cerebral spinal fluid analysis, standing survey radiographs, nuclear scintigraphy, ultrasonography, cervical myelography, computed tomography (CT), and magnetic resonance imaging.[2–9] Cervical vertebral stenotic myelopathy is the leading cause of noninfectious spinal cord ataxia in horses.[10] Spinal canal stenosis anywhere from the first cervical vertebral body (C1)

NOTES



Fig. 1. Right-sided pectoral muscle atrophy and atrophy of the musculature where the neck and shoulder tie in together.

to the first thoracic vertebral body (T1) may result in clinical signs suggestive of cervical vertebral stenotic myelopathy. Ventral interbody fusion of C2–C3, C3–C4, C4–C5, C5–C6, and C6–C7 is commonly performed in multiple breeds used for various equestrian disciplines.[11–14]

Patients with C7–T1 pathologic lesions can be separated into two different classes. Class 1 patients present with a varying degree of neurological deficits that originate from dorsal and/or lateral spinal cord compression. Class 2 patients usually present with moderate to severe forelimb lameness that cannot be eliminated with forelimb perineural anesthesia or forelimb intra-articular anesthesia.[15] Horses with C7–T1 pathologic lesions often have uni- or bilateral atrophy of pectoral muscles, atrophy of muscles where the neck and shoulder muscles tie in together, and antebrachial muscle atrophy (Fig. 1). Horses can also demonstrate difficulty eating at ground level, often resist moving forward with the head and neck elevated, and often drag all four toes when backing up, which can be exacerbated with head elevation. Gait abnormalities are often amplified when ridden.

Pathologic lesions involving the C7–T1 articulation are becoming more commonly recognized using standard myelography and CT myelography. Multiplanar reconstruction of CT images allows for evaluation of the cervical spine in the coronal, sagittal, and axial axis. CT myelography should be considered the gold standard for caudal cervical spine diagnostic imaging and presurgical planning. In contrary to an article discussing intervertebral disc disease of the cervical and cranial thoracic vertebrae stated that surgical fusion would be logistically challenging,[16] ventral interbody fusion of the C7–T1 articulation is possible and indicated when (1) dorsal dye column compression is present on myelography and/or CT myelography (Fig. 2), (2) lateral spinal cord compression is present on CT myelography (Fig. 3), (3) intervertebral foramen stenosis is present on CT myelography (Fig. 4), or (4) disc

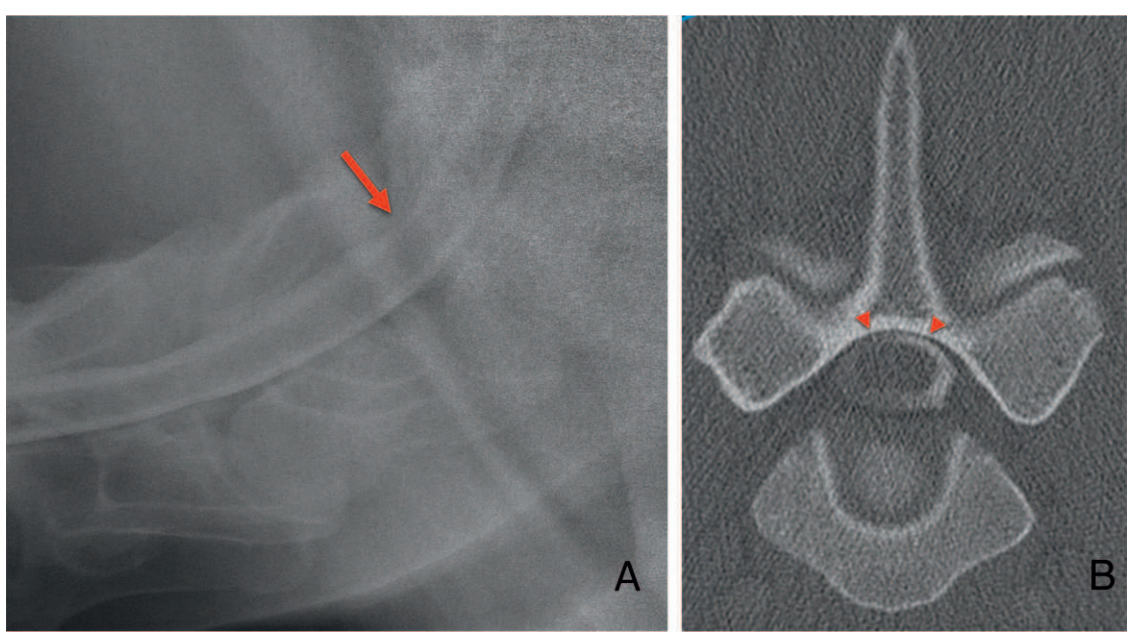


Fig. 2. A, C7–T1 dorsal contrast dye column compression (red arrow) during a standard myelogram. B, C7–T1 dorsal spinal cord compression (arrowheads) during CT myelography of the same horse in Panel A using an axial imaging sequence.

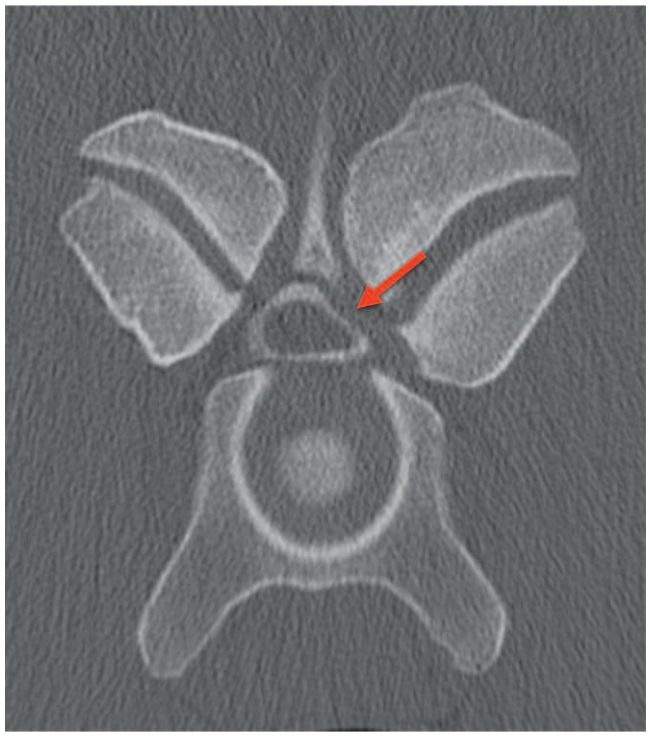


Fig. 3. CT myelography showing primarily right-sided lateral spinal cord compression (arrow) at the level of C6–C7. The right articular facet is larger than the left side and has secondary intervertebral foramen stenosis. There is also mild left-sided lateral spinal cord compression secondary to articular facet arthropathy.

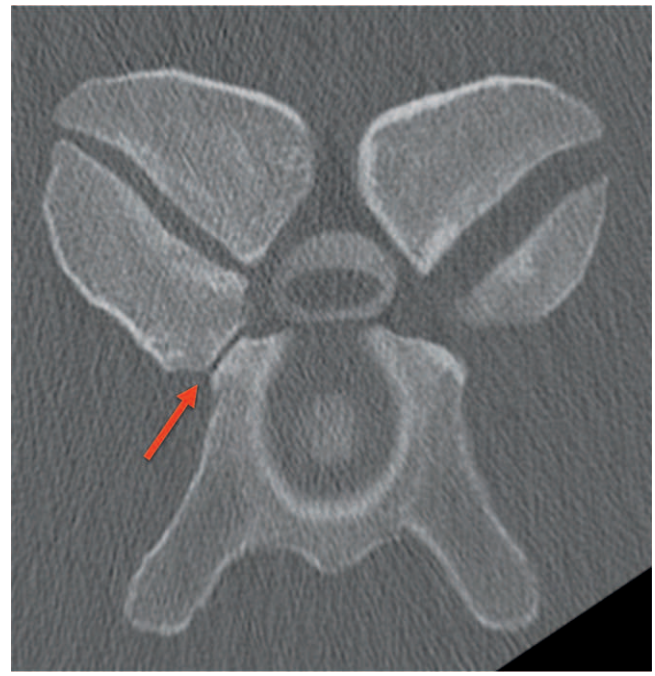


Fig. 4. CT myelography showing right-sided intervertebral foramen stenosis (arrow) at the level of C6–C7.

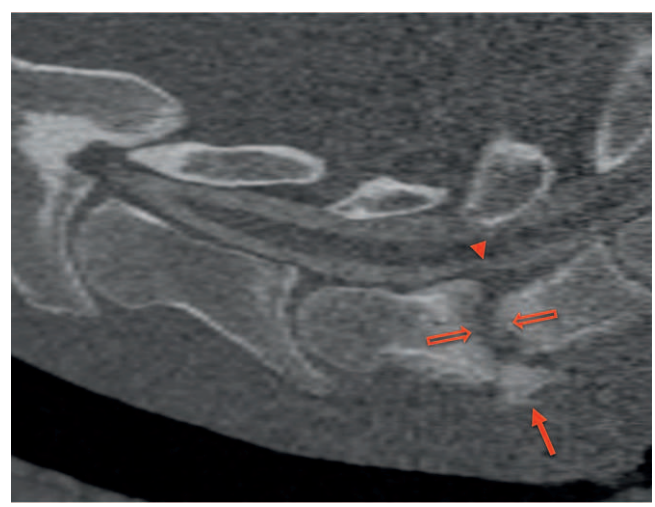


Fig. 5. C7–T1 Intervertebral disc disease characterized by presence of discospondylitis (arrow), intervertebral disc protrusion into the spinal canal resulting in ventral spinal cord compression (arrowhead), and caudal C7 and cranial T1 vertebral epiphyseal disease (hollow arrows).

degeneration is detected on nuclear scintigraphy and/or CT myelography (Fig. 5).

2. Materials and Methods

Imaging

Obtaining survey radiographs of the C7–T1 region is a challenge as this area is covered by heavy muscle and the scapulohumeral joint often superimposes this region. To offset these challenges at the C7–T1 level, the forelimb ipsilateral to the generator can be flexed, and the entire limb should be pulled caudally to reduce soft tissue coverage and remove the scapulohumeral joint from the primary field of view (Fig. 6). Generators with at least 90 kV are often needed to obtain quality radiographs in this region. Myelography of the C7–T1 region can easily be obtained with appropriate generators and by pulling the forelimbs caudally as far as possible while under anesthesia (Fig. 7). Computed tomography of the caudal cervical spine is commonly performed with the horse under positioned in lateral recumbency (Fig. 8). Every horse requires different body manipulation to fit through the CT gantry, and CT machines require a minimum gantry size of at least 85 cm to obtain CT imaging down to the level T1 or more caudal.

Surgical Description

Access to the C7–T1 region requires retraction and securing the forelimbs caudally before the area is aseptically prepared and draped. The surgical approach to C7–T1 is no different than when performing ventral interbody fusion in the remaining cervical regions.[11–14] However, gaining access to and visualization of the C7–T1 area is a challenge because this area is deeper and partially obstructed by the cranial sternum. Special instrumentation includes a 14-inch kerf cutter,

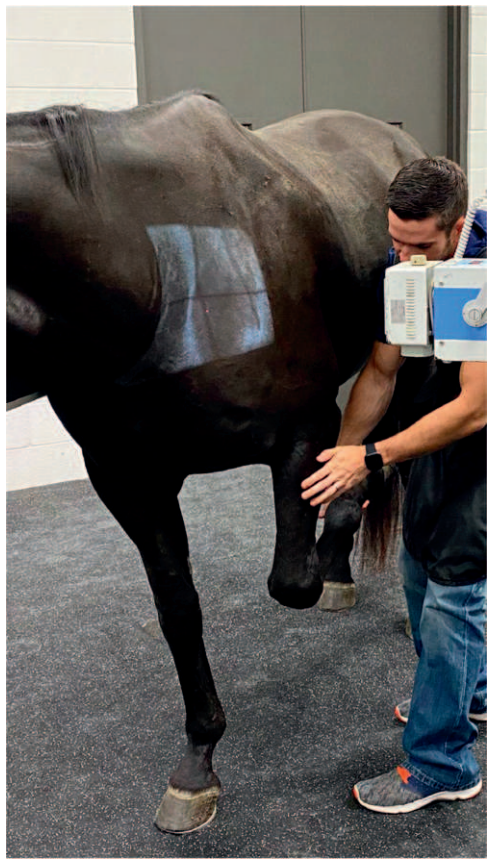


Fig. 6. The forelimb ipsilateral to the generator can be flexed, and the entire limb should be pulled caudally to reduce soft tissue coverage and remove the scapulohumeral joint from the primary field of view when radiographing at the level of C7–T1.

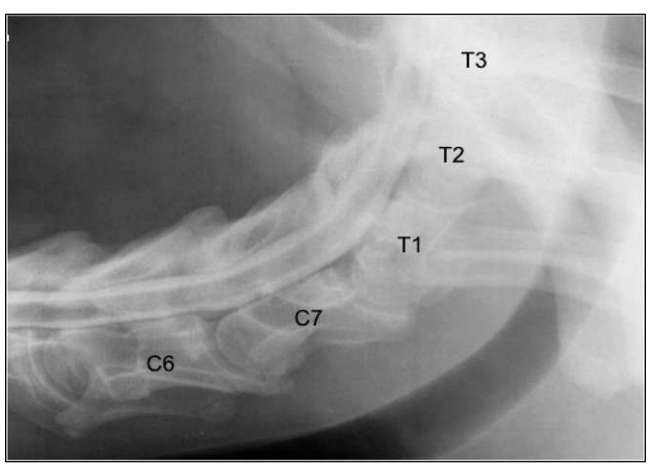


Fig. 7. Good quality standard myelography can be obtained using at least 90-kV X-ray generators. It is important that T1 is included in all myelographic studies.

14-inch tap, and 14-inch implant driver (Fig. 9). The surgeon should be prepared for variable positions and length of the truncus bicaroticus, which is the common trunk arising from the brachiocephalic artery. The common trunk then gives rise to the two common carotid arteries; this bifurcation typically occurs directly

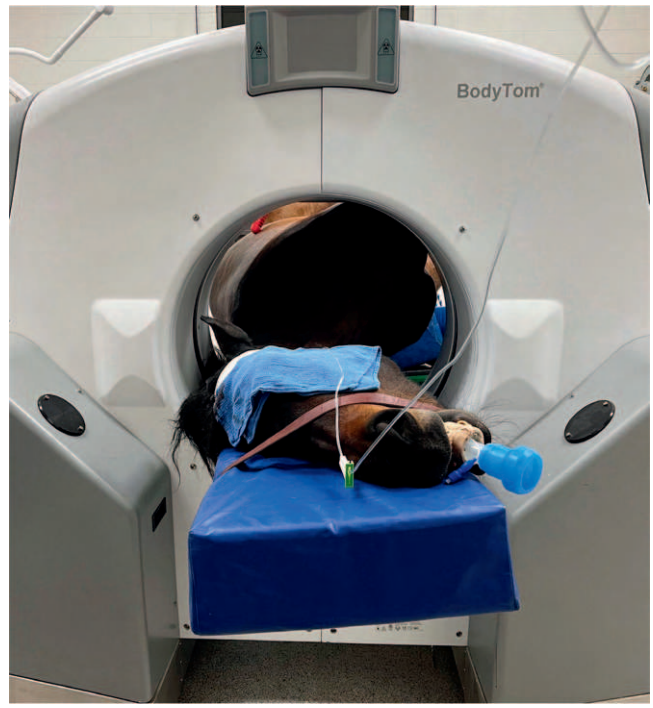


Fig. 8. Computed tomography of the caudal cervical spine is commonly performed with the horse positioned in lateral recumbency. CT machines require a minimum gantry size of at least 85 cm to obtain CT imaging down to the level T1 or more caudal.

over the C7–T1 articulation. Careful dissection is necessary to allow for the common carotid trunk to be retracted from the drill site without damaging either the sympathetic trunk or the recurrent laryngeal nerve. C7 does not have a ventral spinous process but does have two small chevron-shaped bony tubercles on the ventral midline in the midbody area. Preoperative radiographs with large needles being placed over the cervical articulations should be obtained to identify the appropriate surgical site. High-quality intraoperative radiographs are necessary during surgery for measurement purposes and proper implant placement (Fig. 10). Management after surgery and rehabilitation is no different than horses with ventral interbody fusions performed at other levels in the cervical spine.

3. Results

Twenty-nine horses with C7–T1 pathologic processes were included in this study (Table 1). Thirteen horses were Warmbloods, 9 were Quarter Horses, 1 was an Irish Sport Horse, 1 was an American Saddlebred, 1 was an Andalusian, 1 was a Thoroughbred, 1 was a Tennessee Walking Horse, 1 was a Warmblood-Thoroughbred Cross, and 1 was an Akhal-Teke. Two horses were sexually intact males, 8 were females, and 19 were geldings. The mean age of horses was 6 ± 4 years (range 1–14 years).

Twenty-two of 29 (76%) horses were deemed to have a successful outcome. Thirteen horses returned to riding, training, or showing. Nine horses had

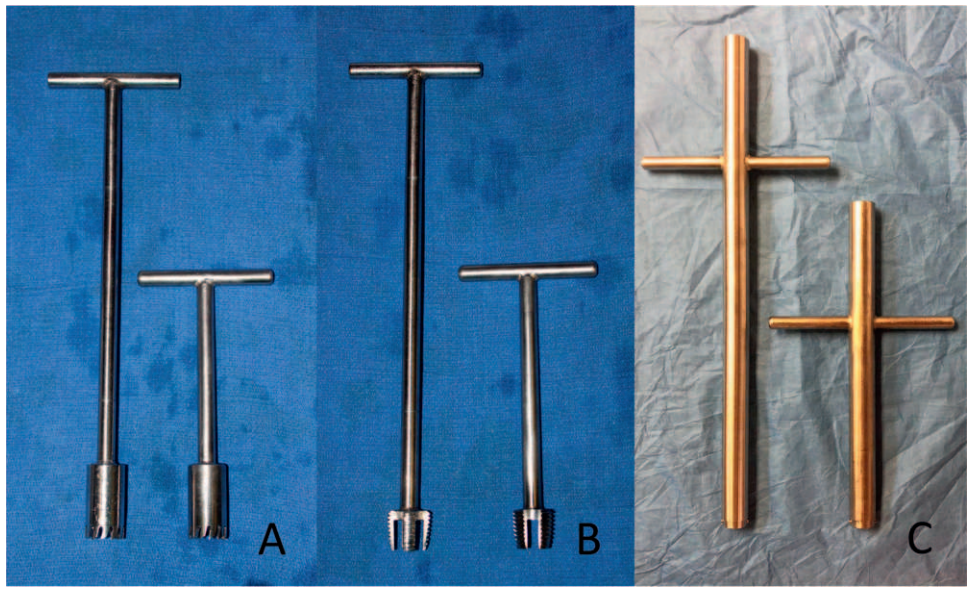


Fig. 9. Comparison of longer handled spinal instruments needed for C7–T1 ventral interbody fusion; the shorter instruments are used for ventral interbody fusion between C2 and C6 vertebra. A, Kerf cutter; B, Tap; C, Implant driver.

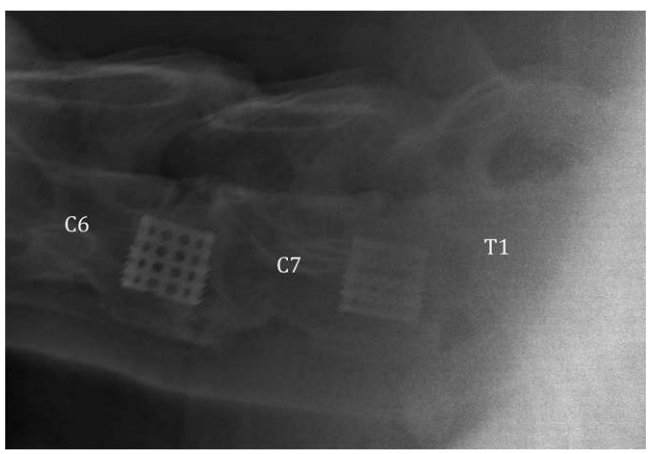


Fig. 10. Double level ventral interbody fusion at C6–C7 and C7–T1 using partially threaded titanium implants. These radiographs were obtained 12 months after surgery. Articular facet atrophy has occurred.

pasture or paddock turnout. Two horses were euthanized because of persistent pain after surgery. Two horses died because of anesthesia complications. One horse was euthanized because of dorsal disc displacement into the spinal canal after surgery. Two horses were lost to follow-up.

4. Discussion

Lameness, spinal pain, and ataxia attributable to C7–T1 pathology is becoming increasingly more recognized in horses. Standard myelography is valuable in cases of cervical vertebral stenotic myelopathy when compression of the dorsal contrast column is present but limits the ability to assess articular facet pathologic lesions, lateral spinal cord compression, intervertebral foramen stenosis, and/or disc degeneration. Computed tomography combined with myelography has improved the diagnostic and prognostic abilities of the caudal cervical spine. Standing CT using cone-beam units can be performed to provide multiplanar reconstruction and three-dimensional imaging of the caudal cervical spine, but standing cervical CT myelography using a cone-beam unit is not routinely performed as a standalone diagnostic modality. In contrast, standing fan-beam CT can be performed, but imaging is limited to the cranial cervical spine (usually C3) because the horses' shoulders and/or withers physically interfere with the CT scanner in the standing position. Multiplanar CT reconstruction and three-dimensional imaging using fan-beam CT technology is consistently attainable at the C7–T1 level with the horse under general anesthesia, allowing for thorough examination of dorsal and lateral contrast dye columns; assessment of articular facet sizes, shapes, and associated pathologic lesions; determining intervertebral foramen stenosis; and detection of disc degeneration. Ventral interbody fusion results in ankylosis of the cervical vertebral bodies, which eliminates dynamic dorsal spinal cord compression. Ventral interbody fusion also results in articular facet atrophy, which can eliminate static and dynamic dorsal spinal cord compression. Articular facet atrophy can also provide relief from lateral spinal cord compression and can reduce intervertebral foramen stenosis and nerve root compression (Fig. 11). Disc degeneration results in intervertebral instability and persistent pain, which can be eliminated with ventral interbody fusion.

There are not enough numbers in this case series to statistically compare the outcome of horses with a C7–T1 pathologic lesion alone versus those with combined C6–C7 and C7–T1 pathologic lesions. Clinically, there does not appear to be a difference in outcome

Table 1. Signalment and Outcomes of Horses Undergoing Ventral Interbody Fusion

Patient	Age (years)	Sex	Breed	Site	Postoperative Status	Time to Follow-Up	Complications
1.	8	G	WB	6/7, 7/1	Riding	>10 years	None
2.	1	F	WB	7/1	Unknown	>10 years	None
3.	14	F	ASB	7/1	Showing	>5 years	Horner's syndrome
4.	4	M	TWH	7/1	Euthanized	6 months	Persistent pain
5.	1	F	QH	7/1	Pasture turnout	>5 years	None
6.	10	G	QH	7/1	Pasture turnout	1 year	Intermittent pain
7.	Unknown	F	WB	7/1	Riding	2 years	None
8.	4	F	WB	7/1	Died in surgery	None	Anesthesia death
9.	12	G	WB	7/1	Riding	Unknown	None
10.	10	G	ISH	7/1	Riding	7 months	Lightning strike death
11.	7	G	AND	6/7, 7/1	Riding	Unknown	None
12.	2	G	TB	7/1	Pasture turnout	7 months	Laryngeal paralysis
13.	7	G	QH	7/1	Riding	8 months	None
14.	10	G	WB	6/7, 7/1	Unknown	18 months	None
15.	6	G	WB	4/5, 7/1	Pasture turnout	18 months	None
16.	6	G	WB	6/7, 7/1	Small pen turnout	3 months	None
17.	12	F	WB	6/7,7/1	Prix St. George	5 years	None
18.	8	G	AT	6/7,7/1	Euthanized	6 days postop	Dorsal disc displacement into spinal canal
19.	4	G	WB	6/7,7/1	Died in recovery	None	Laryngeal spasm during anesthesia recovery
20.	5	G	QH	7/1	Pasture turnout	5 years	None
21.	1	G	WB	6/7, 7/1	Training	3 years	None
22.	2	M	QH	6/7, 71	Training	20 months	None
23.	2	F	WB	6/7, 7/1	Euthanized	15 months	Persistent pain
24.	4	G	QH	7/1	Training	9 months	None
25.	1	F	QH	6/7, 7/1	Pasture turnout	9 months	None
26.	3	G	QH	6/7, 7/1	Pasture turnout	8 months	None
27.	9	G	WB	6/7,7/1	Pasture turnout	8 years	None
28.	5	G	WBxTB	7/1	Riding	2 years	None
29.	3	G	QH	6/7,7/1	Training	2 years	None

Abbreviations: F, females; G, geldings; M, intact males; WB, Warmblood; QH, Quarter Horse; ISH, Irish Sport Horse; AND, Andalusian; TWH, Tennessee Walking Horse; ASB, American Saddlebred; TB, Thoroughbred; AT, Akhal-Teke.

between C7–T1 fusions alone versus C6–C7/C7–T1 fusions. When multiple locations of confirmed spinal cord compression or other pathologic lesions are present, then multilevel ventral interbody fusion should be performed. Surgical arthrodesis of a single site in cases in which multiple sites are affected will result in continued neurological dysfunction. Response to surgical treatment and the prognosis both depend largely on the age of the horse, severity of the neurological deficits, duration of neurological disease, number and severity of cord compression sites, severity of the pathologic lesions, whether the dynamic or static cord compression is present, level of performance expected from the horse, and postoperative complications encountered.[10,17]

Laryngeal spasm is an important complication most likely from pressure on the recurrent laryngeal nerve secondary to the retraction necessary for instrumentation at C7-T1. If the left recurrent laryngeal nerve was damaged or dysfunctional before surgery, then laryngeal spasm can occur and can be fatal. This complication can be reduced by performing a preoperative endoscopic exam; if the left arytenoid is not abducting properly, then left recurrent laryngeal neuropathy is assumed and the surgical approach should be performed on the left side of the trachea. If a left-sided approach is necessary, then preoperative nasogastric tube placement will aid in identification of the esophagus and will facilitate dissection to the ventral cervical spine. A nasotracheal or orotracheal tube can be securely placed to aid in anesthetic recovery. Having an emergency tracheostomy kit available at the surgery recovery stall is recommended. Head and tail ropes are recommended to help control recovery from general anesthesia. Generally speaking, horses are confined to a stall for 30 to 45 days after surgery and then progress to stall confinement with controlled hand walking for 30 days. At that point, if the horse is showing improvement in clinical signs, the horse is allowed small pen turnout for 60 days. Four months after surgery, the horse can have incremental enlargements in paddock size. Movement early in the rehabilitation process is encouraged to improve strength and proprioception if the horse can safely tolerate exercise. Rehabilitation should be tailor fit for each horse depending upon the level of ataxia before surgery and level of comfort and ataxia after surgery but generally begins 4 months after surgery. Dynamic mobilization via lateral and ventral bending of the cervical spine improves range of motion. Exercises that engage the abdominal and epaxial musculature help strengthen the core musculature. Balance pads can help activate and strengthen musculature and improve proprioception.

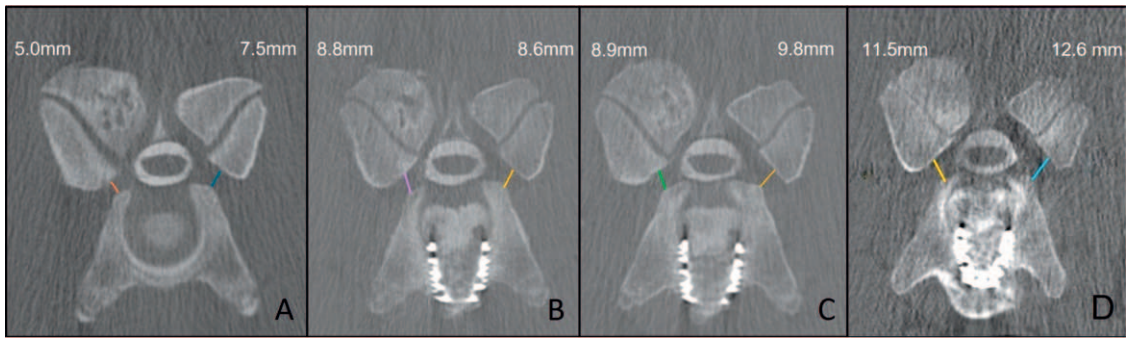


Fig. 11. Serial CT imaging of C6–C7 articulation showing progressive articular facet atrophy and widening of the intervertebral foramens. A, CT imaging before surgery. B, CT imaging 6 months after surgery. The left and right intervertebral foramen stenosis has improved by 76% and 15%, respectively, in comparison to the CT imaging before surgery. C, CT imaging 16 months after surgery. The left and right intervertebral foramen stenosis has improved by 78% and 31%, respectively, in comparison to the CT imaging before surgery. D, CT imaging 60 months after surgery. The left and right intervertebral foramen stenosis has improved by 130% and 68%, respectively, in comparison to the CT imaging before surgery.

Horses typically return to training 8 to 12 months after surgery after caudal vertebral interbody fusion.

Ventral interbody fusion of C7–T1 can be successfully performed in mature equine patients. Results of this study suggest that C7–T1 ventral interbody fusion has a good prognosis and that ventral interbody fusion of the cervical spine should no longer be considered a salvage procedure. Interestingly, more geldings than females or intact males underwent C7–T1 ventral interbody fusion, which further suggests that this procedure is not limited to valuable broodmares or breeding stallions. The goal of ventral interbody fusion is to return horses back to athleticism and/or improve performance when applicable; however, the intent of surgery is to improve comfort level, resolve lameness, and/or reduce the neurological grade that is safe for riding or provides a good quality of life. Seventy-six percent of the cases in this study had successful outcomes; 45% have currently returned to some level of training and/or showing, and 31% are still in the rehabilitation stages or have regular pasture or paddock turnout.

It is important for veterinarians to be aware that diagnostics and treatment of the C7–T1 level is possible with a good prognosis.

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.

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18F-NaF PET Monitoring of Racehorses Resuming Training After a Lay-Up Due to Fetlock Injury

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Resolution or recurrence of fluorine-18 sodium fluoride positron emission tomography lesions in horses resuming training is associated with racing outcomes, with unsuccessful racing associated with the latter. Lesion recurrence is typically detected on positron emission tomography at 4 to 6 months after resuming training. Additional studies are warranted to determine if lesion location, severity, and length of convalescence are correlated with resolution or recurrence and successful return to racing. Authors' addresses: University of California – Davis, School of Veterinary Medicine, One Shields Avenue, Davis, CA 95616 (Spriet, Pye); Southern California Equine Foundation, 285 Huntington Drive, Arcadia, CA 91007 (O'Brion); von Bluecher, Blea, and Hunkin, Inc., 282 W Sierra Madre Blvd, Sierra Madre, CA 91024 (Blea); Equine Medical Center, 10542 Walker Street, Cypress, CA 90630-4715 (Carpenter); Equine Medical and Surgical Group, 400 Harvard Drive, Arcadia, CA 91007-2638 (Dowd, Birch); e-mail: mspriet@ucdavis.edu. *Corresponding and presenting author. © 2023 AAEP.

1. Introduction

Fluorine-18 sodium fluoride (18F-NaF) positron emission tomography (PET) has been used to diagnose fetlock injuries in racehorses and monitor their healing through lay-up. Little is known regarding risk, timing, and severity of recurrence of fetlock lesions once training resumes. The goal of this study was to monitor, with serial 18F-NaF PET scans, the fetlocks of racehorses resuming training after a lay-up due to fetlock injury.

2. Materials and Methods

Twelve horses, previously diagnosed with fetlock lesions with 18F-NaF PET, were included in this study as they were resuming training after a period of lay-up. Fluorine-18 NaF PET of the fetlocks was performed immediately prior to resuming training and 1, 2, 4, and 6 months later.

All images were independently reviewed by a board-certified radiologist for sites of abnormal uptake. Racing performance data were collected.

3. Results

Six horses completed the study, reaching 6 months in training without recurrence or development of new lesions. All these horses went back to racing, with 5 of them racing successfully. The other 6 horses all had a

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recurrence of lesions; none of them developed new lesions. Recurrence occurred at 2 months in 1 horse, at 4 months in 3 horses, and at 6 months in 2 horses. There was a significant association between lesion recurrence and racing outcome ($P = 0.04$).

4. Discussion

Fluorine-18 NaF PET is a pertinent tool for monitoring recurrence of fetlock lesions in horses resuming training. Scans performed at peak training, 4 to 6 months after resuming training, are the most likely to detect lesion recurrence associated with the racing outcome.

Acknowledgments

Funding Sources

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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.

Characterization of Radiographic Lesions in Western Performance Horses with Lameness Localized to the Fetlock Joint

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Non-specific signs of radiographic joint degeneration are the most common radiographic finding in Western performance horses with lameness localized to the fetlock but are not associated with degree of lameness. Certain radiographic findings were associated with greater degrees of lameness.
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1. Introduction

Pathologic changes of the fetlock joint are well documented in Thoroughbreds but less so in other breeds. This study describes radiographic findings in western performance horses with lameness localized to the fetlock joint. It was hypothesized the degree of lameness would correlate with severity of radiographic findings.

2. Materials and Methods

A retrospective review (2012–2022) of horses with lameness isolated to the fetlock joint and corresponding fetlock radiographs were included. Signalment, lameness, flexion, and effusion grades were recorded. Radiographs were evaluated for presence, severity, and location of pathology and assigned an overall subjective score. Correlations between outcome parameters were evaluated with Spearman's correlation coefficient.

3. Results

Ninety cases met inclusion criteria. The majority were Quarter Horse geldings with mean age of 5.9 years old and mean lameness grade of 2.2/5. Radiographic lesions were identified in 96.7% of cases. Distal cannon bone sclerosis, periarticular osteophytes, soft tissue swelling, proximal phalanx (P1) sclerosis, and subchondral bone (SCB) defects were most common. Weak correlations between age and osteophytes, overall radiographic score, and

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lameness grade were observed. Weak correlations between lameness grade and P1 sclerosis, SCB cyst, and P1 fissures were found. Horses with sagittal ridge defects, P1 demineralization, joint narrowing, SCB cysts, and P1 fissures had significantly higher lameness grades. No significant correlation was established between overall radiographic score and lameness grade.

4. Discussion

Horses in this study commonly demonstrated changes associated with chronic exercise-induced remodeling and degenerative joint disease. While degree of lameness did not correlate with overall radiographic score, certain radiographic findings were correlated with higher degree of lameness.

Acknowledgments

Declaration of Ethics

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Conflict of Interest

The authors have no conflicts of interest.

How to Use Ultrasound to Investigate Acute Femoral Swelling in Horses

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Diagnostics are limited in horses with acute femoral swelling and lameness. Ultrasonography can be used to differentiate between major injuries to aid in prognostication and treatment planning. Frequent injuries include fractures of the tuber ischii or femoral third trochanter and tears of the gracilis, semimembranosus, or semitendonosus muscle bellies. Catastrophic femoral fractures less often found on ultrasound exams. Authors' addresses: Department of Surgical & Radiological Sciences, School of Veterinary Medicine, University of California – Davis, CA 95616 (Whitcomb, Vaughan); Great & Small Veterinary Imaging, 1437 Moreno Street, Oceanside, CA 92054 (Goorchenko); Ultra Equine, 83 Federal Drive, Victoria, Australia, 3024 (Jones); e-mail: marybethwhitcomb@gmail.com. *Corresponding and presenting author. © 2023 AAEP.

1. Introduction

Although sporadic in nature, horses presenting with acute femoral swelling can create a stressful situation for the horse, owners, and veterinarians. Femoral swelling may occur after major trauma such as falling, becoming cast, or limb entrapment and is frequently accompanied by significant lameness. This often leads to an emergency where emotions can run high for all stakeholders. Catastrophic fracture of the femur is often the primary differential in such instances,[1,2] yet much less catastrophic injuries can produce similar clinical signs in the acute injury phase. These include fractures of the tuber ischii or femoral third trochanter and tears of the gracilis, semimembranosus, and semitendinosus muscle bellies.[3–7] Rapid differentiation between injuries is important to aid in prognostication and appropriate treatment planning. Unfortunately, imaging options for this region in horses are limited compared with the distal limb.

Radiographic evaluation of the equine femur is difficult in the ambulatory or hospital setting due to the large body mass and upper limb musculature in adult horses and is made even more challenging by the presence of femoral swelling that can be profound in affected horses.[1–2] Femoral diaphyseal views in the standing horse are typically nondiagnostic, in which case the practitioner is often limited to radiography of the distal femur as part of a stifle radiographic examination or ventrodorsal views performed under general anesthesia, which may not be desirable in horses suspicious for upper limb fracture.[8] Standing radiographic projections of the femoropelvic region have been described but provide limited visibility of the femur.[9,10] Skyline radiographic projections of the

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femoral third trochanter have been used to diagnose trochanteric fractures but may take multiple attempts to obtain a diagnostic view.[6,7,11]

In contrast, ultrasonography is readily available to most veterinarians and provides excellent bony and soft tissue detail to enable detection of upper limb fractures and other soft tissue injuries that result in femoral swelling. Ultrasound has been used to diagnose many types of equine pelvic fractures for years,[4,12–15] as well as fractures of the femoral third trochanter,[6–7] and more recently to diagnose more catastrophic femoral fractures in large animals.[16] The purpose of this presentation is to describe the use of ultrasound in horses with severe femoral swelling and the appearance of the most commonly diagnosed injuries. This information should be beneficial stall-side in both ambulatory and hospital settings to differentiate between injuries, to aid in prognostication, and to benefit patient care and owner peace of mind.

2. Methods

Equipment

Most portable and console-type ultrasound machines available to equine practitioners are appropriate for evaluation of the femoral region when equipped with a low-frequency (2–5 MHz) curvilinear transducer. Depending on the size of the horse and the structure of interest, required scanning depths can range up to 20 to 25 cm, which is beyond the limit of high-frequency transducers. Curvilinear transducers also produce a sector shaped image, yielding a wider field of view to aid in image interpretation. As more ambulatory clinicians expand their use of ultrasound to include deep cavity imaging, it is increasingly likely that a practice will have access to this transducer. In foals, however, a high-frequency linear or small curvilinear transducer may be sufficient for examination. Micro-machines with dedicated rectal transducers (often marketed for reproductive ultrasound) are unlikely to be suitable for imaging the deep structures of the femoral region.

Patient Preparation

It cannot be overstated that clipping the hair with #40 blades, washing the skin with soap and water (ideally warm if possible), and application of ultrasound coupling gel will result in the best image quality. Doing so is well worth the extra time in large, heavily muscled, or overweight horses and those with long hair coats. Despite widespread belief to the contrary, any time "saved" by not clipping is often eclipsed by the added time necessary to obtain diagnostic images without clipping. In thin or short-coated horses, alcohol saturation without clipping is often adequate. Light sedation is usually helpful and often necessary to prevent swaying and other horse movements to maximize examiner safety. In horses with severe or extreme pain, additional pain management is often necessary.

Ultrasonographic Evaluation of the Tuber Ischii/Pelvis

Ultrasonographic evaluation of the tuber ischii is generally performed as part of a pelvic ultrasound examination and has been described by multiple authors.[4,12–15] The ultrasonographic technique utilized in this report includes evaluation of the ilial wing, ilial body, and coxofemoral joint using a low-frequency (2–5 MHz) curvilinear transducer and either a portable or console ultrasound machine. Evaluation of the superficially located tuberosities of the pelvis, including the tuber ischii, can be performed with the same low-frequency transducer. In smaller or thinner horses, a high-frequency linear or midrange frequency curvilinear/microconvex transducer may be adequate. Transverse views (essentially a paramedian approach) often provide the best images for interpretation (Fig. 1A). The normal tuber ischii shows a relatively smooth hyperechoic surface that slants away from the skin surface toward its ventral margins (Fig. 1B). Fractures are often ventrally displaced, creating either step defects or obvious fragments with separation from the parent bone (Fig. 1B, C). It is helpful to position the transducer slightly ventral to the tuber ischii due to the frequency of ventral fracture displacement and to assess the ventral musculature, which often shows concurrent evidence of localized muscle tearing and/or hemorrhage. It is important to evaluate the entire medial to lateral extent of the tuber ischii. Fragments can otherwise be missed if only a few slices are obtained.

Ultrasonographic Evaluation of the Femoral Third Trochanter

Evaluation of the third trochanter is also typically performed as part of a pelvic ultrasound examination at the authors' hospital because fractured horses often have similar historical and clinical presentations to those with pelvic injuries. Evaluation is relatively straightforward and adds little to acquisition time. Although superficial in location, a low-frequency transducer is often the transducer of choice, but higher-frequency transducers can be used in some horses. The third trochanter is located at approximately the proximal third to middle third junction of the femoral diaphysis along its plantarolateral border. It is most easily evaluated in a transverse plane from a lateral and slightly plantar approach by starting at the proximal extent of the femur and sliding the transducer distally until its prominent finger-like projection is seen (Fig. 2A, B). Its entire length should be evaluated until the finger-like projection is no longer visible as the transducer is moved distally. The majority of third trochanter fractures are displaced cranially by traction from the superficial gluteal muscle attachment (Fig. 2C, D). Regional hemorrhage and edema may be present in some horses, but extensive muscle tearing is not a common finding. Radiographic confirmation of third trochanter fractures is possible with a 50° cranial and 30° lateral to caudomedial oblique projection (Fig. 3).[6,7,11]

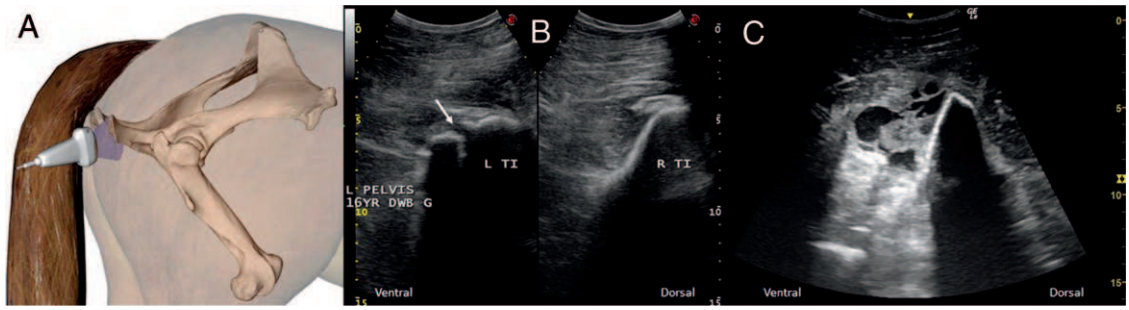


Fig. 1. A, Transducer placement to evaluate the tuber ischii. B, Ultrasonographic images of a fractured left (arrow) and normal right tuber ischii from a 16-year-old Warmblood gelding that slipped and fell 2 months previously. Only minimal fracture displacement is seen in this horse. C, In another horse, moderate hemorrhage and muscle tearing is seen in association with a tuber ischii fracture. While the ventrally displaced fragment is not visible in this image, the contour of the parent bone is more angular than expected. Both images were obtained with a low-frequency curvilinear transducer.

Ultrasonographic Evaluation of the Femur

Ultrasonographic examination of the femur is performed with a low-frequency curvilinear transducer using a console or portable ultrasound machine. The femur should be evaluated in a proximal to distal direction, beginning at the greater trochanter and continuing to the stifle joint using both transverse and longitudinal views. In the authors' experience, longitudinal views are most useful to visualize fractures because deviation(s) from the normally smooth bony contours of the femur are more readily detected (Fig. 4). Multiple visible fragments are not uncommon in comminuted diaphyseal fractures, and movement of fractured bone ends can sometimes be seen as the horse shifts its weight. In horses without significant comminution, attempts to follow fracture lines in a semicircumferential fashion may be possible to aid in fracture configuration. Regional hemorrhage and edema are expected findings in most cases and can be extensive. It is worth reminding the reader that the normal appearance of the femoral third trochanter should not be mistaken for a step defect or fracture. When in doubt, comparison to the contralateral limb is recommended.

Ultrasonographic Evaluation of the Caudo-Medial Thigh Musculature

Evaluation of the gracilis, semimembranosus, and semitendinosus muscle bellies can be performed with multiple transducers, depending on the site of interrogation. When scanning from the caudal femoral region, a low-frequency curvilinear transducer is recommended to reach the depths necessary to image multiple muscle bellies in the same image. From a medial approach, the narrow shape of a linear format rectal transducer is helpful to slide as far proximally

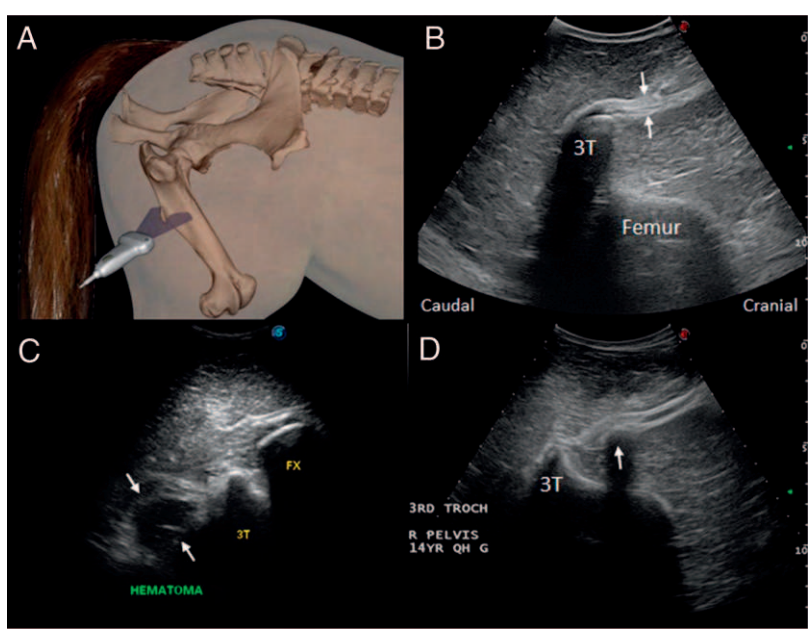


Fig. 2. A, Transducer position to obtain a transverse view of the femoral third trochanter. B, Normal sonographic appearance of the third trochanter (3T) showing its smooth fingerlike projection extending from the femoral body and the tendinous attachment of the superficial gluteal muscle (arrows). C, Cranial displacement of a large fracture (Fx) of the third trochanter (3T) with a moderate size area of distal hemorrhage (arrows). D, Fracture of the third trochanter (arrow) in another horse also showing cranial displacement.

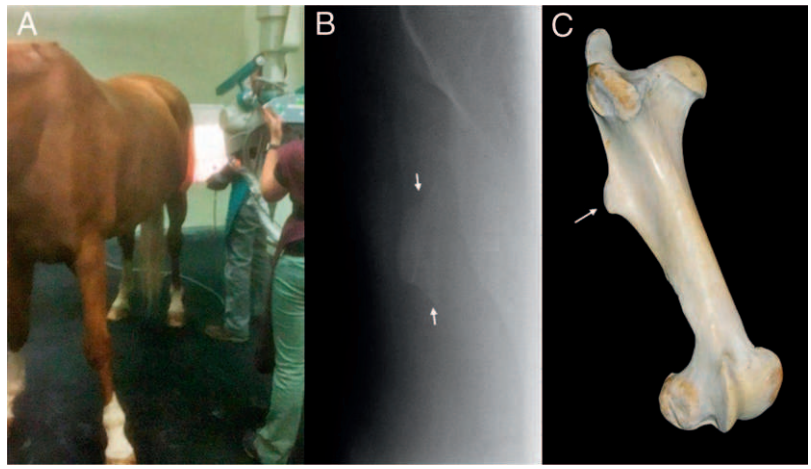


Fig. 3. A, Acquisition of a 50° cranial and 30° lateral to caudomedial oblique radiographic projection (B) to confirm the displaced third trochanter fracture (arrows) visualized on ultrasonographic examination. C, Anatomic specimen highlighting the prominent equine third trochanter (arrow).

as possible between the hind legs to image the flat and superficially located gracilis muscle belly as well as other muscles that can be affected. Disrupted muscle bellies can take on various appearances, including avulsions where the muscle architecture is somewhat maintained and recognizable, but the muscle appears relaxed due to tearing at a site of attachment (Fig. 5). There may also be gross disruption with partial or complete loss of recognizable muscle architecture and large fluid accumulations that can give a lacy appearance to affected muscles. Consultation with an anatomy book that contains cross-sectional slices of the upper limb is very helpful to compare with ultrasonographic images and differentiate between muscle bellies. Another tip is to begin the scan in a less affected or normal area where it is possible to define muscle boundaries and fascial planes and then to follow each muscle individually toward and beyond the area of injury. In cases with tears of multiple muscle bellies, it can be challenging to definitively identify specific muscles. Regardless of the muscle affected, there is often significant regional fluid accumulation (hemorrhage and/or edema) within, between, and surrounding muscle bellies, including subcutaneous spaces. Fluid accumulations and/or hemorrhage can sometimes be mistaken for extramuscular, rather than intramuscular, seromas or hematomas. If time to presentation is prolonged, blood clots may have formed within these fluid accumulations. These will appear as hyperechoic rounded structures within fluid pockets that can become dense enough to cast shadows.

3. Results

Electronic and paper medical record review was performed from January 1, 2000, through December 31, 2022, to identify all horses that underwent ultrasonographic examination at the William R. Pritchard Veterinary Medical Teaching Hospital at the University of California, Davis School of Veterinary Medicine and diagnosed with the above-described injuries. Over this 23-year period, a total of 69 horses were diagnosed with at least one injury type. Tuber ischii fractures were identified in 25 horses; tearing of gracilis, semimembranosus, or semitendinosus muscle bellies in 23 horses; femoral third trochanter fractures

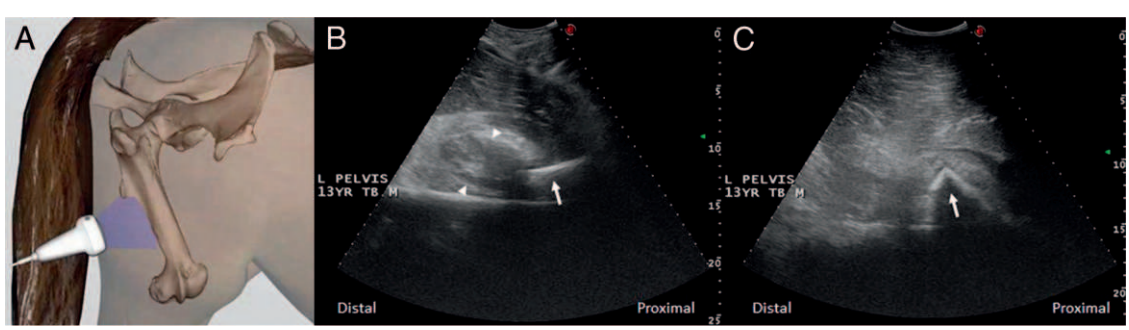


Fig. 4. A, Transducer orientation to obtain longitudinal images of the femoral diaphysis with corresponding views of a fractured femur in a 13-year-old Thoroughbred breeding stallion found at pasture with femoral swelling and non-weight bearing lameness. B, A large step defect (arrow) is seen with associated regional hemorrhage (arrowheads). Movement of the transducer semicircumferentially revealed additional fragmentation (arrow) and step defects (C). These findings were consistent with a comminuted fracture, which was later confirmed at necropsy.

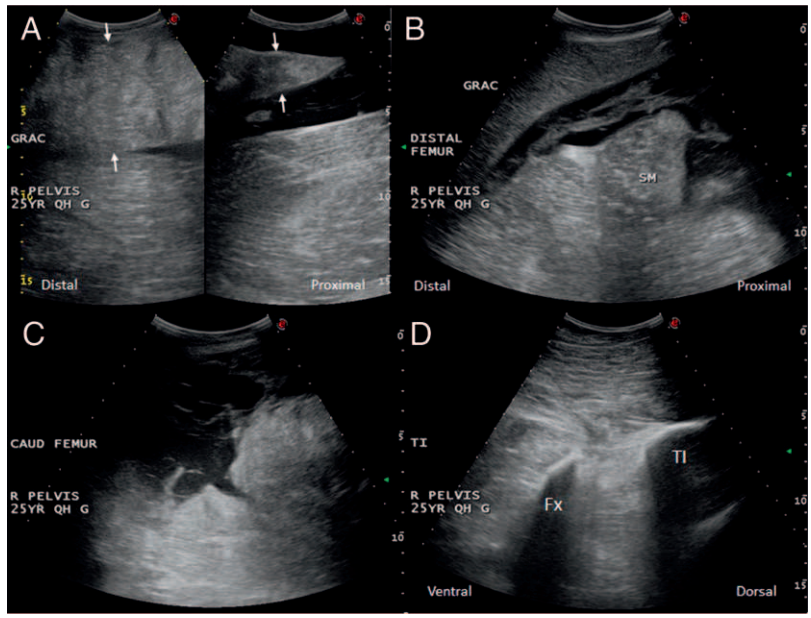


Fig. 5. Ultrasonographic images of the caudomedial thigh region in a retired 25-year-old Quarter Horse gelding with acute onset femoral swelling and lameness after an unknown incident 4 days previously. A, There is relaxation of the gracilis muscle (arrows) due to proximal avulsion and fluid accumulation surrounding its detached proximal end. B, Evidence of semimembranosus (SM) muscle tearing and relaxation is also present. C, A large fluid accumulation was noted in the region of the caudodistal femoral region. D, This horse also had a concurrent tuber ischii (TI) fracture (Fx). While some degree of localized muscle tearing is commonly identified in association with tuber ischii fractures, the extent of distal muscle tearing involving the gracilis and semimembranosus muscles is not a common concurrent finding. All images were obtained with a 2- to 5-MHz curvilinear transducer.

in 21 horses; and catastrophic femoral fractures in 4 horses. Two horses had concurrent tuber ischii and third trochanter fractures, one affecting the ipsilateral limb and one affecting contralateral limbs. Two horses with extensive tearing of their caudomedial thigh musculature also had ipsilateral tuber ischii fractures.

Tuber Ischii Fractures (25 Horses)

Fragments were displaced ventrally in all but one horse that showed slight dorsal displacement. Hemorrhage, edema, and localized disruption of muscle bellies ventral to the tuber ischii were seen in most cases. Of these horses, 8/25 had a history of falling. All but 2 showed some degree of lameness at the time of presentation ranging from Grade 1 to 5/5 (mean = 3.44; AAEP grading scale), and 13/25 demonstrated regional swelling, including the 2 horses with concurrent tearing of the caudomedial thigh muscles and 1 horse with a concurrent third trochanter fracture.

Femoral Third Trochanter Fractures (21 Horses)

Fracture fragments were characteristically displaced cranially and were readily identifiable; however, 2 horses showed only minimal displacement. Regional hemorrhage and edema were seen in a few horses. Of the 21 affected horses, 3 had a history of falling and all showed lameness ranging from Grade 1 to 5/5 (mean = 2.89). The lone horse with a Grade 5/5 lameness also had a comminuted acetabular fracture. Femoral swelling was recorded in 5/21 affected horses.

Femoral Fractures (4 Horses)

Catastrophic femoral fracture was identified in a total of 4 horses, all adults. These included 3 horses with comminuted diaphyseal fractures where disrupted cortical surfaces were readily visualized in the diaphyseal region, most prominent on longitudinal views. Multiple bone fragments as well as movement of fractured bone ends could be seen with voluntary weight shifting. Hemorrhage and edema were also present. These horses were in extreme pain, and ultrasound examinations took place within the horses' stalls to avoid any unnecessary movement. The fourth horse had a fracture that involved the greater trochanter, seen as a step defect extending from the cranial, lateral, and caudal margins of the proximal femur. All showed severe femoral swelling and Grade 4 to 5/5 lameness after a major trauma. All were euthanized shortly after diagnosis. It should be mentioned that capital physeal fractures were excluded because swelling is a somewhat inconsistent finding.[16,17]

Muscle Tears of the Caudomedial Thigh (23 Horses)

The gracilis muscle was the primary muscle belly affected in most horses. The semimembranosus and semitendinosus muscle bellies were frequently affected but often to a lesser degree. In horses with severe extensive tearing, it was challenging to differentiate muscle bellies by appearance. Most horses showed extensive fluid accumulation within and surrounding affected muscles. All horses (23/23) showed femoral swelling, which was often severe. Lameness

was recorded in 19/23 horses and ranged from Grade 2 to 4/5 (mean = 3.68). Falls were recorded in 7/23 horses, one of which was reported to have done the "splits." Horses evaluated for fibrotic myopathy type gaits and found to have regional/focal scarring of the semimembranosus/semitendinosus musculature were not included as these horses typically show a dissimilar clinical presentation.

Recheck ultrasound examinations were performed in a small number of cases. Fractures of the third trochanter and tuber ischii typically remained displaced; however, improvement in edema, hemorrhage, and muscle architecture was seen in most cases. Horses with severe caudomedial thigh muscle tears showed very slow sonographic improvement, with persistent but reduced fluid accumulations and evidence of muscle remodeling over time.

Other injuries encountered during the study period included rare cases of deep femoral abscessation, vascular thrombi, foreign bodies, and/or deep muscle injuries. While such conditions can cause femoral swelling and lameness, onset of clinical signs was typically much more prolonged or insidious in these horses.

4. Discussion

Ultrasonography has been highly useful at the authors' hospital to aid in the diagnosis of horses with acute femoral swelling and lameness. It is recognized that not all presented cases demonstrated swelling, but it was considered important to share the frequency with which injuries are diagnosed ultrasonographically at a referral hospital with a heavy lameness and emergency caseload. As mentioned previously, femoral fracture was often the primary differential among in-house and external referring veterinarians, yet this injury was found in only 4/69 horses undergoing femoro-pelvic ultrasound over a 23-year period. The relatively large number of horses diagnosed with other injuries illustrates the importance of regional ultrasonographic evaluation whenever possible. Conversely, it should be mentioned that several additional horses were diagnosed with femoral fracture from 2000 to 2022 that did not undergo ultrasonographic examination. Search of medical records revealed an additional 27 horses with necropsy confirmed femoral fracture, many of which were euthanized in the field based on radiographic and clinical findings by ambulatory clinicians.

Differentiation of injuries is important to aid in prognostication. While some injuries can result in reduced performance, persistent lameness, or gait abnormalities, most are considered non-life threatening except comminuted femoral fractures. Femoral fractures generally carry a poor prognosis whether the fracture involves the diaphyseal region or the distal femur.[1,2,16,18] Surgical repair is often not considered in horses weighing > 200 kg,[2] and conservative management of such destabilizing injuries is not recommended due to humane reasons in affected horses. On the other hand, horses with femoral third trochanter fractures have been reported to return to full function despite fractures remaining displaced on recheck examinations.[5–7] While third trochanter fractures do not destabilize the bony column, they can result in persistent mild to moderate lameness in some horses.[7]

Tuber ischii fractures have been reported within several imaging studies related to pelvic fractures,[4,5,11] but focused reports are lacking. Prognosis appears to be somewhat variable in the relatively few reported cases.[4,5] The authors' experience is similar, with some affected horses returning to their previous level of function and others remaining persistently lame. A few horses with tuber ischii fractures have even required euthanasia, including one horse that suffered unrelenting severe pain, presumably from fracture contact with adjacent nerves, and another due to uncontrollable subcutaneous blood loss and impending exsanguination. The frequency of hemorrhage associated with tuber ischii fractures is not surprising given the large number of regional blood vessels that are readily visible during most ultrasound examinations. Similar to third trochanter fractures, fragments often remain displaced, although gradual resolution of hemorrhage and muscle tearing should be expected.

The authors were somewhat surprised by the relatively large number of muscle tears involving the caudomedial thigh musculature. Focused publications on gracilis, semimembrosus, and semitendinosus injuries are also lacking;[3,19] however, those practicing in regions with frequent icy conditions are quite familiar with such injuries. Horses are often described as slipping on ice and "doing the splits." Ice is a rare occurrence in the authors' referral area and was not a source of injury in any horses in this study, yet there were still numerous cases. Falls were often reported as the cause of injury (7/23), but it was interesting that only one horse was reported to have done the splits. Although generally not a life-threatening injury, horses may develop substantial muscle scarring over time and possibly a fibrotic myopathy type gait.[20] It has been found that evidence of healing is prolonged from an ultrasonographic standpoint on recheck examinations. Reabsorption of fluid accumulations can take months and even longer to detect evidence of muscle repair. As mentioned previously, however, the examiner should be aware of the frequency of clot formations within such tears and not overinterpret their hyperechoic appearance as a more sinister finding.

Some authors have suggested that the location of swelling can help differentiate between upper hindlimb injuries on physical examination. Depending on the timeframe from injury to examination, swelling can change dramatically within hours or days due to continued hemorrhage/inflammation and/or distal migration that confounds its initial location. Furthermore, large swellings can readily obscure anatomic structures on clinical exam, making ultrasound even more useful in this region. Due to the variety of injuries that can cause femoral swelling,

it is recommended that affected horses undergo ultrasonographic examination of the entire femoropelvic region rather than a focused examination. For example, a lone focus on the femur may result in an undetected tuber ischii fracture or excessive focus on the pelvis could result in a missed third trochanter fracture, diaphyseal femoral fracture, or muscle injury.

While not meant to be an exclusive list of injuries that can cause femoral swelling, the above-described findings were identified with some frequency at a referral hospital where ultrasound is often used to evaluate horses with upper limb injuries. These injuries can be detected with most of today's ultrasound machines equipped with transducers regularly used in equine practice. While some experience is helpful to evaluate the femoral region, abnormalities are seldom subtle and show considerably less vagaries than more mainstream ultrasound examinations such as the metacarpus, metatarsus, and pastern. It is hoped this information will be valuable to practitioners in both hospital and ambulatory settings when presented with horses with acute femoral swelling and lameness.

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.

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The Prevalence of Lameness in FEI Equine Athletes and Its Correlation to Performance

Erin Contino, DVM, MS, DACVSMR*; Jodie Daglish, BVSc, MS, DACVSMR, MRCVS; and Christopher Kawcak, DVM, PhD, DACVS, DACVSMR

Mild, and often multilimb, lameness is extremely common in elite-level equine athletes but does not tend to negatively influence performance. Authors' addresses: Colorado State University College of Veterinary Medicine, 300 West Drake Road, Fort Collins, CO 80523 (Contino, Kawcak); Newmarket Equine Hospital Referrals, Cambridge Road, Newmarket, Suffolk, CB8 0FG, UK (Daglish); e-mail: erin.contino@colostate.edu. *Corresponding and presenting author. © 2023 AAEP.

1. Introduction

Lameness is exceptionally common in horses, yet the relationship between lameness and performance is not well understood. This study aimed to determine 1) the prevalence and magnitude of lameness in Federation Equestrian International (FEI)-level horses and 2) the impact of lameness on performance.

2. Materials and Methods

Horses were voluntarily enrolled at an FEI-level eventing, show-jumping, or dressage competition. Lameness was evaluated subjectively (Grade 0–5; modified AAEP grading scale) by consensus of 2 lameness specialists and objectively with a commercially available inertial measurement system. Competition results, including final raw score, finishing place, and finishing percentile, were compared to the lamest limb grade and a cumulative lameness score (sum of lameness grades of all 4 limbs) using Spearman Rank and Pearson correlations.

3. Results

Eighty-four horses were included, which represented a 28% enrollment rate; there were 47 eventers, 22 show jumpers, and 15 dressage horses with a mean age of 11.6 years. Lameness was present in 88% (subjective) to 89% (objective) of horses, many of which (44–51%) were lame in multiple limbs. Mean lameness was Grade 1 (range 0–3.5), and mean cumulative lameness was 1.4 (range 0–5). No significant correlations between lameness and performance parameters existed for any discipline. There was a trend for increasing lameness to be modestly correlated (r = 0.46) to decreased dressage performance and weakly correlated (r = 0.37) to improved show-jumping performance.

4. Discussion

Lameness in FEI-level horses is extremely common but tends to be mild. No statistically significant correlations between lameness and performance were found, but a larger sample size may help elucidate

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some trends that were present. Lameness may not be a good measure of a horse's readiness to compete.

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.

Metacarpal/Metatarsal Condylar Fracture Location, Exercise History, and Outcome in 82 Thoroughbred Racehorses

Thomas Bergstrom, DVM*; Mathieu Spriet, DVM, MS, DACVR, DECVDI, DACVR-EDI; Ryan Carpenter, DVM, MS, DACVS-LA; Kevin Jacques, BS; and Susan Stover, DVM, PhD, DACVS

Thoroughbred racehorses that incur metacarpal/metatarsal condylar fracture appear to be from two distinct populations relative to fracture location either within or outside the parasagittal groove further abaxial on the condyle. These two populations have significantly different exercise histories prior to fracture, suggesting different pathophysiology. Authors' addresses: William R. Pritchard Veterinary Medical Teaching Hospital (Bergstrom) and Department of Surgical and Radiological Sciences (Spriet, Jacques, Stover), University of California – Davis, Davis, CA 95616; Equine Medical Center, 10542 Walker Street, Cypress, CA 90630 (Carpenter); e-mail: bergstrom.tb@gmail.com. *Corresponding and presenting author. © 2023 AAEP.

1. Introduction

Metacarpal/metatarsal condylar fractures are the most common fractures in Thoroughbred racehorses. The objectives of this study were to describe the location of these fractures and assess the association between fracture location and prior exercise history as well as outcome following repair.

2. Materials and Methods

Clinical data, exercise history, diagnostic radiographs, and outcome of Thoroughbred racehorses undergoing a metacarpal/metatarsal condylar fracture repair between January 1, 2018, and February 28, 2021, were collected. Fracture location was classified as either within the parasagittal groove (PSG) or outside the PSG. Exercise history was compared between PSG and outside the PSG fracture groups using one-way analysis of variance and a Wilcoxon test. Outcome (return to racing and earnings) following fracture repair was compared between groups using a Fisher's exact test.

3. Results

Eighty-two horses with 84 fractures met the inclusion criteria. Forty-five fractures were located in the PSG, and 39 were located outside the PSG. Mean age was not significantly different between groups (PSG: 3.4 $\pm$ 1.3, outside the PSG: 3.7 $\pm$ 1.3, $p = 0.29$). Mean number of races (PSG: 5.3 $\pm$ 7.1, outside the PSG: 11.4 $\pm$ 8.9, $p < 0.001$) and total race furlongs (PSG: 38.2 $\pm$ 54.7, outside the PSG: 79.2 $\pm$ 64, $p = 0.003$) prior to fracture were significantly higher in horses with

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fracture outside the PSG. The mean total number of active days was significantly higher (PSG: 304 ± 224, outside the PSG: 488 ± 314, $p = 0.003$) and the mean total number of layoffs was significantly lower (PSG: 1.0 ± 1.2, outside the PSG: 0.5 ± 0.7, $p = 0.019$) in horses with fracture outside the PSG prior to fracture. Outcome following fracture repair was not significantly different between groups for either return to racing ($p = 0.23$) or positive earnings following return to racing ($p = 0.26$).

4. Discussion

The data from this study indicate that Thoroughbred racehorses with condylar fracture outside the PSG have a more extensive exercise history than horses with fracture in the PSG. This difference in exercise histories suggests a difference in pathophysiology of these two fracture populations, which should be the focus of future research studies.

Acknowledgments

Declaration of Ethics

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Conflict of Interest

The authors have no conflicts of interest.

Substantial Variability Exists in the Interpretation of Survey Radiographs Among Equine Veterinarians

Angie M. Esselman, DVM*; Erin Contino, DVM, MS, DACVSMR; Sherry A. Johnson, DVM, MS, PhD, DACVSMR; David D. Frisbie, DVM, PhD, DACVS, DACVSMR; Myra F. Barrett, DVM, MS, DACVR; and Tianjian J. Zhou, PhD

The perceived clinical relevance of radiographic abnormalities among equine practitioners differs widely, making purchase recommendations highly variable. Authors' address: Colorado State University, 300 West Drake Road, Fort Collins, CO 80523; e-mail: angie.esselman@colostate.edu. *Corresponding and presenting author. © 2023 AAEP.

1. Introduction

Radiographs are a common diagnostic tool utilized during survey examinations, yet differences surround the clinical and diagnostic interpretation of radiographic abnormalities. Investigations that document the perceived risk of radiographic abnormalities according to a veterinarian's professional demographic have not been reported.

2. Materials and Methods

A worldwide electronic survey of veterinary professionals was performed. Respondents graded their level of concern from 1 (no concern) to 10 (very concerned) based on radiographs of varying severity of the tarsal, stifle, and navicular pathology for 3 different case scenarios (English sport horse or western performance horse performing at the intended level or prospect horse).

3. Results

In general, as the grade of pathologic change increased for each anatomic location, so did the level of purchase concern, but a wide range of answers were submitted for all grades of pathology. Board-certified practitioners had a higher level of concern over marked radiographic changes of the navicular bone for both western performance and English sport horses as well as prospect horses (mean = 7.23 vs. 6.13; $P < 0.05$). Board-certified respondents had a lower level of concern over marked radiographic changes of the tarsus regardless of the performance status of the horse (mean = 7.12 vs. 8.01; $P < 0.05$). Western performance horse practitioners had a lower level of concern over mild radiographic changes of the tarsus regardless of the performance status of the horse (mean = 3.26 vs. 4.16; $P < 0.05$).

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4. Discussion

These findings highlight the variability in radiographic interpretation that exists among equine veterinarians. Statistically significant differences were found between respondents according to board certification status and discipline.

Acknowledgments

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Conflict of Interest

The authors have no conflicts of interest.

The Anatomy and Biomechanics of the Suspensory Apparatus and Associated Structure of the Distal Forelimb

Mitch Taylor, CJF, AWCF, APF

The suspensory apparatus of the distal limb is an important structure involved in the anatomy and mechanism of support of the equine distal limb during the static and dynamic loading phases of the stride. The suspensory apparatus and associated structures that are critical to the functional mechanism of support of the equine distal limb will be discussed in this paper. Author's address: Kentucky Horseshoeing School, 3612 Lexington Road, Richmond, KY 40475; e-mail: mtaylor@khs.edu. © 2023 AAEP.

1. Introduction

Over the horse's 55-million-year migration from North America to the Steppes of Asia, the ancestor of the modern equine has evolved from a smaller-framed digitigrade browser with multiple toes into a relatively large-framed ungulate with a single toe.[1–3] Documented within the fossil record, several significant developmental musculoskeletal adaptations throughout the appendicular system are observed.[1–4] During the horse's evolution, the long bones of the lower limb elongated, and multiple toes evolved into a single toe increasing the limbs' potential leverage.[5] Other skeletal adaptations including the well-developed mass of the sesamoid bones and complementary fibrocartilage have resulted in an increase of mechanical advantage of the tendinous and ligamentous structures that produce stabilizing and propulsive force by increasing the moment arms of the proximal and distal scuta. The supportive and recoil abilities of the limb consistent with the modern horses' locomotion characteristics are primarily attributed to the increased tendon recoil capabilities from the length of the tendons and the adaptation of limb musculature to ligamentous function (Fig. 1).[6]

The locomotor adaptations evident in the distal limb of the modern horse result in a high degree of dynamic automacity and serve to maximize speed and endurance, enhance athletic potential, and minimize energy expenditure.[7]

The suspensory apparatus has three principal functions:

1. Passive support of the metacarpophalangeal joint primarily and the proximal interphalangeal joint (PIPJ) and the distal interphalangeal joints (DIPJ) secondarily
   a. To resist hyperextension of the metacarpophalangeal joint
   b. To resist hyperflexion of the PIPJ
   c. To resist hyperflexion of the DIPJ

2. Shock dissipation and temporary storage of elastic energy

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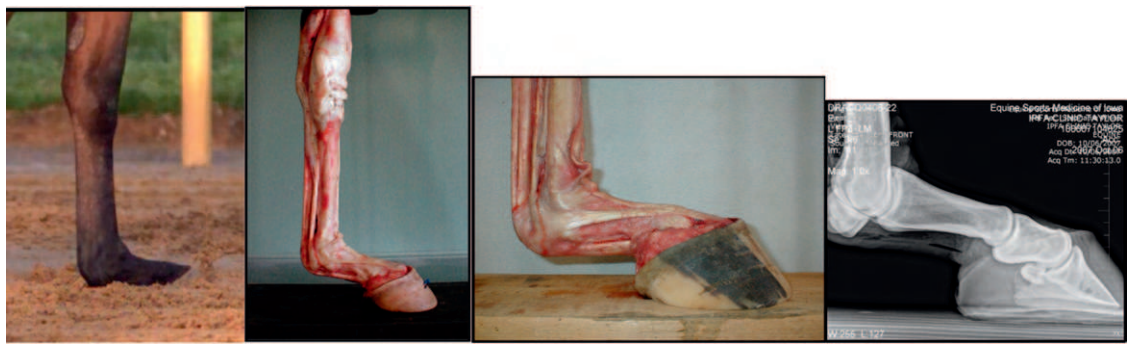


Fig. 1. The progressive images of a loaded front limb from skin to radiograph.

3. Impulsion and return of elastic energy used for flexion of the distal joints during the initial flight phase

The principal and secondary anatomic structures that play a critical role in the support of the distal limb as well as elastic energy that are to be discussed are listed below:

- the body of the suspensory ligament (SL) including the medial and lateral branches
- the medial and lateral extensor branches of the suspensory ligament
- the accessory ligament of the superficial digital flexor tendon (SDFT)
- the accessory ligament of the deep digital flexor tendon (DDFT)
- the straight and oblique sesamoidean ligaments
- the SDFT and DDFT
- the collateral ligaments of the DIPJ
- Bone and fibrocartilaginous structures of the proximal, middle, and distal scuta



Fig. 2. Note the increased size and radius of the medial condyle of MCIII. An osteochondral lesion is present in the distal aspect of the medial condyle.

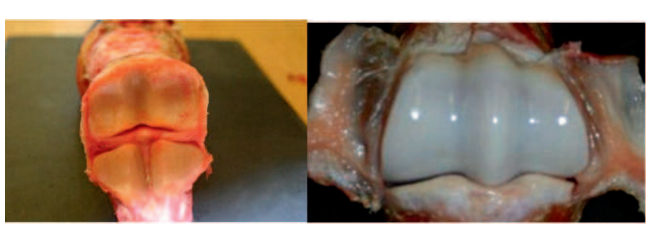


Fig. 3. Example of articulation between MCIII and proximal phalanx.

2. Support Structures of the Distal Limb

Skeletal Adaptations

The specific skeletal adaptations that influence the function of the distal limb work on the principles of utilizing bone shape, bone length, and joint architecture to increase leverage and mechanical advantage to the tendons and ligaments for passive weight bearing. Some examples of skeletal adaptations are changes within the morphological makeup on the cellular level, and some involve an increase in overall size.

The 3rd metacarpal\bone (MCIII) has been shown to change in late gestation from circular to conical, and the dorsal cortex increases density,[8,9] facilitating the ability to run hours after parturition. A mid sagittal ridge separates the distal articular surface of MCIII into medial and lateral condyles, with the medial condyle usually having a greater surface area and corresponding rotational range to accommodate the asymmetrical loading of the bone column (Fig. 2).

The sagittal ridge articulates with a complementary sagittal groove of the proximal phalanx. Together, the



Fig. 4. Note the displacement of the fetlock over the medial heel under load and example of nonlinear axial dorsiflexion.

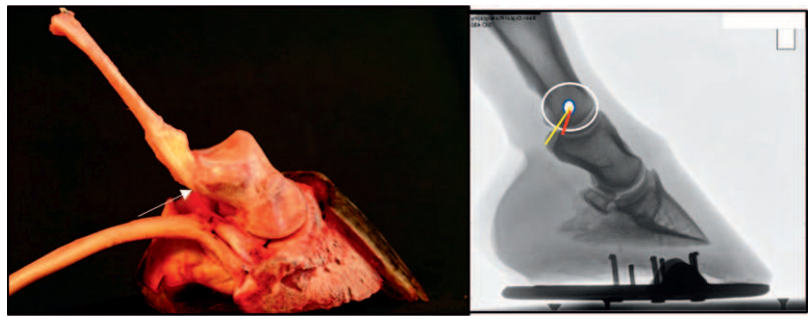


Fig. 5. Note the well-developed flexor tuberosity of the middle phalanx, which serves as the skeletal attachment of the middle scutum. The palmar fibrocartilage adds to the extension of the moment arm of the pastern joint and functions as a smooth and buffered gliding surface for the DDFT. Right image, the yellow line in the radiograph depicts the extension of the moment arm that the flexor tuberosity provides. The red line depicts the theoretical moment arm of the joint without the flexor tuberosity. Left image, the white arrow depicts the exposed view of the flexor tuberosity.

ridge and groove provide lateral stability to the fetlock (Fig. 3).

The asymmetrical architecture of MCIII and the fetlock joint surface commonly result in nonlinear flexion and extension of the fetlock joint in horses with normal lateral set conformation. The degree of nonlinear axial dorsiflexion (fetlock loading over the medial heel) is directly correlated to the degree of lateral deviation of the limb (fetlock valgus and rotational deviations; Fig. 4).[10–12]

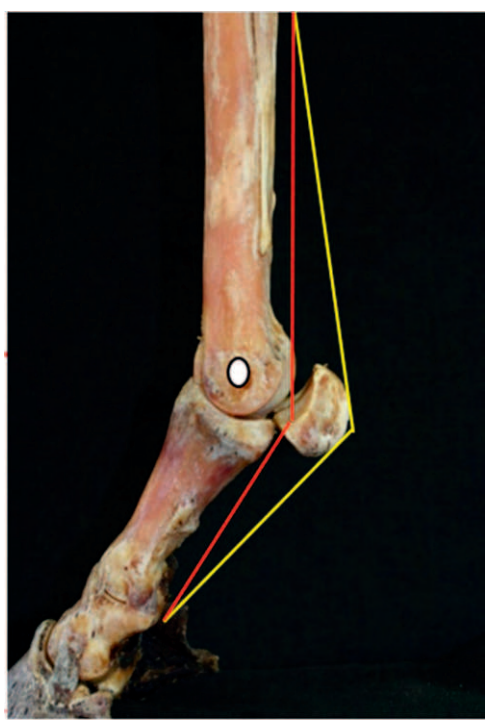


Fig. 6. Note the change in tendon angulation with the addition of the proximal sesamoid bones. The proximal sesamoid bones are the foundation of the proximal scutum and extend the moment arm of the tendon fulcrum giving the tendons mechanical advantage. The white dot represents the center of rotation of the fetlock joint; the yellow and red lines denote the position of the SDFT with and without the proximal sesamoid bones, respectively.

The middle phalanx (P2) has a well-developed flexor tuberosity on its proximopalmar aspect that serves as the attachment of the middle scutum. The middle scutum functions to increase the moment arm of the PIPJ and to anchor several major ligaments that are essential in the stabilization of the suspensory apparatus and distal limb (Fig. 5).[13]

The proximal sesamoid bones are triangular, well-developed bones that together form the foundation of the proximal scutum. The medial and lateral branches of the SL insert onto the abaxial margin of each sesamoid bone. The paired bones are connected to each other axially by a strong intersesamoidean ligament that resists abaxial separation of the bones. The proximal sesamoid bones lie on either side of the sagittal ridge on the palmar aspect of MCIII. The medial and lateral collateral sesamoidean ligaments of the fetlock joint extend from the distal abaxial margin of each sesamoid bone to the medial/lateral collateral fossae of MCIII.

The proximal sesamoid bones with the palmar fibrocartilage provide a pully wheel effect for the flexor tendons by extending the flexor moment arm palmarly, repositioning the fulcrum of the flexor tendons farther away from the center of rotation of the joint.[7] In addition, the relatively large size of the proximal sesamoid bones results in a larger flexor surface area for tendon contact, thereby decreasing the compressive force per unit area of the tendons on the palmar aspect of the proximal sesamoid bones under load. The well-developed proximal scutum changes the direction of applied force by changing the angle of attack of the flexor tendons, which in turn gives mechanical advantage to the tendons, allowing them to maximize tensile load (Fig. 6).[14]

The navicular bone is secured in the podotrochlear apparatus with 3 ligaments. The distal sesamoidean ligament or impar ligament originates on the distal border of the navicular bone and inserts on the solar aspect of P3 (Fig. 7). The medial and lateral branches of the collateral sesamoidean ligament of the navicular bone (also known as the navicular suspensory ligament) originate from the medial and lateral eminences

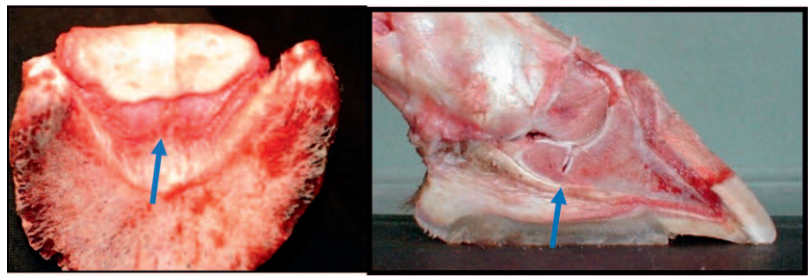


Fig. 7. The left image shows the impar ligament from a solar view; the right image reveals the ligament from a midsagittal view. The arrows depict the impar ligament's location within the hoof capsule.

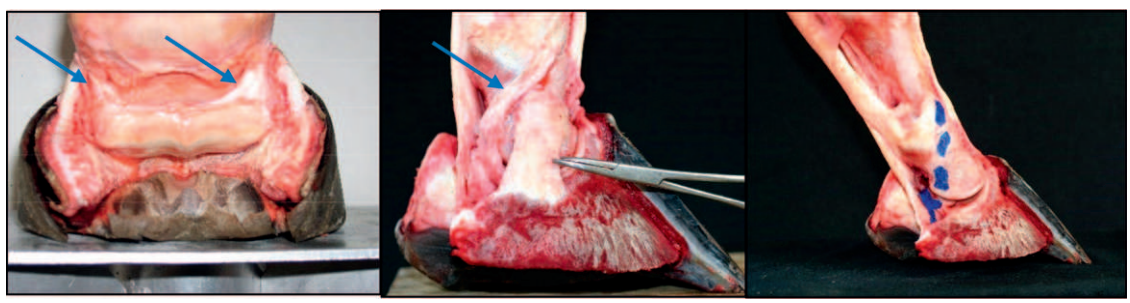


Fig. 8. The collateral sesamoidean ligament of the navicular bone is denoted by a blue arrow and is shown from the palmar and lateral angles from left to right. The blue dotted line indicates the path of the ligament from origin to insertion.

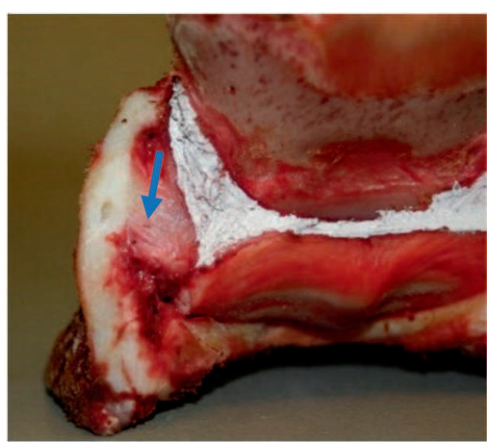


Fig. 9. This is a palmar view of the dissected DIPJ. The chondronavicular ligament (indicated by the blue arrow) originates from the medial/lateral aspect of the navicular bone and inserts on the deep aspect of the corresponding ungular cartilage. The collateral sesamoidean ligament of the navicular bone mentioned in Fig. 8 is highlighted with white paint in this image.



Fig. 10. Note the extension of the moment arm of the distal interphalangeal joint by the presence of the navicular bone. The red lines indicate the hypothetical position of the DDFT without the navicular bone. The white dot is the biomechanical center of rotation of the DIPJ.

of the distal first phalanx, coursing distopalmarly to insert on the abaxial and proximal border of the navicular bone (Fig. 8). The medial and lateral chondronavicular ligaments originate from the medial and lateral aspects of the navicular bone and insert on the ungular cartilages.

The medial and lateral chondronavicular ligaments originate from the medial and lateral aspects of the navicular bone and insert on the ungular cartilages (Fig. 9).

A primary function of the navicular bone is to serve as the distal scutum, which lengthens the flexor moment arm of the DIPJ, giving mechanical advantage to the tensile forces of the DDFT during the loading phases of the stride.[7] The positional advantage of the distal scutum results in a constant angle of insertion for the DDFT on the third phalanx (P3) during the various orientations of P2 during the stance phases of the stride (Fig. 10).[7,10]

Tendons and Ligaments

The proximal sesamoid bones are anchored to P1 and P2 by a group of sesamoidean ligaments. The sesamoidean ligaments work in concert to support and anchor



Fig. 11. Palmar view of the fetlock joint and proximal scutum showing the cruciate and short sesamoidean ligaments. The blue arrow depicts the cruciate ligament, and the yellow arrows depict the short sesamoidean ligaments.

the proximal sesamoid bones in place during the range of motion of the fetlock in the loading phases of the stride. They provide an opposing tensile force to the suspensory ligament, which inserts on the proximal aspect of the sesamoid bones.[15] This maintains the positional advantage of the proximal scutum.

The deepest and least developed in this grouping of sesamoidean ligaments are the short and cruciate sesamoidean ligaments. They have little influence in the suspension of the fetlock joint but serve to stabilize the position of the proximal sesamoid bones (Fig. 11).[16]

The oblique (middle) and straight (superficial) sesamoidean ligaments (OSL and SSL, respectively) are structurally more substantial ligaments than the short and cruciate ligaments.[17] They play a primary role in resisting the pull of the suspensory ligament.

The medial and lateral OSL form a "V" shape. Each ligament originates from the base of the corresponding proximal sesamoid bone and courses along the palmar aspect of P1 in a distoaxial direction. The ligaments converge on palmar P1. Gross observation by dissection and ultrasonographic imaging[15] shows the ligament has much less density than its corresponding straight sesamoidean ligament, which may align with its biomechanical function. The OSL inserts on the entire trigonum of P1 as opposed to having a more focal insertion. The function of the oblique sesamoidean ligaments is to stabilize the joint by limiting extension and stabilizing the collateromotion of the fetlock joint (Fig. 12).[13]

The SSL is the largest of the sesamoidean ligaments.[15] It originates from the distopalmar margin of the medial and lateral proximal sesamoid bones and the fibrocartilage palmar to the proximal sesamoid bones that forms the proximal scutum. The SSL courses distally bridging the PIPJ and inserting axially onto the flexor tuberosity and palmar fibrocartilage of proximal P2, providing stabilization of the pastern joint (Fig. 13).

The functions of the SSL are twofold. It provides an opposing force on the proximal sesamoid bones that resists the force of the suspensory ligament resulting in positional stabilization of the proximal scutum throughout the loading phases of the stride.[17] The force exerted on P2 by the SSL stabilizes the PIPJ by resisting hyperextension during the loading phases of the stride.[7]

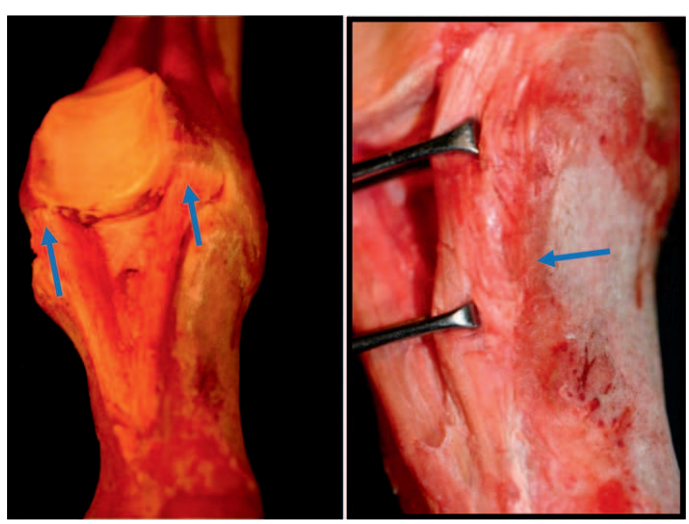


Fig. 12. Palmar oblique views of P1. In the picture on the left, the blue arrows depict the origination of the oblique sesmoidean ligaments from the distal aspect of the proximal sesamoid bones. In the picture on the right, the blue arrow depicts the attachment of the entire length of the oblique sesmoidean ligament on the trigonum of P1 instead of a more focal insertion point.

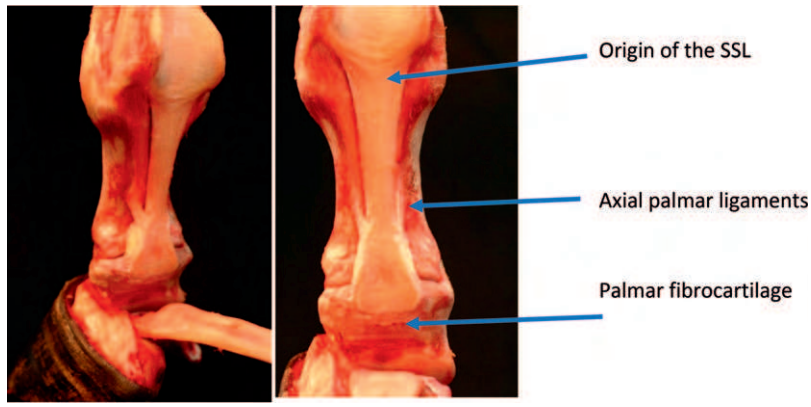


Fig. 13. Palmar view of the PIPJ showing the origin of the straight sesamoidean ligament from the proximal sesamoid bones and the proximal scutum, crossing over the PIPJ and inserting onto the middle scutum and proximal P2. Note the pair of axial palmar ligaments on either side of the SSL that insert onto the palmar fibrocartilage of the middle scutum.

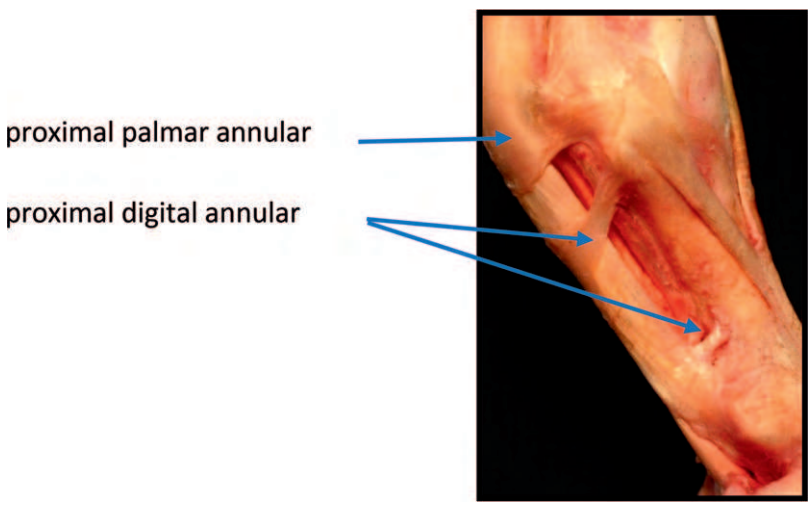


Fig. 14. Lateral view of the pastern showing the proximal palmar annular and the proximal digital annular ligaments.

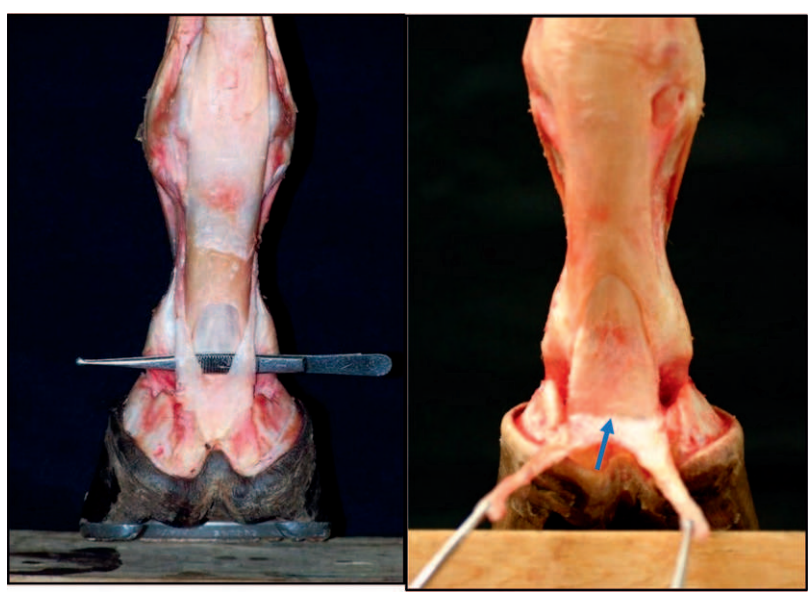


Fig. 15. The picture on the left shows the medial and lateral branches of the distal digital annular ligament exposed. The picture on the right depicts the reflected distal digital annular ligament branches. The blue arrow depicts the point of insertion into the DDFT.

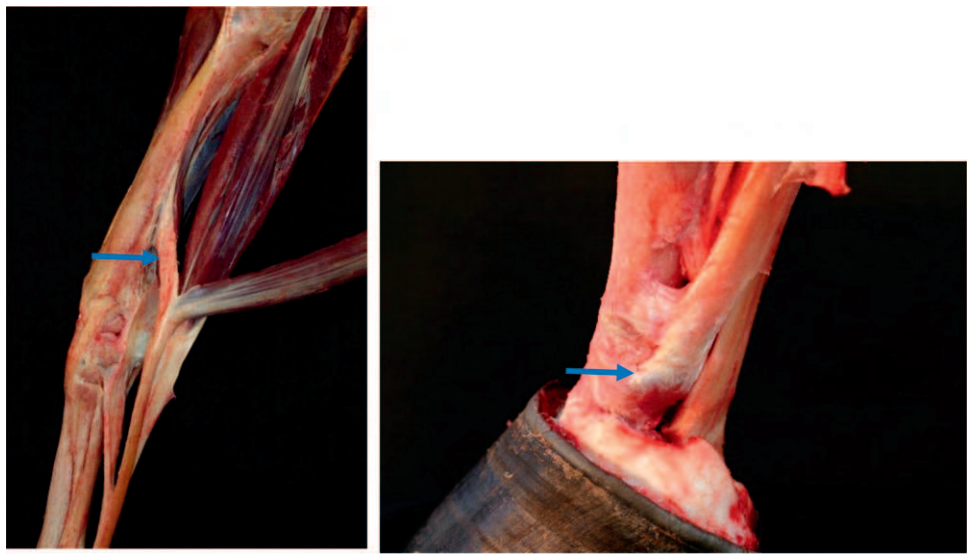


Fig. 16. On the left picture, note the superficial flexor muscle reflected to the right exposing the accessory ligament of the SDFT (blue arrow) that originates from the distal radius and converges with the superficial digital flexor tendon at the myotendinous junction. In the image on the right, the blue arrow depicts the insertion of the lateral branch of the SDFT onto the flexor tuberosity of P2.

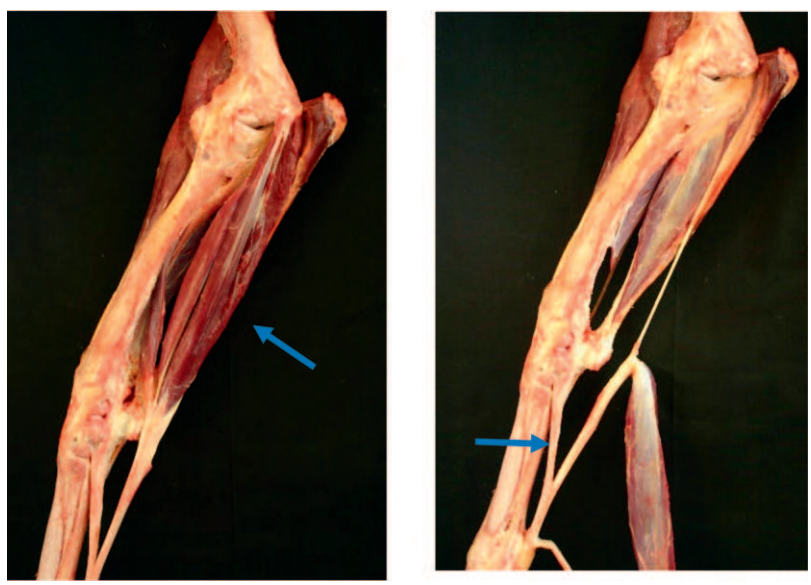


Fig. 17. The image on the left depicts the medial view of the antebrachium; the blue arrow indicates the 3 heads of the deep digital flexor muscle intact. The blue arrow on the right image indicates the accessory ligament of the DDFT; the flexor muscle grouping is reflected down.

Two flexor tendons (DDFT and SDFT) provide support and aid in the tensile resistance to dorsiflexion of the fetlock joint and to control the flexion of the digit during the early swing phase. Both flexor tendons have associated accessory ligaments that aid the tendon in resisting tensile forces by significantly decreasing the need for the parent muscle to accept tensile load.[18]

The flexor tendons provide indirect support for the suspension requirements of the loaded digit by supporting the fetlock through a hammock effect, generating horizontal and vertical tensile force vectors on the tendons, causing a multiplying effect used to support load.[19] As weight increases, the tensile modulus of tendons increases, directing forces dorsally onto the proximal and distal scutum, increasing the compressive force at those points. The flexor tendons are secured from mediolateral displacement of the sagittal plane by a series of annular ligaments.[17]

The palmar annular ligament extends between the abaxial margins of the medial and lateral proximal sesamoid bones and restricts lateral and medial displacement of the tendons in the fetlock region. The proximal digital annular ligament has 4 points of attachment, medially and laterally on the proximal and distal tubercles of P1. It holds the SDFT (and consequently the DDFT) to the palmar surface of the P1,

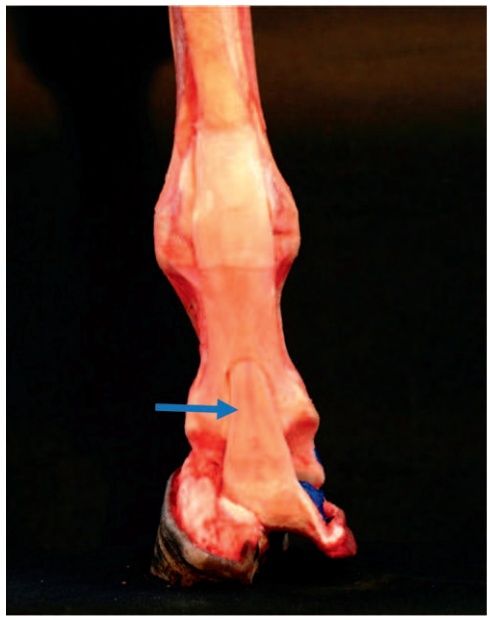


Fig. 18. Palmar view of the distal limb showing the branching of the SDFT and the continuation of the DDFT passing over the middle scutum (blue arrow) and continuing distally to insert on the palmar surface of P3. The palmar annular ligament has been dissected away from this specimen.

preventing any significant displacement of the tendons from the sagittal plane (Fig. 14).

The distal digital annular ligament originates from the medial and lateral aspect of distal P1 and inserts on the palmar aspect of P3 along with the deep digital flexor tendon. (Fig. 15).

The SDFT is considered an energy-storing tendon.[20,21] It originates from the superficial flexor muscle at the caudal aspect of the antebrachium and courses distally parallel with the radius. The tendon joins its accessory ligament just proximal to the carpus and continues through the carpal canal formed by the palmar aspect of the carpal bones and the accessory carpal bone. The tendon continues distally, widening and forming the manica flexoria that wraps around the DDFT, compartmentalizing both flexor tendons as it passes over the fibrocartilage flexor groove of the proximal scutum. Continuing distally, the tendon bifurcates at the level of P1, and medial and lateral branches insert onto the flexor tuberosity and palmar fibrocartilage of the palmar aspect of P2 (Fig. 16).

Due to the palmar location, the SDFT is farther from the center of rotation of the fetlock joint than the DDFT. Biomechanically, this results in greater tensile force applied to the SDFT during the loading phases of the stride when compared to the DDFT.[7,22] Both the SDFT and the SL must resist greater tensile loads in direct correlation to the degree of fetlock extension. When the fetlock is at maximal extension, the SDFT and SL are at maximal tensile load. There is evidence to suggest the SDFT has morphological differences that accommodate greater tensile loads when compared to other distal tendons,[23] and it has been shown that the tendon can stretch and recoil up to 16%[24] with each load cycle as compared to the common digital extensor tendon.

The DDFT originates from multiple muscle heads in the caudal antebrachium deep to the SDFT. It courses distally through the carpal canal and joins with its accessory ligament distal to the carpus (Fig. 17).

The tendon continues distally and is wrapped within the manica flexoria as the tendon passes over the palmar surface of the proximal scutum, where both flexor tendons are secured from sagittal displacement by the palmar annular ligament and lubricated by the digital flexor tendon sheath.

At distal P1, the SDFT branches to its insertion, leaving the DDFT in the most superficial orientation (Fig. 18) and exposing the tendon to potential blunt force trauma from the hind foot at this area.

At the level of the PIPJ, the DDFT passes over the middle scutum. Tissue extends from the dorsal surface of the DDFT to form a vinculum (referred to informally as the "T-ligament").[25] The T-ligament inserts on the palmar aspect of P2 at the proximal border of the DIPJ (Fig. 19).

The DDFT continues over the flexor cortex of the navicular bone and inserts on the semilunar crest of the distal phalanx. The navicular bursa separates the

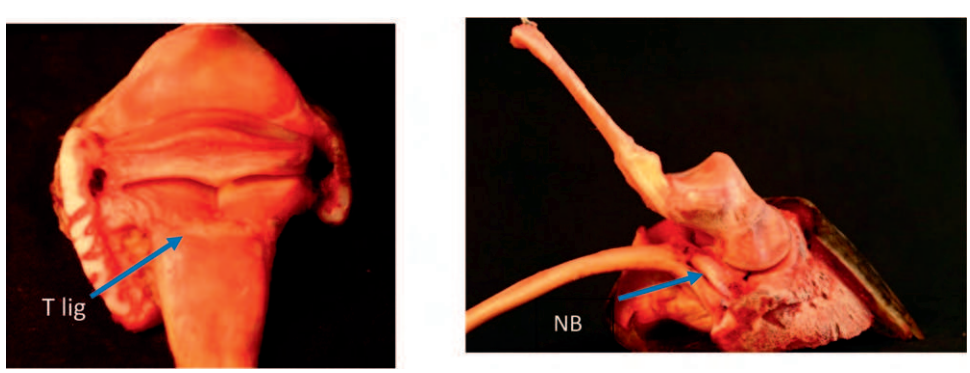


Fig. 19. The picture on the left shows a dorsal view of P3 and the navicular bone, one ungular cartilage, the DDFT, and the remnants of the tissue commonly referred to as the "T ligament" (T lig). The picture on the right is a lateral view and the blue arrow shows the DDFT passing over the flexor surface of the navicular bone with the navicular bursa (NB) between the tendon and the bone.



Fig. 20. The image on the left demonstrates the loaded limb at midstance where the SDFT and SL are under maximum tension. Note the fetlock joint is at maximum extension and the DIPJ is at maximum flexion. The image on the right shows the moment prior to heel off where the DIPJ is at maximum extension and the DDFT is under maximum tension.

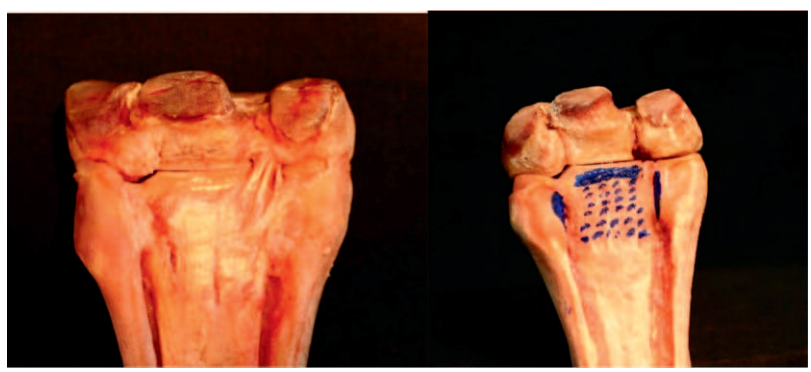


Fig. 21. The origination of the suspensory ligament. The image on the left shows the intact suspensory ligament. The image on the right shows the origin of the ligament after dissection (highlighted by blue dots).

dorsal surface of the DDFT and the flexor surface of the navicular bone.

The DDFT functions to flex the DIPJ in the early swing phase and to indirectly support the suspension of the fetlock joint during the loading phases of the stride. Tensile requirements and forces of the DDFT are dependent on and influenced by the degree of flexion and extension of the fetlock and DIPJ. Unlike the SDFT and SL, the DDFT is not under maximum tension at midstance because of the influence of the DIPJ. At midstance, the fetlock joint is at maximum extension and the DIPJ is at maximum flexion. DIPJ flexion results in a reduction of tensile force on the DDFT by decreasing the tendon span distance.

The DDFT is under maximum tension when the DIPJ is at maximum extension, which is just prior to heel off (Fig. 20).

The remaining soft-tissue structure of the suspensory apparatus is the SL. The SL originates at the proximal palmar aspect of the metacarpal region and palmar portions of the carpal fascia and bones. It courses distally along the palmar aspect of MCIII (Fig. 21). The origin of the SL is innervated by the deep branch of the lateral palmar nerve.[26] The proximal portion contains skeletal muscle and fat, as well as ligament fibers. The amount and distribution of each varies with age, breed, and training condition.[27] Studies have shown that 95% of the muscle fibers found in the SL are Type I slow-twitch fibers with normal fiber diameter and cross-sectional area, which infers that the muscle fibers are undergoing normal recruitment activity.[28] In addition, the fiber length is short and has highly pinnated angles, which suggests an isometric function to resist lengthening rather than isotonic contractile function.[28]

The SL bifurcates in the middle to distal portion of MCIII into medial and lateral branches. The branches



Fig. 22. An oblique view of the proximal scutum; the blue arrow depicts the insertion point of one of the branches of the suspensory ligament on the dissected proximal sesamoid bone. The fibrocartilage has been left intact on the opposing proximal sesamoid bone.



Fig. 23. A lateral view of the fetlock showing the lateral extensor branch of the suspensory ligament (blue arrow).

insert on the abaxial margin of the medial and lateral proximal sesamoid bones (Fig. 22).

There are two smaller medial and lateral extensor branches of the SL that continue from suspensory branches, pass over the axial surface of the proximal sesamoid bones, and insert onto the aponeurosis of the common digital extensor tendon. The extensor branches of the SL provide additional suspension capabilities to its parent ligament. They are subject to an increase in tensile load when the fetlock joint extends. Digits with a broken forward hoof-pastern axis will commonly have prominent extensor branches indicating an increased load on the extensor branches resulting from flexion of the DIPJ with or without an increase in fetlock extension (Fig. 23).

The SL is the underpinning structure of the suspensory apparatus. Its functions are to support the suspension of the fetlock by preventing hyperextension of the fetlock joint and to store and return elastic energy at the appropriate time in the late stance phase of the stride.



Fig. 24. Lateral view of the DIPJ. The hemostats identify the lateral collateral ligament of the DIPJ.

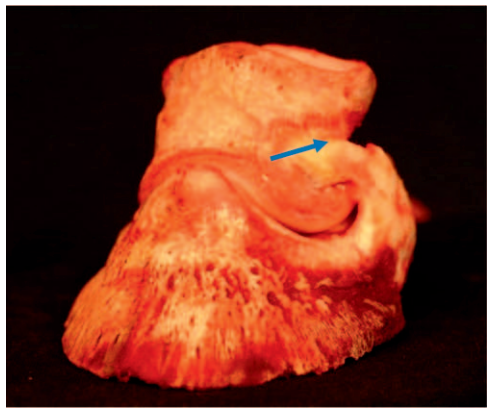


Fig. 25. Oblique view of the foot showing the chondrocoronal ligament (blue arrow).

The medial and lateral collateral ligaments of the DIPJ (Fig. 24) provide stability to the joint by resisting hyperflexion of the joint under full load in addition to resisting collateromotion.

The collateral ligaments of the DIPJ originate from depressions on the distal medial and lateral aspects of P2 and insert in the collateral fossae on the dorsomedial and dorsolateral aspects of P3 close to the joint margins and to the dorsal aspect of the medial and lateral ungular cartilages.[29] These ligaments control the range of flexion and extension of the DIPJ and have been shown to restrict collateromotion of the DIPJ arising from the medial migration of the fetlock during the loading phases due to rotational conformation issues involving the distal MCIII.[30] The flexion and extension range of motion of the DIPJ is dependent on the tensile limitations of the collateral ligaments, health and vitality of the digital cushion, the vertical depth and angulation of the bars in the caudal hoof, and the chondrocoronal ligaments.

The medial and lateral chondrocoronal ligaments are paired ligaments that originate from the medial and lateral eminences of P2 slightly dorsoproximal to and immediately adjacent to the origination of the collateral ligaments of the DIPJ. They insert onto their respective medial and lateral ungular cartilages at a similar level as the insertion of the common extensor tendon on the extensor process of P3.[31,32] The chondrocoronal ligaments share tensile load with the collateral ligaments of the DIPJ and redistribute some of the forces to the ungular cartilages at the extreme ranges of flexion, extension, and collateromotion of the DIPJ (Fig. 25).[13]

The suspensory apparatus and supporting structures of the distal limb are the result of evolutionary anatomical adaptations that allow the limb to efficiently use, store, and release energy developed by cursorial locomotion for smooth and powerful gaiting characteristics. The overlapping ligamentous architecture accommodates the nonlinear joint function and can fully stabilize torsional strain and collateromotion under extreme loading conditions with a marked degree of automacity by minimizing the need for muscular influence.

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.

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Why and How to Design an Efficient Damage Assessment Protocol for a Variety of Foot Issues

Ric Redden, DVM

Damage assessment is an invaluable protocol that can aid diagnosis, pathological shoeing, surgery, and treatment decisions, thereby enhancing success with foot issues. Author's address: PO Box 2507, Versailles, KY 40383; e-mail: rfreddendvm@gmail.com. © 2023 AAEP.

1. Introduction

Career and life-threatening foot issues undoubtedly are the most problematic challenges for veterinarians and farriers and subsequently often have an equally troubling success rate. There are numerous preparatory steps for the farrier and veterinarian from the request for service to outcome, and the efficiency of the mission is relative to the expertise and team experience. Treatment recommendations for specific trim and shoeing protocols for pathological issues should be based on an accurate diagnosis and an efficient damage assessment protocol. This offers the vet/farrier team insight into lesion intensity, which is paramount for setting treatment goals and electing the most appropriate treatment strategy. The past 20 years has seen tremendous growth and advancements in equine diagnostic imaging, with emphasis on a proper and correct diagnosis as an absolute requirement for an appropriate choice of treatment.[1] Not to dilute the value of localizing the seat of injury or disease and forming an accurate diagnosis, it is of equal importance to have working knowledge of the intensity and extent of the damage and how these fit into the overall scheme of the plan. The damage scale varies relative to lesion intensity and other factors that demand respect; therefore, the treatment must be tailored to meet specific criteria with the foot presented.

An efficient damage assessment protocol is a relatively new concept that has emerged out of necessity to better understand the gravity of the lesion intensity and to enhance success. This leads to a better understanding of the root cause, opening the door for more specific treatment goals and improved medical and mechanical treatment options. This new mindset and perspective can enhance the thought process that leads to improved clinical decisions.[2]

The advent of the clinical venogram has become a valuable damage indicator as it sets the stage for better understanding the intensity of vascular alterations to vital strategic components and germinal horn growth centers. Obtaining this information can run simultaneously with the search for diagnostic discovery clues, with both playing intricate roles in finalizing the conclusive evidence for a diagnosis and treatment goals.

NOTES

This paper deals specifically with the basic damage assessment protocol as an aid to improving success with commonly occurring foot issues.

2. Discovery Exercise

There are many steps from the client's request to the outcome, and numerous obstacles often defeat the best of efforts. The discovery exercise is proportionally as complex as the level of working knowledge and experience of the clinician. Understanding the relevance of the history and impact of key words sets the stage for the exam and lays the groundwork for damage assessment. Good working knowledge of the foot, an acceptable level of farrier skills, diagnostic capabilities, and understanding of the anatomy and function of the support and suspension components complement the overall evaluation. These are learned arts and continuous works in progress requiring extensive on-going, hands-on experience and an unquenchable thirst for knowledge and success. However, there is a starting point and an inevitable learning curve that applies to everyone. Due to the historical lack of formal podiatry education and training of the team players, preparation for success treating foot issues is often a daunting task for even the most experienced veterinarian and accomplished farrier.

The proficiency of searching information is determined by the intensity of the data collection process and the overall magnitude of purpose.

Tremendous progress has been made in the fledgling field of equine podiatry over the past 40 years, offering an array of options to reveal information not available in the past, especially the specific primary beam/subject/detector orientation for podiatry issues and the advent of the clinical venogram.[3–6] The enhanced quality and volume of imperative information has helped better define lesion intensity.

This information, along with assessment of the overall characteristics of the start model, can be a game changer, enhancing the efforts of the vet/farrier team and ultimately increasing success.

3. History

Current history often holds key words that help direct the thought process as the physical and clinical exams proceed. The present complaint as it relates to recent or previous issues can allude to the chronicity of observations and clinical signs that may be directly linked to cumulative damage. Chronic crushed heels, for example, will be plagued with heel bruising, quarter cracks, and numerous issues involving excessively traumatized components. Primary syndromes that often proceed acute laminitis such as dystocia, metritis, colic, Potomac fever, pneumonia, Salmonella, grain overload, and ill effects of obesity allude to a remarkable insult level that normally signals an intense level of vascular and subsequently lamellar damage.

4. Physical Exam

This stage can help locate the general area of lameness and detect unique asymmetrical features that can offer valuable clues. In the past, the lameness scale has been considered a reliable damage indicator. However, caution is due as it can also be quite deceptive. The pain response does not always parallel the degree of damage to sensitive components. Complacency often sets in with an immediate favorable pain response derailing the need for ongoing soft tissue and vascular assessment. This is a common error that can have serious consequences.

5. Radiographic Exam

Podiatry-focused radiographs require a specific, low primary beam/subject/detector orientation (0.5–0.75 inches, 12–18 mm over the positioning block) to reveal the most accurate assessment of pertinent soft tissue parameters. Sole depth, palmar angle (PA), digital breakover, horn laminae, coronary band/extensor process, and bone angle, routinely observed and measured, can be valuable diagnostic and damage indicators.[7]

The traditional higher beam invariably superimposes the shoe over the ground surface of the hoof capsule, remarkably diminishing the true depth of the sole. This can lead to misinterpretation and a wrongful diagnosis. There is only one chance to take the first scout images; all others are comparative views, and the closer to onset of clinical signs, the more valuable the images become. The initial images become valuable reference points that can define information relative to current or previous radiographic alterations and cumulative damage.

Case Example High/Low Syndrome (Crushed Heel Versus Club)

The high/low syndrome is one of the most problematic issues that threatens careers and is prevalent in most breeds. High and low are relative terms, compared to what? It is important to recognize the level of stark differences of the unique characteristics between the mismatched pair (front and rear) as pathological issues that will produce likewise different results. The timing of the exam relative to the last trim or shoeing should be noted as external and internal parameters are routinely altered with farrier services and can be a cause for misinterpretation. The low-profile foot has a strong tendency to have a crushed heel and digital cushion, negative PA, and growth rings wider at the toe than heel. The lateral growth rings are most often wider than medial rings, indicating a remarkable discrepancy in the rate of growth that results in a steadily increasing medial list of the palmar rim between resets. The large healthy frog often sags through the heels of the shoe distal to the folded heel tubules. An upright pastern (broken back digital alignment) and a low bone angle of 45° or less are also common findings (Figs. 1 and 2).

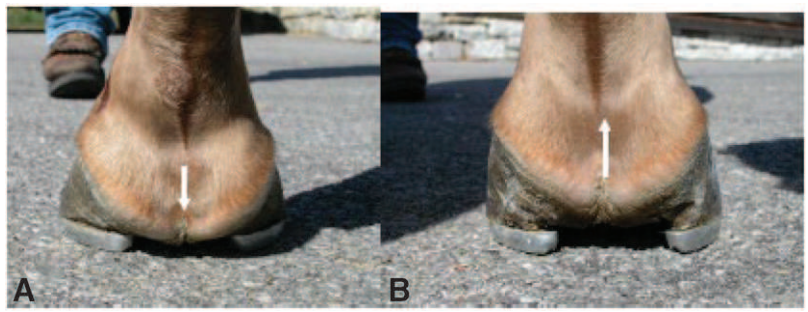


Fig. 1. A typical pair of mismatched feet on a racehorse. A, Note the sagging frog and buttress and crushed heel on the left front foot. B, Note the increased lift or suspension on the right front club foot.

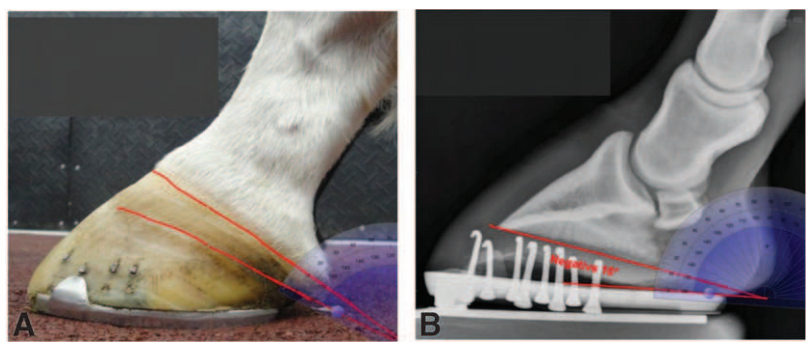


Fig. 2. The negative PA can be detected by the growth pattern. A, Note the crushed heel and steep angle of the coronary band. B, Note the negative 10° PA is very similar to the horn growth pattern.

The more upright foot will have a strong heel with ground surface tubules located at the base of the frog, positive PA, healthy digital cushion, growth rings wider at the heel than toe, and most often a 50° to occasionally 60° bone angle. The more upright foot will have a smaller frog suspended higher in the foot than the low foot and often be void of ground contact. The mechanical suspension function of the deep digital flexor tendon (DDFT) muscle unit is apparently different between these two feet, resulting in varying levels of disparity. Further observation of the internal structures reveals the intensity of the mismatched alterations (Fig. 3). The remarkable discrepancy of DDFT function that is revealed in the anatomical model can also be observed in the vascular pattern. This should be considered when assessing the damage to specific components and planning the mechanical strategy to aid healing of injured or diseased tissue.

The baseline images offer the veterinarian and farrier a reference and guide relative to the information being sought complementing their respective task (Fig. 4). The farrier is often eager to know the particulars of what they are working with (sole depth, PA, digital breakover, palmar rim balance as it relates to bone asymmetry). Asymmetrical joint space and articulation listing are also important points of interest for the team when planning the strategy for a specific problematic issue.

Routinely measuring soft tissue parameters is the key to developing working knowledge of the range of

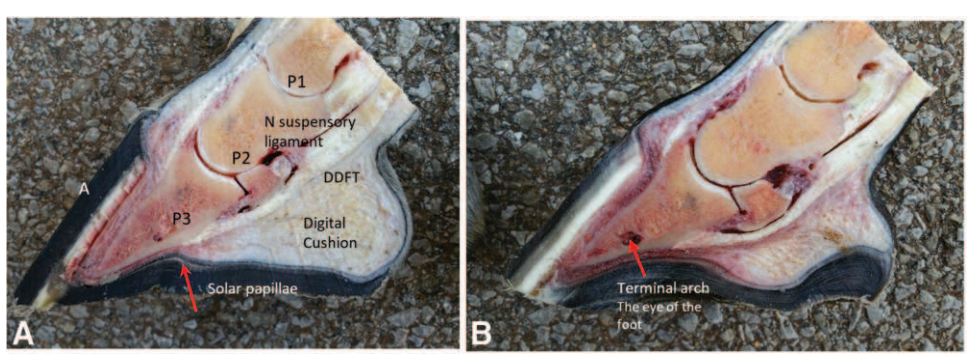


Fig. 3. A and B, Note the discrepancies of the anatomical components in this high/low syndrome horse. B, The DDFT reveals evidence of less tension than A, which is more linear, and the size of the digital cushion indicates more DDFT suspension and less load on the cushion than the low foot.

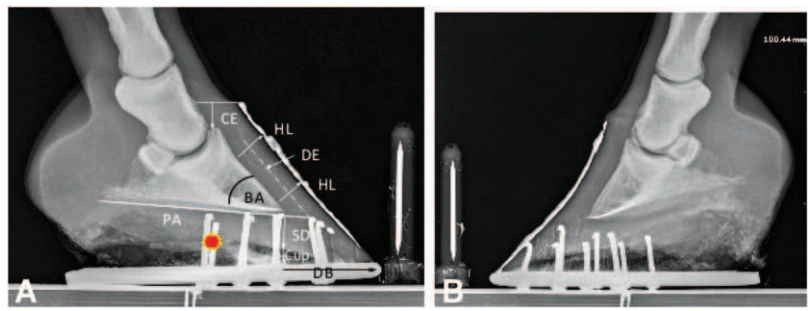


Fig. 4. A, Soft tissue parameters of interest. CE, coronary band/extensor process; HL, horn/laminae; DE, dermal/epidermal; PA, palmar angle; SD, sole depth; BA, bone angle; DB, digital breakover. Note radiopaque paste defines the wall margin, growth rings, and coronary crest. Low beam superimposes the branches of the shoe and offers true sole depth and cup of foot. B, The left front foot of this mismatched pair. Note the stark difference in hoof shape, soft tissue parameters, and coffin bone characteristics.

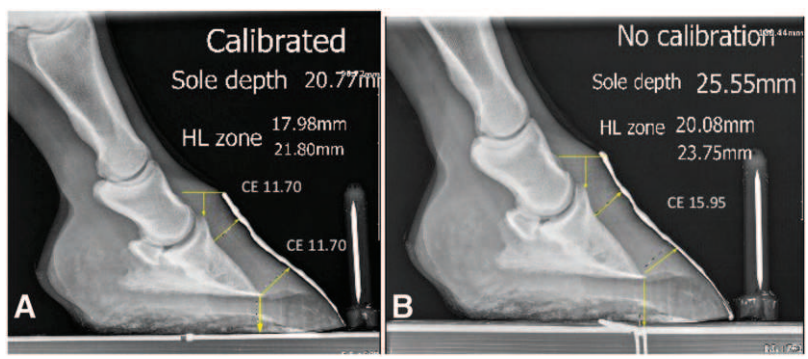


Fig. 5. Sagittal plane measurements should be calibrated for magnification as the mouse reads and measures the image at the detector level. Note the range of error between the calibrated (A) and noncalibrated (B) measurements. HL, horn laminae; CE, coronary band/extensor process.

norms that varies with age, use, breed, and farrier influence. Digital measurements are made at the detector level; therefore, they do not adequately represent the sought-after information due to remarkable magnification. A calibration aid placed along the sagittal plane for lateral views and the transverse plane for the DP views offer a means to calibrate image magnification, enhancing accuracy (Fig. 5). These baseline values are not written in stone and should not be considered as absolute values. They vary relative to the proficiency of the operator and the human error factor. However, a methodical, disciplined protocol can minimize the error factor and provide consistent information aiding diagnosis, the intensity of altered parameters, and invaluable reference points for the farrier who is ultimately responsible for the mechanical application that alters internal as well as external parameters. Execution of specific trim and shoe recommendations void of radiographic control is fraught with inherent errors that can lead to counterproductive efforts.

6. Venogram Exam

The venogram can provide interesting and valuable data when accessing the vascular alterations that occur with a variety of commonly occurring foot issues. This in turn helps explain the root cause for disparity in growth patterns and offers a new perspective concerning more specific treatment protocols designed to enhance germinal center function. This offers the vet/farrier team tremendous advantage over the traditional concept of trimming and shoeing for balance without consideration of the root cause of hoof distortion and imbalance.

The venogram can be performed in the standing, sedated horse using local anesthetic proximal to the injection site. The goal is to produce a diagnostic set of specific images that reveal the vascular tree and the influence that load has on the patency of healthy as well as pathologically compromised vessels (Figs. 6 and 7). The procedure is technique sensitive and easily performed once getting through the learning curve. The tourniquet is applied over the fetlock. The traditional midcannon tourniquet recommended for regional perfusion does not adequately occlude the patency of the vessels and frequently results in nondiagnostic images due to tourniquet leak. Tourniquet leak and perivascular injection are two common technique negatives that can result in under perfused and nondiagnostic images. Caution is due because faulty technique can lead to devastating misinterpretation that carries over to treatment recommendations and potentially euthanasia. Twenty milliliters of contrast media is adequate for feet up to 4.5 to 5

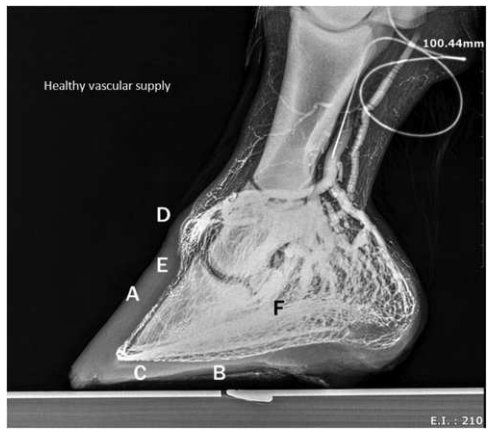


Fig. 6. Vascular areas of concern. A, sublamallar vessels; B, solar corium; C, solar papillae; D, coronary crest; E, tubular papillae; F, terminal arch.

inches in width. Larger feet may require up to 30 mL. Contrast is injected into the palmar vein (either lateral or medial), and all views should be taken as quickly as possible as the contrast pattern does not remain crisp and loses diagnostic quality within minutes. Technique and interpretation skills should be learned and honed on healthy feet to assure good working knowledge of the healthy range of normal. The pitfalls of poor technique and interpretation should be well-known by the clinician.

Recommended Views

Optimum information requires loaded and totally unloaded lateral (comparative view of the standing lateral, loaded DP, unloaded PD [comparative view of the standing DP]), late loaded lateral, and DP. A fetlock exposure as the last view confirms tourniquet efficiency. The influence of load, no load, and late load views offers tremendous information regarding the ability for compromised laminae and solar corium vessels to be reperfused when the load and suspension function of the DDFT is remarkably altered.

7. White Line Disease Versus Laminitis

White line disease and laminitis have much in common but have stark differences as well. The history will have key words that can help direct the focus toward a diagnosis. The lameness scale score is normally quite low even in advanced cases of WLD and is not a reliable damage indicator. It is not uncommon for racehorses to continue training and racing with excessive horn damage and capsule rotation.

Physical Exam

Information alluding to a diagnosis as well as the damage intensity starts with the visual hands-on exam. Caution is due as there are several clinical similarities between WLD and laminitis. The sole surface may be dropped, center toe, medial or lateral, and painful to hoof testers. This may allude to laminitis when the sag is center line. The sole will migrate over the terminal cornified laminae, obscuring the wall at the horn defect (Fig. 8). This occurs with WLD but is strikingly different from laminitis.

Radiographic Exam

Radiographic information is essential for diagnosis, damage assessment, treatment goals, and a blueprint guide for farriers for both syndromes. There is a direct correlation between the level of soft tissue alterations and the intensity of the damage to the horn capsule with WLD and laminae, solar corium, and palmar rim damage with laminitis.

Chronic WLD and chronic laminitis often have excessive capsule rotation, a 10° to 20° PA, and thin soles. Despite appearing very similar on the lateral radiograph, the root cause is quite different. WLD involves the inner, nonpigmented horn (therefore the origin of the descriptive term). The air density lesion has irregular borders, often superimposed over the bone, extends to the ground surface, and is often filled with ground debris (Fig. 9).

Laminitis is confined to the dermal and epidermal laminae, initially leaving the horn wall unchanged. Capsule rotation occurs between the dermal/epidermal zone and dorsal face of the third phalanx (P3). The gas line normally develops in 4 to 6 weeks from onset. The lucent lesion that forms along the line of separation has leaner margins and does not communicate with the ground surface even when penetration of P3 has occurred. The horn wall and laminae are strategic components of the digit suspension that function as antagonists to

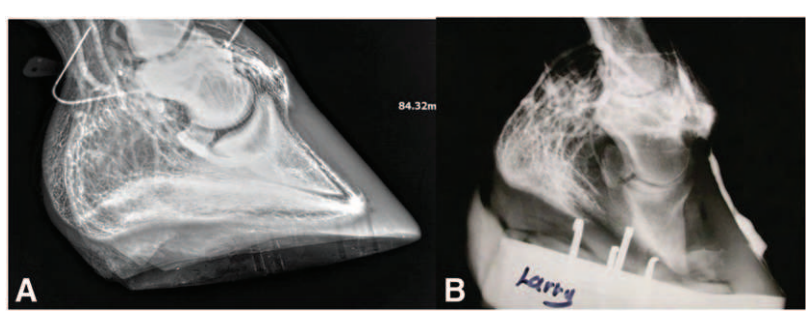


Fig. 7. A, Note the healthy foot on the left has extensive vascular supply compared to B, the catastrophic vascular shut down on the right. Note the terminal arch is not present; the distinct coronary cap and stark loss of contrast with exception to the heel is consistent with the highest damage level. The lesion intensity has destroyed most of the vascular tree.

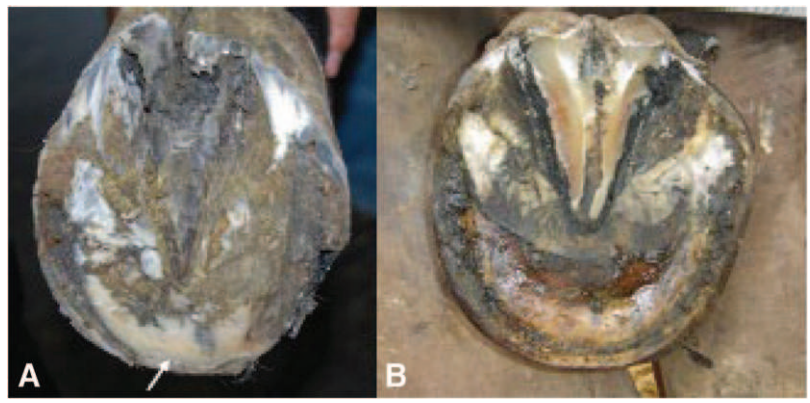


Fig. 8. A, Foot that has WLD. Note the sole has migrated over the wall defect (white arrow). B, This foot has penetrated coffin bone due to laminitis. Note the wall and sole junction is intact.



Fig. 9. Typical WLD. Note the large irregular shaped defect packed with ground debris, capsule rotation, and thin sole. This Standardbred racehorse was in active training and racing.

the DDFT. Capsule rotation occurs when dysfunctional horn or laminae are challenged by load through the digits, directed via the tension of the DDFT.

Venogram data can be a valuable damage indicator and aid a definitive diagnosis when WLD and or chronic laminitis is in question.

8. Case Example WLD

History and physical exams can strongly support WLD (Figs. 10 and 11). Radiographs confirm WLD but do not exclude laminitis. Venogram information confirms the diagnosis of WLD and can exclude laminitis as a primary syndrome. Chronic WLD can have associated focal laminitis, and chronic laminitis can have bacteria and fungi invade the lamellar scar, resulting in WLD (Fig. 12). The prognosis is strikingly different despite the similarities. Venograms can help distinguish stark differences in the vascular pattern of the respective syndromes, aiding damage

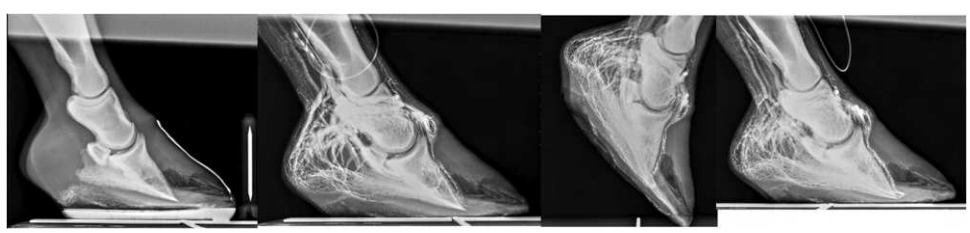


Fig. 10. Typical WLD encountered in racehorses often in full training. This horse presented 95% sound. Note the vascular pattern in the sequence of loaded, unloaded, and late images. The history and lateral radiograph are compatible with a diagnosis of WLD. They are similar to chronic laminitis yet remarkably different. The venogram confirms that this is horn disease and not associated with significant laminae inflammation.



Fig. 11. The same horse as Fig. 10, 8 months posttreatment. Note the defect is no longer present, the sublamellar and circumflex vessels are remarkably improved, and the medial toe quarter continues to have compromised supply routes (white arrow). Note the horn scar continues to grow out.



Fig. 12. This foot is recovering from extensive chronic rotation and a large septic rupture at the coronary band. The lamellar scar became an ideal harbor for the invading WLD organisms.

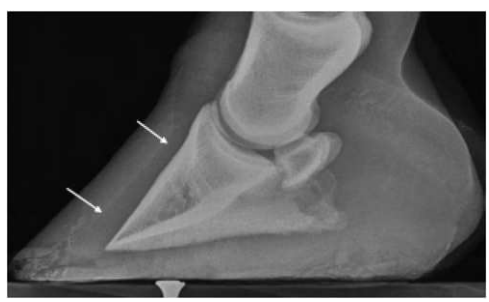


Fig. 13. This acute case has remarkable laminae swelling. Note the location of the opaque dermal/epidermal border (white arrows).

assessment, treatment goals, and follow-up comparative exams to monitor tissue response.

9. Acute Laminitis

History

History holds key words that can allude to diagnosis, give direction to the exam, and add to the severity of onset considering several predisposing primary syndromes. Colitis, colic, dystocia, metritis, Salmonella, Potomac fever, pneumonia, pleuritis, and others can be associated with high-level laminae insult.

Physical Exam

The lameness scale score varies from sound to 5/5 Obel grade bilateral, unilateral, rear feet only, or a combination. A pain scale is not a reliable damage indicator due to the stark differences in pain tolerance, benefits of mass of foot, or lack of and loss of innervation to sensitive structures that can vary throughout the sequence of the syndrome. Hoof testers can be deceptive relative to foot mass and severity of onset. Diagnostic blocks can be counterproductive, causing further unwarranted structural damage to the weakened lamellar anchor.

Radiographic Exam

Historically, capsule rotation has been considered conclusive evidence confirming a diagnosis and indicating damage. However, this can be misleading as the horn wall and laminae are both within the angle of rotation, and extensive laminae swelling and damage can occur in absence of capsule rotation. Therefore, rotation is not pathognomonic for laminitis. Astute attention should be focused on the laminae zone instead of capsule rotation.

Baseline, low-beam, calibrated radiographic images are indicated at the first signs of lameness to establish a reference point necessary for comparative measurements that can help confirm efficiency of the emergency mechanical and medical protocol and treatment of choice.[8] Alterations of the laminae zone are the first radiographic evidence confirming a diagnosis of acute laminitis. Radiographic technique should be tailored to reveal the opaque dermal/epidermal line on the lateral view (Figs. 13 and 14). Minute signs of laminae thickening can occur within hours to days of onset and can go unnoticed for several days postonset even when comparative radiographs are being made. The speed of swelling alludes to the severity of insult and potential damage. A few degrees of rotation should be considered a red alert since extensive vascular compromise weakens the lamellar anchor and the domino effect of strategic instability is imminent. Waiting days to weeks to detect rotation has inherent risk of escalating the ill effects of the existing vascular deprivation.

Caution is due when monitoring the laminae zone. The distal third of the dorsal face of P3 is consistently remodeled in the lower grade, sound, club feet that can give the impression of capsule rotation (Fig. 15).

Venogram Exam

Venograms offer invaluable damage assessment as early as the first subtle signs of the syndrome. Evaluating the initial vascular insult offers a dependable means of setting emergency treatment goals. Monitoring the efficacy of the chosen treatment with comparative exams every 3 to 5 days offers a dependable means of staying alert to a favorable response or regression of the syndrome. This is a game changer for veterinarians and farriers as they seek improved success with this devastating disease syndrome.

The stark differences in the loaded, unloaded, and late views are the information being sought. The influence of load and the suspension tension of the DDFT and its vascular compromised antagonist can be observed at various levels of altered patency of the vessels of greatest interest. Clinical evidence strongly supports the hypothesis that the venogram offers insight into the degree and location of vascular compromise that is exacerbated by load on the structures.

10. Acute Case Example

Venogram data can confirm that the mechanical and medical treatments are adequately promoting a

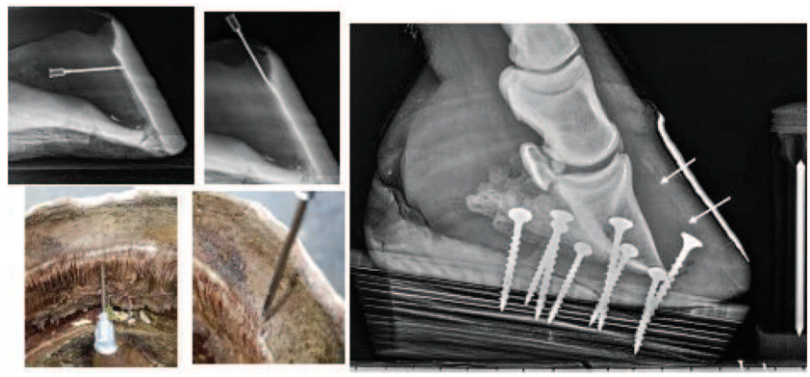


Fig. 14. The needle is touching the junction between the dermal/epidermal laminae and the inner horn wall. This landmark is invaluable as a damage assessment indicator and can help describe the health status of the laminae. Note the dermal/epidermal line in the X-ray (white arrows).



Fig. 15. Bone remodeling along the distal third of the coffin bone on a low-grade club foot. This is not to be confused with capsule rotation.

continuous healing pattern (Figs. 16 and 17). A steadily improving circumflex and dorsal sublamellar pattern can typically require 6 to 8 months to recover. Accelerated horn growth and sole production are favorable healing indicators, and they parallel the improved patency of previously affected vessels. Monitoring the high-level insult case can indicate that damage exceeds the benefits of the chosen treatment and surgical deep flexor tenotomy and that complementing pathological shoeing may be indicated.

11. Chronic Laminitis

Cases presented 4 to 8 weeks from onset are most often in the septic stage and acutely lame with penetration level capsule rotation and abscess drainage at the coronary band. Despite the extensive damage and poor prognosis, the venogram can offer insight relative to the thread of hope that may still exist given efficient reperfusion focused treatment. The venogram may also reveal stark loss of contrast throughout the foot to include the terminal arch and recommendation for euthanasia. Caution is due since diagnostic images are paramount for competent interpretation.

Excessive capsule rotation resulting in penetration has historically been used as a high-level damage indicator and criteria for euthanasia. Advancements in the damage assessment protocol and indicated treatment regime offer a more positive perspective for treating laminitis. Saving lives and careers is now possible utilizing venogram information to make timely, decisive shoeing and surgery decisions.

12. Case Study: High-Scale, Chronic Laminitis

Radiographs revealed extensive capsule rotation had resulted in penetration through the soles, exposing solar corium (Figs. 18 and 19). At this stage, a distinct gas line defined the path of travel along the horn/laminae junction, and this case was well into the septic



Fig. 16. A, Acute laminitis case presented 4/5 lame a few days from the first clinical signs. Note the compromised circumflex, slight prolapse dorsally, and no solar papillae (white arrows). B, View is unloaded, and the sublamellar vessels are tighter and more linear. C, This image reveals the remarkable alterations in the sublamellar vessels. Note the feathering into the dermal space (white arrow).

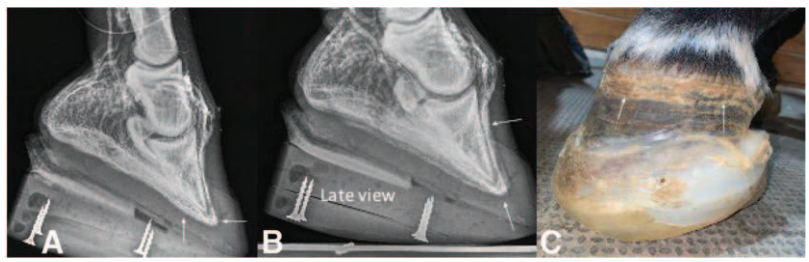


Fig. 17. A, The third venogram in the 40 days since onset. Note the improved contrast pattern in the circumflex and distal sublamellar zone in the loaded view. B, Reveals a tighter sublamellar pattern and less contrast within the epidermal leaves. Monitoring the response to the initial chosen treatment within 3 to 5 days and then every 10 to 12 consecutive days is the key to confirming treatment efficiency during the most critical phase of the syndrome. C, The horn growth response with uniform toe to heel growth is an indication that the mechanical package is adequate for this present stage of the healing process. When optimum mechanics fails to aid reperfusion, it is an indication that the level of damage exceeds the mechanical benefits and a higher level of DDFT release is indicated. Derotation shoeing followed by DDF tenotomy offers optimum perfusion benefits.

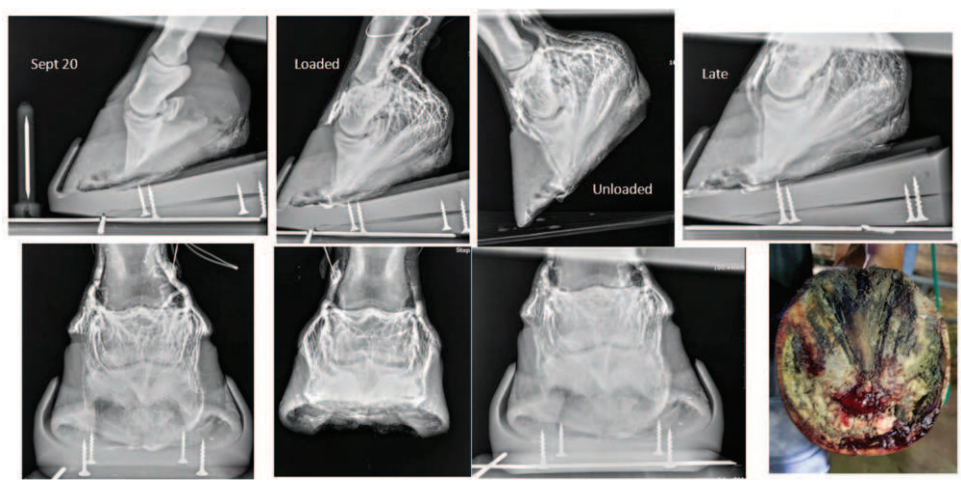


Fig. 18. This chronic case had bilateral penetration and septic drainage at the coronary band. Note the contrast leaking at the opening in the sole. The venogram revealed stark improved contrast on the unloaded and late views, which is very encouraging information. The owner elected extensive treatment versus euthanasia and agreed to adhere to follow-up aftercare despite the inherent risk of serious complication.

stage. The left front foot abscess had ruptured at the coronary band, and both feet had sole corium prolapse through the sole. This case is typical of the sequence of events that continues to classify laminitis as the second largest killer next to colic. Damage assessment is just as indicated at this advanced stage as it is the acute case. The extensive degree of rotation and penetration does not reveal the status of the vascular supply. Therefore, the value of vascular assessment may or may not indicate that there is reasonable potential for recovery and a quality life. It is not in the scope of this paper to dwell on the specific treatment that can save the life or even the career of penetrated cases but to describe the importance of the assessment protocol. Assessing the degree of vascular compromise in the loaded view compared to the reperfusion capabilities in the unloaded and late images offers useful information that helps the vet/farrier team make crucial recommendations for the owner. It is of greatest importance to inform the owner of the significance of extensive vascular, soft tissue, and bone damage; the options; inherent risk of expected complications; long-term recovery with various levels of response; and potential emotional and financial considerations.

Perspective is one's ability to see a situation from another person's point of view. Having empathy and compassion for the client and their horse suffering from laminitis is important, regardless of the outcome.

Efficient damage assessment makes it possible for the team to analyze the gravity of the damage, recognize the mechanical and medical requirements, and formulate and execute a plan to enhance the vital nutrient supply to germinal growth centers, ultimately increasing success.

Sinkers

Exceptions are classic sinkers with coronary band ledge, radiographic ledge across entire coronary band, double-width L zone, full-length gas line, and apex distal to ground surface of the wall (Fig. 20). Radiographic and clinical assessment in most cases, as described, meet the criteria for euthanasia. However, performing the venogram on the scale of damage enhances interpretive skills relative to the magnitude of vascular damage that can occur to the laminae, solar corium, and terminal arch.

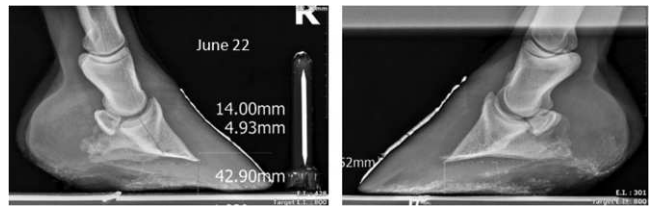


Fig. 19. The penetrated case in Fig. 18 showed a favorable response and returned to light riding soundness 1 year postop. Note the residual bone remodeling that most likely would not have occurred with early, timely, and efficient treatment.



Fig. 20. This horse developed catastrophic vascular shutdown in one rear foot following castration, apparently due to a thrombus precluding major supply route. Note the stark loss in the entire dorsal half of the foot, terminal arch, and palmar zone. The heel typically appears perfused despite the catastrophic lesion intensity. The extensive gas line and dark laminae are typical of acute laminae necrosis.

13. Conclusion

An efficient damage assessment protocol offers the vet/farrier team a reliable means to better understand the gravity of lesion intensity, set realistic treatment goals, develop and execute the most favorable option, and monitor tissue response. A disciplined, methodical approach to career- and life-threatening foot issues is paramount for optimum results.

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.

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Adaption of Therapeutic Shoeing on the Rehabilitation Status of the Orthopedic Patient

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1. Introduction

Various injuries and disorders affecting the equine distal limb, or the equine hoof, require treatment with special shoeing. Specific orthopedic concepts have been developed for several diseases over time, through shoe modification or the use of different materials to provide relief to the affected tendons, ligaments, joints, and hoof regions.[1–3] Thus, these support the healing of a specific structure. In the best-case scenario, the patient's diagnosis simply improves through the application of therapeutic shoeing. Yet the following questions are of interest in the daily practice:

1. Which orthopedic treatment or shoe modification is appropriate for that specific case?
2. How and to what extent can the shoe be modified? How much is necessary to achieve the intended relief of diseased structures, and when do the inevitable, undesirable side effects cause secondary damage to the loaded structures?
3. How can the side effects be reduced?
4. How long can the shoe modifications be applied, and when or how can a return to "standard shoeing" be achieved?

2. Factors Influencing the Choice of the Orthopedic Measure/Shoe Modification

Before making the choice for treatment strategy, different factors must be clarified.

First, the disorder the patient initially presented for orthopedic treatment must be evaluated and clarified (Fig. 1). Orthopedic patients can be presented in the status of an acute disease or injury or in a chronic status of disorder, incurable (e.g., progressive, degenerative diseases, arthrosis, podotrochlosis), or healing in progress (e.g., tendon injuries, suspensory ligament lesions, injuries of the hoof). Furthermore, patients in the process of rehabilitation with controlled load, with low-level training, or that have already regained their athletic abilities are introduced to a veterinarian or farrier for shoeing and treatment.

Depending on the status of the disorder, different requirements and aims have priority in the orthopedic treatment. In the acute status of disease/injury, collaboration between farrier and veterinarian is crucial to identify the affected structure. In addition, it is important to know where the lesion is located, how big the structural damage is, and how much functional insufficiency is being presented. One of the most important factors for future prognosis and therapeutic success is the pain level of the patient. In some cases, effective pain management is required to enable orthopedic treatment of the patient and improve the prognosis. The severe pain correlated with manipulations of the hoof requires the application of a systemic painkiller or local anesthesia. Any painful treatment without pain therapy is against animal welfare. Primary aims in the acute phase are prevention of further damage, improvement of the prognosis, and

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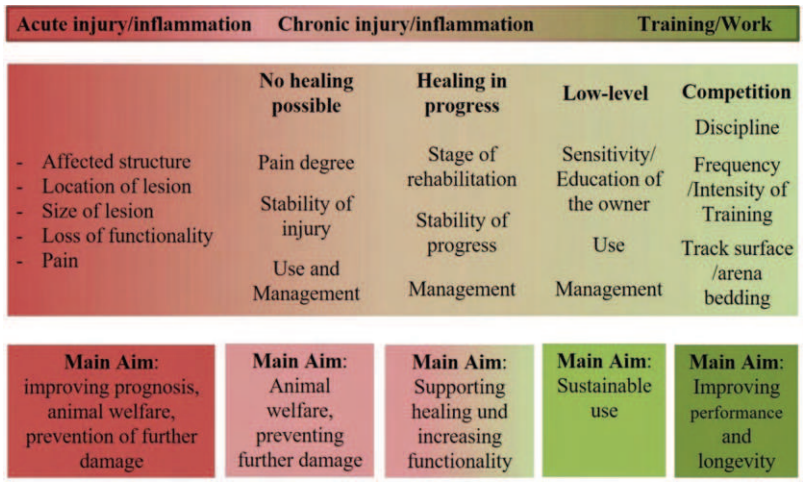


Fig. 1. Overview of the different options the orthopedic patient can be initially presented with for treatment, including optimal choice of shoeing and the varying aims in each status.

pain reduction for the animal's welfare. The owners should be informed about the risks and the chances of success. The expectations, compliance, and financial limits of the owner need to be clarified. There should be an agreement about the extent of the therapy. Particularly, in the acute status of disorder treatment, intervals can be frequent and short, which means high costs and efforts for the involved veterinarians, farriers, and owners.

The chronic status of a disease/injury can start days or weeks after the beginning of the orthopedic disorder and can last over months or years. For example, in the case of laminitis, the chronic status is defined with first observations of morphological changes at the hoof (rotation/sinking of the distal phalanx, structural alterations at the hoof capsule, etc.). The occurrence could be observed within hours or could be initially seen after weeks or even months. In this context, the frequency of the disorder should be taken into consideration; is it the first occurrence, or have several recurrences happened? In general, it is valid that the more recurrences, the worse the prognosis for the patient. Even if the structural damage is already manifested (bone loss, arthrosis) or so extended that neither conservative nor surgical treatment shows improvement (complete tendon ruptures), application of orthopedic treatments/ therapeutic shoeing can enable a worthy life for the animal. Relevant factors to identify before choice of treatment are the stability of the injury/structural damage (e.g., sinking of the distal phalanx in laminitic horses), if worsening of the damage should be expected (e.g., arthrosis), or if phases of recovery alternate with phases of aggravation (e.g., podotrochlosis). Additionally, the severity of pain and its management should be assessed. The use of the horse is essential to choose the optimal orthopedic treatment.

Main aims in the chronic status of disease/injury are improvement of animal welfare, stabilization of the damage, and deceleration of progress of the disorder.

Fortunately, in many cases, healing of the disease/ injury is possible. For shoeing horses in this situation, in which phase of rehabilitation the horse is in and how stable the progress of healing is must be considered. In some cases, conservative therapy and controlled locomotion enable a progressive healing of the lesion (tendon lesions). In other cases, intermittent worsening of the symptoms occurs (arthritis). Dependent on this, the orthopedic treatment/shoeing must be selected to enable support of healing with the possibility of flexible reaction to clinical signs and changes and to improve the functionality of the hoof and the distal limb step by step.

The next status is the progress of rehabilitation of the equine patient and the reintroduction into use and training. Factors influencing the choice of orthopedic treatment/shoeing are the compliance and sensitivity of the owner, frequency and intensity of training, and the management of the horse. In this phase, the main aim is to enable a sustainable use of the horse and minimize the risk of recurrence. In the end, athletic longevity and sound performance of the horse should be provided.

The described status of disorder has an important impact on the choice of each specific orthopedic treatment because the management and load of the horse also differ in these phases (Fig. 2).

In the acute status of disease/injury, horses are in box rest or only controlled motion. Walking is permitted. The orthopedic treatment or shoeing is carried out for static conditions. Most important in this status is to relieve the affected structures. To achieve this, more extreme shoe modifications or treatments can be applied due to static management of the horse. However, it has to be considered that with extreme manipulation, the higher are the undesirable side effects. To a certain degree, the use of cushions, pads, bandages, or painkillers can minimize these side effects. But most of the time, it is impossible to fully eradicate side effects of necessary but extreme shoe

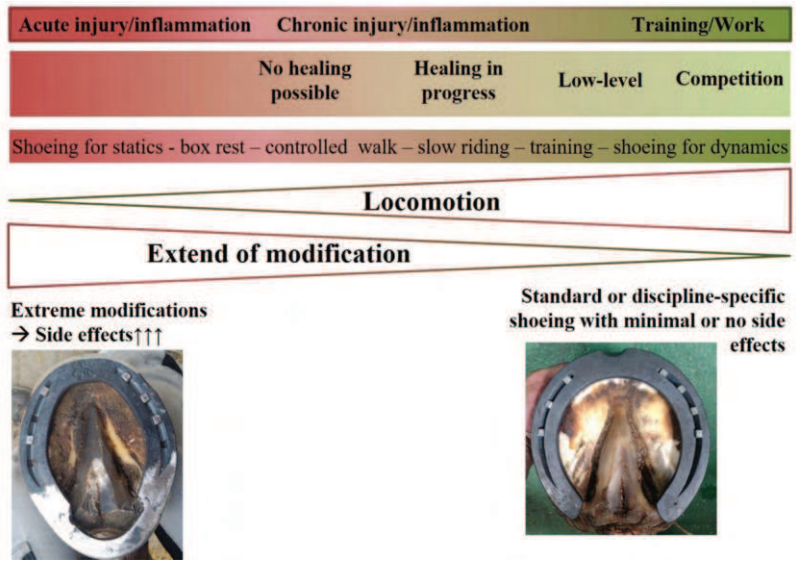


Fig. 2. Overview of the correlation between the status of disorder, the increase of locomotion, and the extent of the applied shoe modification.

modifications, which limits the duration of use of the orthopedic treatment. In general, orthopedic shoes are initially applied as long as the intended, positive therapeutic influences exceed the impact of unintended, negative side effects. Examples for quite extreme orthopedic manipulations in acute phases of disorders are either glued foal shoes for club foot correction or application of pattern bar shoes for horses with severe deep digital flexor tendon (DDFT) injuries. Glued shoes with a toe extension are an effective measure to increase tension of the DDFT, causing improvement of the toe conformation, but on the other hand, they narrow the hoof capsule and cause pressure and narrowing of the hoof. Therefore, glued shoes need to be changed after 7 to 16 days, and the amount of extension needs to be adapted to avoid damage of the hoof capsule or too much strain on the DDFT and the navicular region. The use of a pattern bare shoe in adult horses enables a very steep toe angulation, combined with long palmar support, which means optimal relief of the DDFT. However, side effects are an extreme load on the tip of the distal phalanx and strain on the dorsal suspension of the distal phalanx. In addition, there is a high risk of stepping into the shoe with the hinds when management of the horse becomes more dynamic.

Usually, in the chronic phase of disorders, patients move more and less controlled. In this status, the orthopedic treatment/shoeing has to be adapted dependent on the keeping, management, and rehabilitation status of the horse. Modifications and manipulations should become less extreme the more the horse moves. Safety of the horse during locomotion needs to be ensured. Side effects need to be minimized to enable long-term use of the modified shoes. An example of the adaptation of therapeutic shoeing in the chronic phase during progress of healing is the use of a long eggbar shoe in the acute phase of tendon injury. During the chronic phase and progress of healing, the length of the bar should be reduced, and with increasing locomotion of the horse, a change toward a shoe with extended heels until it is again similar to "standard shoeing" might be a good concept.

In practice, it is very common that horses are reintroduced to use and training much too early. In these cases, the treating veterinarian or farrier needs to be enlightened about the increasing risks of recurrence. If the horse is back to athletic use and competition, ideally no extreme modifications of the shoes are present. Sometimes, application of pads, packing, soft wedge pads, or light bars can be tolerated if their use reduces the risk of recurrence. But in general, healthy horses should compete with discipline and good specific shoeing without severe modifications.

As stated above, the chronic status of disease/injury is the most challenging for the correct application of therapeutic shoeing. In this phase, the treating veterinarian and farrier need to expect sudden changes between structural healing, improvement of clinical signs or pain reduction, and aggravation of the symptoms and lesions. In addition, side effects need to be monitored critically to avoid secondary damage of loaded structures, which could eliminate the first success of the treatment. Dependent on the progress of healing and the pain level, high flexibility in adaptation of the orthopedic measures is essential. Quite often in practice, no diagnostic control of the progress of healing is possible. Clinical status of the horse (pain, lameness, secondary damages) is the reference for the choice and adaptation of the orthopedic treatment/shoeing. Furthermore, amount of motion and load of the animal (motion in walk, trot, controlled, uncontrolled, etc.) as well as management of the patient (pasture, small paddock, bell boots, keeping alone or in groups, etc.) need to be considered for adaption of the treatment.

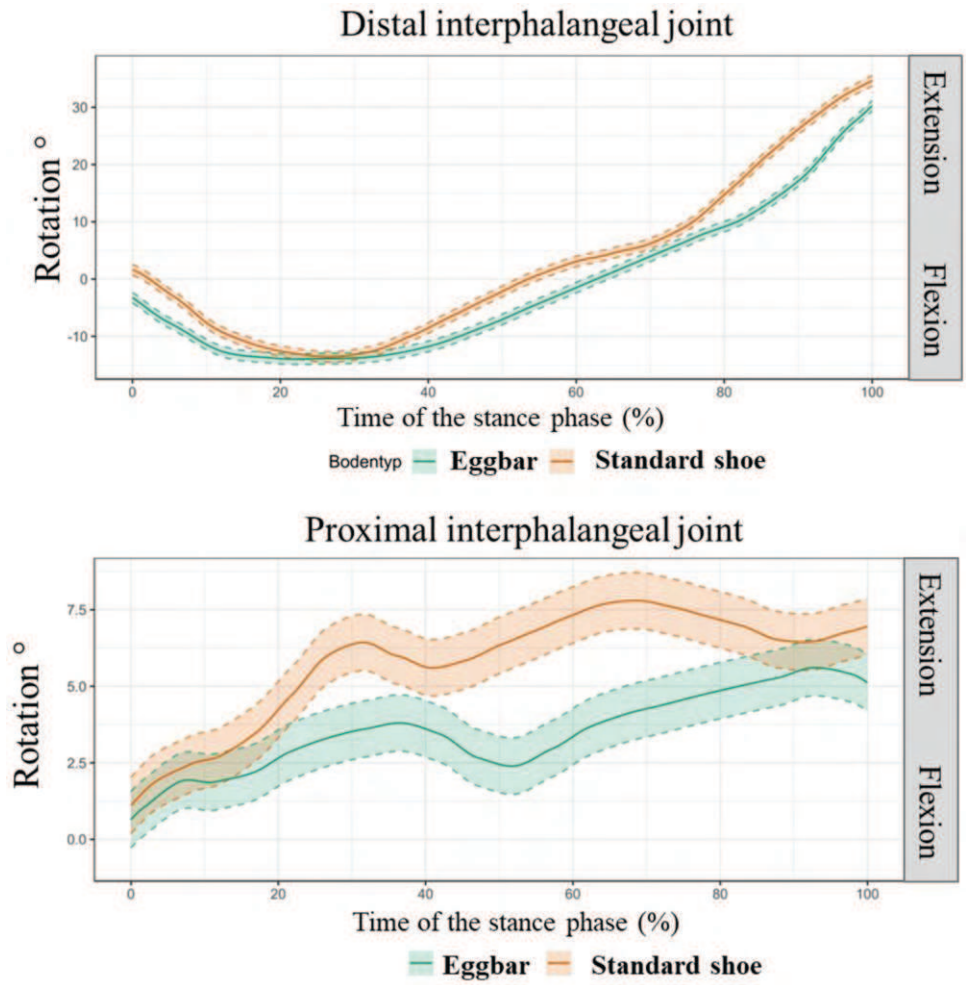


Fig. 3. Decreased flexion in the proximal and distal interphalangeal joint using an eggbar shoe compared to a standard horseshoe on firm ground.[21]

3. Useful Therapeutic Shoe Modifications and Their Adaption to the Rehabilitation Status

Horseshoes can be modified for therapeutic use. In general, the following parameters are influenced by shoe modification:

- the toe angulation[2–5]
  - change of load affecting the digital joints
  - change of the strain affecting soft tissues, such as tendons and ligaments
- the supporting area[6,7]
  - increase of medial, lateral, or palmar/plantar support
  - change of load affecting joints, ligaments, and tendons
- the weight-bearing surface[6,7]
  - change of load distribution between different regions of the hoof
- the moment arms and leverages[7,8]
  - decrease or increase of moment arms at the digital joints and load to the associated structures
- the weight of the shoeing
  - decrease or increase of weight[9]
- the shock absorbing properties of the shoeing[10,11]
  - decrease or increase of shock and vibration during motion

The modification of all these parameters can be used individually or in combination to achieve the intended relief of affected structures. However, as previously stated, the application of each shoe modification involves the risk of side effects. In the following section, the use and risk of the most common shoe modifications will be discussed.

4. The Change of Toe Angulation

The toe angulation can be changed by creating a steeper or lower hoof position on the ground. A steeper

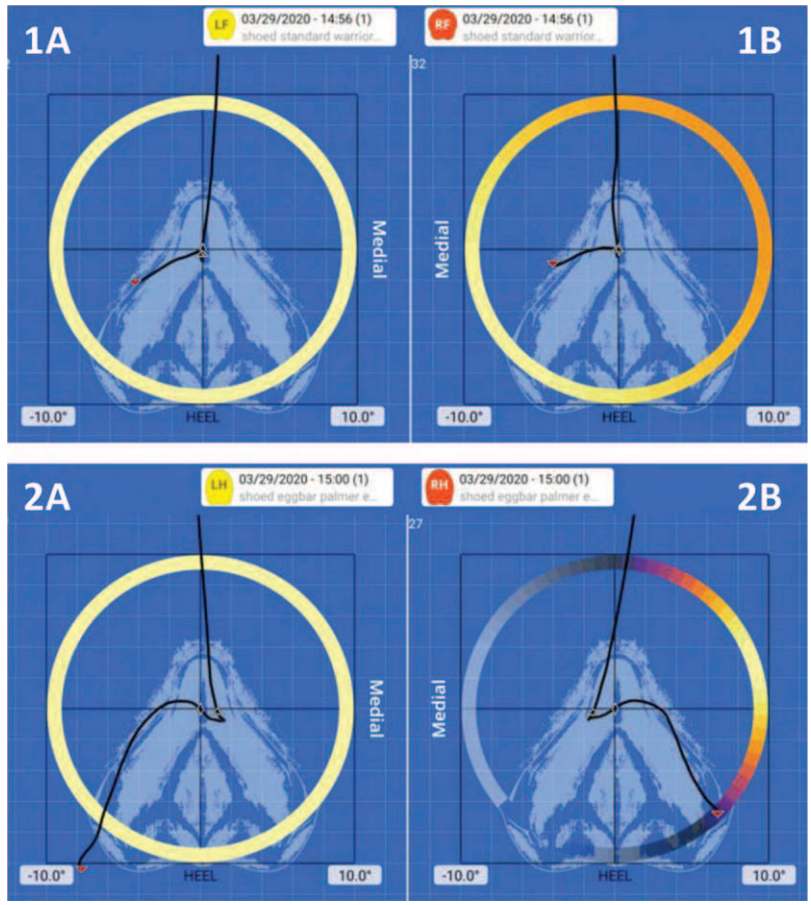


Fig. 4. These graphs were obtained from the Hoof Beat System (inertial measurement unit [IMU] system) and visualize the left and right front hooves of one horse under different conditions. Of interest is the black line that shows the motion of the hoof during stance phase. The red triangle represents the initial contact, the black rectangle represents midstance, and the black triangle the beginning of breakover. The end of the line is the last contact with the ground. The colors do not have importance. The graphs show a horse with a tendency of lateral landing at the left foot (1A) and medial landing at the right foot (1B) with a standard horseshoe and with forced heel (bar) landing in the same horse shod with an eggbar shoe (left 2A, right 2B).

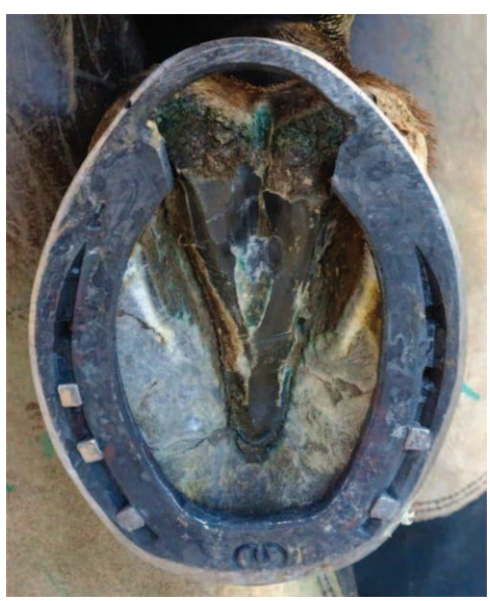


Fig. 5. Eggbar shoe with long extension but a light and thin bar.



Fig. 6. Wide branch shoe with lateral extension created by a double fuller and forging.

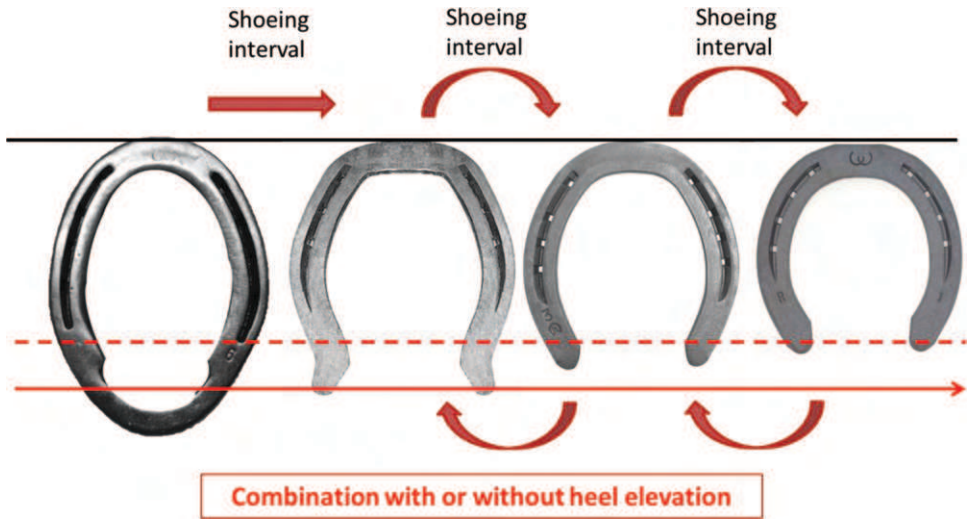


Fig. 7. Shoeing protocol for treating tendon or suspensory ligament injuries.

hoof orientation is achieved by heel elevation with wedges independent from the ground or with bar shoes, increasing the palmar support, on penetrable ground.[5, 7] The therapeutic effect of heel elevation has been scientifically confirmed by more flexion in the distal interphalangeal joint correlated with a relief of the navicular region,[2,4] with less strain on the superficial digital flexor tendon (SDFT) and DDFT and a faster breakover.[8,12] These findings support the use of a heel elevation for treating horses suffering from podotrochlosis, injuries of the SDFT or DDFT, or acute laminitis.[13–15] However, the side effects of a heel elevation are quite strong. It has been found that a steeper hoof orientation causes more strain on the dorsal suspension of the distal phalanx inside the hoof capsule,[5,16] which must be observed very critically during use of this treatment in horses with severe laminitis since the lamellar junction between hoof capsule and dermis is already inflamed and destructed. A compromise in the height of heel elevation needs to be found. The height needs to be enough to reduce strain on the DDFT to prevent rotation of the distal phalanx and not too strong to protect the affected suspensory apparatus of the distal phalanx from further damage to reduce displacement of the distal phalanx. In addition, heel elevation causes pressure peaks at the heels and the toe region of the hoof.[5] Therefore, long-term use of heel wedges causes destruction and weakening of the heels. In addition, it is described that a steeper hoof orientation is associated with more extension in the fetlock joint, probably increasing the risk of a suspensory ligament injury.[2,3,17] Therefore, the effect of a flatter hoof orientation was described to cause less strain on the suspensory ligament due to reduced extension in the fetlock joint. This is achieved by trimming and the use of a wide toe shoe with narrowed branches on penetrable ground.[1,3] The side effects of a lowered hoof orientation are associated with more extension in the distal interphalangeal joint, causing high strain on the DDFT and load on the navicular region.[1,3,5,12] In addition, pressure peaks at the hoof, under the wide toe section of the shoe. This side effect might cause discomfort in horses with thin and sensitive soles.

If a change of toe angulation is used for therapeutic purposes, it should be considered that the change back to the natural angulation needs to be achieved gradually. Specifically, in cases with long-term application of heel wedges, the lowering of the heels should be performed slowly with a gradual decrease of the wedge height over a few weeks.

Another option to relieve diseased tendons and ligaments is the use of shoes with an increased medial, lateral, or palmar support, created as shoe extensions.[18–20] The therapeutic effect of shoes with extensions is dominant on firm ground. Shoes with medial or lateral extensions are used to support joints and are associated

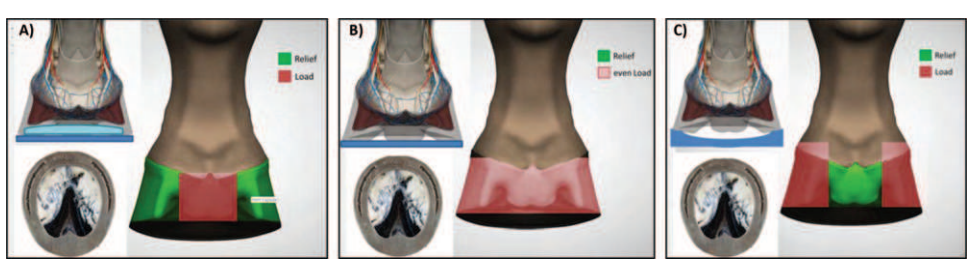


Fig. 8. Possibilities of changing the load distribution at the palmar hoof region by using a bar shoe. A, Relief of the heels, load on the frog. B, Load on the whole palmar region. C, Relief of the frog, load on the heels.

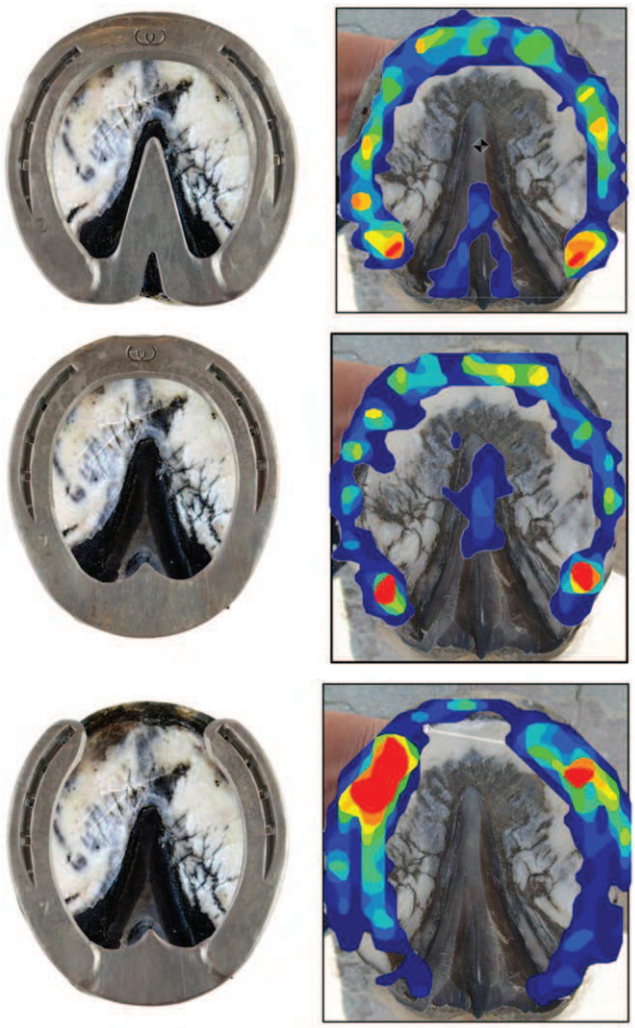


Fig. 9. Pressure images of the left hoof of one horse shod with a heart bar shoe with frog contact (top), shod with a short eggbar shoe without frog contact (middle), and with an open-toe shoe (bottom).

with soft tissues in stance or in midstance during locomotion. Scientific evidence to confirm this application is rare. However, the use of shoes with palmar extension (eggbar shoes) has been partially investigated. On firm ground, the extension in the distal and proximal interphalangeal joint is reduced with the use of a long eggbar shoe compared to standard shoeing (Fig. 3).[6] The effect on the fetlock angulation needs to be investigated further. Still, in practice, the principle of the application of a shoe with palmar extension to reduce extension in the fetlock joint is successfully used in foals with tendon laxity and to relieve a diseased SDFT, DDFT, or suspensory ligament. However, next to the supporting function of shoes with palmar or mediolateral extensions in statics, side effects occur in dynamics. During locomotion, these shoes increase leverage. In horses with lateral, medial, or heel-first landing, the different extensions cause high strain on the joints and ligaments, causing secondary damage. A forced landing on the long bar and an increased landing duration were found in shod horses with eggbar shoes (Fig. 4).[a]

Similar results occur for the use of shoes with lateral or medial extensions. The lateral or medial landing and the landing duration increase. Therefore, it is crucial to decrease the weight of the extensions. This can be done by creating eggbar shoes with a very thin and light bar (Fig. 5) or by forging the mediolateral extensions into the shoe instead of increasing weight by using welding parts to create the shoe modification (Fig. 6).

In addition, the more dynamic the management or the more the locomotion of the horse increases, the less long or extreme the extension should be. Still, in cases of injuries of the SDFT, DDFT, or suspensory ligament, it is advisable to reduce the length of the palmar/plantar extension step wise (Fig. 7).

Other bar shoes (heart bar shoe, straight bar shoe, etc.) are used to relieve diseased regions of the hoof capsule. The therapeutic effect of a change of the weight-bearing surface is a change in load distribution at the hoof itself.[6] If no extensions are created, the use of these modifications is limited to the structures of the hoof. Therefore, these modifications are used to treat disorders such as quarter cracks (relief of the heels, load of the frog), laminitis (relief of the dorsal part of the hoof, load of the palmar region), or podotrochlosis (relief of the frog, load on the heels; Fig. 8). Depending on the manufacturing of the shoe (position or size of the bar) and the use of additional packing and pads, pressure in single regions of the hoof can be reduced.

The side effects of a change in weight distribution with relief of a specific area of the hoof are increased pressure peaks at the bearing parts of the hoof capsule.[6] Over time, the relief of one hoof region causes an overload to another region. The general load affecting the hoof capsule stays the same since it is defined by the mass and velocity acting at the hoof. If the bearing area of the hoof is decreased, for example due to relief of the frog, the acting load is distributed to the remaining parts for weight bearing. Scientific studies showed that bar shoes without frog contact increase pressure peaks at the heels (Fig. 9).[5–7] The use of open-toe shoes to relieve the dorsal toe region of the hoof may also cause pressure peaks at the hoof capsule under the end of the branches (Fig. 9). To minimize these side effects, it is advisable to use pads and packings to decrease the occurrence of pressure peaks.

The use of pads and packings is usually of great therapeutic value. It was shown that the application of different types of packing materials in combination with different pads decreases shock and vibration on firm ground.[10,11] This effect is useful in horses suffering from arthrosis or podotrochlosis. In addition, pads and packing combinations can be used to achieve a less aggressive change of weight distribution (e.g., in horses with laminitis, this is achievable with a packing on the frog and a medium firm pad). In horses with podotrochlosis, this is achieved with a firmer pad and just filling material or a very soft packing on the frog. Moreover, pads can be used to protect very thin

and sensitive soles. The side effect of the use of packing and pads is the increasing weight. It was shown that increasing weight at the hooves causes an increased height of the flight arc, more flexion in the limb joints, a higher acceleration of the hoof during swing phase, and an increased impact peak during landing.[22,23] These are negative effects for all horses suffering from bone or joint associated disorders (fractures, arthrosis, arthritis, podotrochlosis). This side effect becomes more significant the more the horse moves. The more the horse is introduced to training at higher speeds (trot, gallop), the less weight should be applied to the hooves. This can be achieved by using aluminum shoes instead of steel shoes. As described in research, the use of these shoes decreases the height of the flight arc during swing phase, reduces the impact peak during landing, and decreases the flexion in the limb joints.[9] Particularly, if the application of thick bar shoes with pads and packing is required, aluminum is the material of choice.

As shown, many details must be considered for the optimal therapeutic use of horseshoes. In general, the duration of the application of specific shoe modifications for orthopedic treatment is limited as long as it is necessary and useful. The use of modified horseshoes for therapeutic purposes is comparable to the application of medicine. Prescription of specific drugs requires a clear diagnosis. In addition, it is known that the intake of a therapeutic drug causes an intended influence correlated with inevitable side effects. These side effects should be reduced, and duration of intake should also be limited. Usually, medication is adapted to the progress of healing and becomes less harmful. After full convalescence, the medicine is discontinued. In addition, if a disease or injury exists that requires application of medicine, the management of the patient is adapted too. The medical treatment is only successful if the patient is responding positively to the given treatment. This ultimately is comparable with the use of therapeutic 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.

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Practical Approaches to Traumatic Injuries of the Hoof and Repair Techniques

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1. Introduction

The hoof is susceptible to various types of traumatic wounds or injuries. When presented with a hoof capsule injury, the goal is to promote tissue healing that results in normal function and the least amount of distortion. Wounds can be classified based on various characteristics such as appearance, location, depth, and degree of contamination. Assessment and characterization of the wound helps determine the most appropriate course of treatment.

Appearance: Abrasion, laceration, avulsion, cracks, and punctures.

Degree of contamination: Clean, clean-contaminated, contaminated, and dirty. Foot wounds occurring naturally (not surgically) are considered contaminated and dirty.

Depth: Superficial (epidermis only; Fig. 1A), partial thickness (epidermis and dermis; Fig. 1B), and full thickness going through the skin layer (dermis and epidermis; Fig. 1C).

Proper treatment is important to ensure a functional result. The hoof is an important and complicated weight-bearing structure. Dysfunctional healing can cause distortion of the normal anatomy and be a cause of chronic lameness. The hoof capsule, which includes the hoof wall, sole, bars, and frog, is all generated by the underlying dermis or corium: coronary corium, frog corium, sole corium, and lamellar corium. Like rete pegs form undulations in the dermis and epithelium in skin to enhance the mechanical stability and nourishment of the tissue, the dermis and epidermis of the hoof are very similar but more complicated. The dermis of the foot has a very intricate undulation pattern in multiple different planes. The undulations of coronary dermis form the coronary papillae, which produce tubular and intertubular horn depending on where on the papillae the epidermis or horn is produced. The undulations of the sole dermis produce the sole papillae, which produce the sole epidermis, and likewise for the frog. The lamellar dermis (sensitive laminae), which lies on the parietal surface of the pedal bone, produces a thin layer of epidermal tissue known as the lamellar epithelium or nonsensitive laminae. This tissue blends in and is attached to the epithelial tissue (hoof wall) produced by the coronary dermis. The complexity of the dermal and epidermal patterns of the hoof is what gives it incredible strength but also makes it vulnerable to abnormal healing in the event of an injury. Figure 2 is an example of a healed injury and distorted hoof capsule causing chronic lameness. Reconstructive surgeries of old, healed hoof wounds can be difficult and often have complications such as wound dehiscence, infection, and further hoof distortion. Appropriate initial treatment and prevention of distortional healing is more effective and easier than reconstructing a wound later. Wounds should be repaired if possible. This is done by opposing and stabilizing the wound margins to limit scar tissue production. This is especially important in growth centers such as the coronary band.

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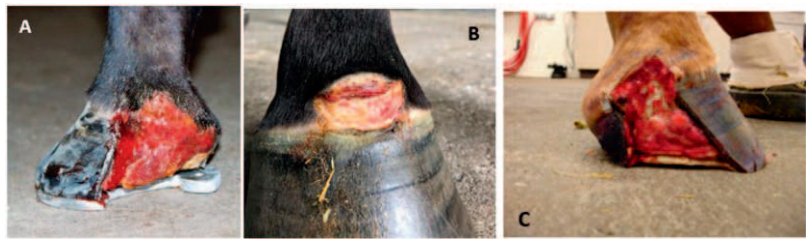


Fig. 1. Examples of wounds. A, Superficial; B, Partial; C, Full.



Fig. 2. Example of a healed injury and distorted hoof capsule causing chronic lameness.

Understanding the different phases of healing and having an effective plan to intervene, when necessary, will help achieve a desirable outcome. There are several stages of healing that occur concurrently but are also interdependent. It is important that each stage progresses normally to set the stage for the subsequent stages of wound healing. Following a traumatic wound, healing can be simplified into 5 stages:

1. Hemostasis: A clot is established, bleeding ceases. Initial vascular constriction will decrease blood flow to the wound. Exposed collagen from the wound will stimulate platelets to become "sticky" and clump together and adhere to the damaged tissue, creating a platelet plug or the initial blood clot. Over time, the clot will stabilize as fibrin is added to the plug by fibroblasts setting the stage for the initial repair of the damaged tissue.
2. Inflammatory phase: Blood flow is increased, and cells are recruited to the area to set the stage for the debridement phase. Neutrophils and macrophages provide a second source of growth factors and cytokines, which further help orchestrate the healing process.
3. Debridement phase: This phase is largely mediated by neutrophils, macrophages, cytokines, and proteases, which actively clean up dead tissue, bacteria, and debris.
4. Repair phase: Compounds such as vascular endothelial growth factor are released from platelets stimulate vessel growth. Fibroblasts and macrophages supported by new capillaries proliferate and synthesize a disorganized matrix of granulation tissue. Once the granulation tissue fills in the defect, then basal epithelial cells proliferate and migrate over the granulation tissue to close the wound surface. Epithelial cell migration and proliferation further heal the defect.
5. Maturation: The initial healed tissue will often be disorganized. It is common for the sole or hoof wall to have an irregular appearance. Ridges and irregular contours are common. Through the action of proteases, the irregular tissue is remodeled over time.

The clinician can play an important role in each stage of the healing process. Evaluation of the initial injury will help determine the structures involved and the most appropriate course of treatment.

On presentation of an acute hoof injury involving hemorrhaging, the first step is to stop the bleeding and examine the wound. This typically involves sedation, tourniquet, and cleaning the area to evaluate the extent of the injury. Desensitization of the foot with an abaxial sesamoid block may be indicated in some situations but contraindicated in others. For example, in the case of a complete hoof capsule slough or an avulsion involving a large portion of the hoof, desensitizing the foot will allow the horse to load the injured foot, which can cause serious damage to the sole corium and pedal bone. This can create more damage, worsening the prognosis and increasing the healing time. After the wound has been physically evaluated, the next step is to determine if deeper structures are involved. Various diagnostic aids are available such as radiographs, fistulogram, magnetic resonance imaging, arthrogram, and arthrocentesis. The involvement of deeper structures may require lavage of synovial structures, surgical debridement, or drain placement, which will be discussed later. The clinician will need to determine which type of wound repair is most appropriate: primary closure, second intention healing, or debridement followed by a delayed repair. Next, the foot is further stabilized and protected with a bandage, shoe, or foot cast.

If the inflammatory/debridement phase is delayed, this can cause additional damage through the activity of tissue damaging microorganisms, proteases, and reactive oxygen species. A delayed or prolonged inflammatory/debridement phase is usually caused by either instability and/or infection. Assessment of the lesion can help determine if the delayed healing is due to

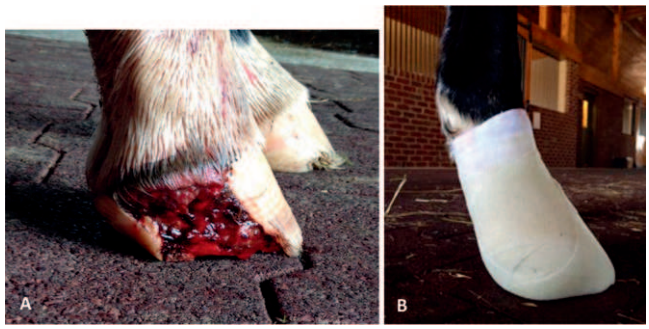


Fig. 3. A, A yearling that suffered a wall avulsion. The wound was slow to heal with bandaging alone. B, The use of a foot cast helped bring immediate comfort and stabilized the hoof, speeding up the healing process.



Fig. 4. A, Modified "Z" bar shoe designed to unweight an infection in the medial quarter that is being treated with larval therapy. B, A hospital plate or treatment plate shoe. The removeable plate provides protection and facilitates treatment of the affected area. C, A "Patton shoe" designed to elevate the heel to take stress off the navicular apparatus. This horse is being treated for an infected navicular bursa.

infection or instability. Tools available to evaluate the wound/lesion are radiographs, fistulogram, magnetic resonance imaging, and systemic blood values: white cell count, fibrinogen, serum amyloid A. Medical management to aid in the inflammatory/debridement phase includes foot soaks and topicals with disinfectants that are not damaging to tissue, topical antibiotics, systemic antibiotics, regional antibiotic perfusions, surgical debridement, larval therapy, and cauterization to remove damaged tissue.[4] Mechanical aids such as shoes with protective plates, casts, splints, protective



Fig. 5. A, A weanling that sloughed the entire sole secondary to a trauma and subsolar infection. The healing process is shown in these images as granulation tissue fills the defect in the dermis or corium. B, The same foot in the process of epithelial cell migration across the bed of granulation tissue. C, The same foot with thickening and maturation of the newly formed epithelial tissue and further migration and closure of the wound.

boots, and bandaging can be very effective means to stabilize, protect, and take stress off the anatomical structures involved. This will facilitate healing and improve patient comfort (Figs. 3 and 4).

The repair phase requires a healthy environment in which infections are resolved and contaminants are removed. The dermis fills in with granulation tissue to fill the defect up to the level of the adjacent epidermis, and then basal epithelial cells will migrate across the granulation bed, filling in the wound with a protective epithelial layer that will thicken and mature with time (Fig. 5). If the wound is located above the coronary band or in the skin, then wound contracture would aid in closing the wound as well, but this does not occur in the hoof. In the event of a hoof wall lesion, the healing process is complicated by different tissue planes that need to heal (Fig. 6). The exposed lamellar epidermis is healed by the activation and migration of the basal cells of the lamellar epidermis. This process can occur rapidly in days to weeks. The coronary epidermis generated by the coronary corium will be produced and grow the hoof wall in a proximal to distal direction. These two layers of epidermis will adhere together to fully repair the wall damage (Figs. 7 and 8).

The maturation phase is the final phase of wound healing in which abnormal tissue and scar tissue

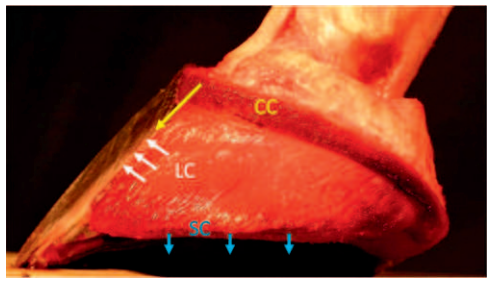


Fig. 6. In the event of a hoof wall lesion, the healing process is complicated by different tissue planes that need to heal. CC, coronary corium; LC, lamellar corium; SC, sole and frog corium.

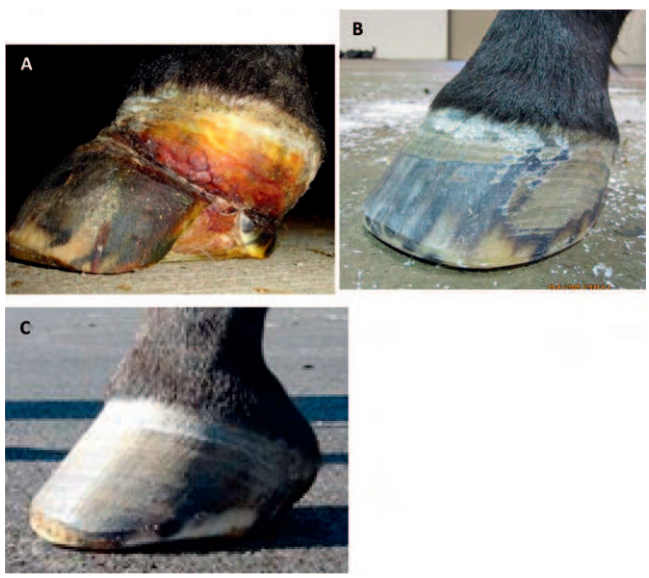


Fig. 7. This case required a medial hoof wall resection for laminitis of the medial quarter. A, The same foot several months after the resection showing the lamellar dermis cornified by lamellar epithelium. B, The same foot 1 year later showing hoof wall (stratum medium) grown down over the area. At this stage, the new wall is irregular with ridges and abnormal wall contour. C, The same foot 2 years later. The wall is normal looking after the remodeling process.

remodels for a more normal and functional looking tissue. This process can take months to years in the hoof (Fig. 7).

2. Hoof Epidermal Dermal Planes

The underlying dermis (corium) of the hoof is thrown up into various folds or planes of tissue and therefore has multiple planes or orientations to the epidermal hoof wall. The coronary corium produces (epidermis) hoof wall in the proximal to distal direction. The lamellar corium produces epidermis outwardly or in the horizontal direction. These two layers combine and grow downward. The sole and frog corium produces epidermal tissue in a proximal to distal direction.

The hoof wall is a complex arrangement of epidermal tissue. It is designed to protect the sensitive inner structures, support, transfer the weight of the horse to the bone column, and absorb vibrations generated



Fig. 8. A, The healing pattern of a foot which has sloughed the entire hoof wall, demonstrating the different growth centers of the hoof and the different epidermal planes. The stratum medium, (pigmented layer) is produced by the coronary dermis and is produced in a proximal to distal direction. B, C, The pigmented layer growing downward.

during ground impact. The hoof wall is made up of three layers: the stratum externum, stratum medium, and stratum internum (lamellatum). The stratum externum and stratum medium are generated from the coronary corium and migrate distally. The stratum internum is generated from the germinal cells of the lamellar epidermis. The layers of the hoof wall merge together and migrate distally toward the ground surface. The stratum internum has very little proliferation activity in the normal horse; its main function is to attach the epidermis to the underlying dermis or nonsensitive (epidermal) laminae to sensitive (dermal) laminae. It does play an important role in healing hoof wall injuries or healing the bed of a full-thickness crack. The stratum medium constitutes most of the hoof wall. It is also the pigmented layer and is made up of tubular and intertubular horns. The coronary papillae form the tubular horn and the tissue between the papillae generate the intertubular horn. The intertubular horn is therefore formed perpendicular to the tubular horn. Thus, a multidirectional, fiber-reinforced composite is created.[1,2] The coronary papillae and thus the horn tubule are most dense toward the external surface and gradually decrease in density as they get closer to the internal layers. The moisture content of the hoof wall follows the tubular concentration and gradually increases toward the internal layers. The change in tubular horn and moisture content is a protective design to dissipate or dampen shock as one gets closer to the sensitive layers and to limit the propagation of cracks to



Fig. 9. A cadaver specimen from a chronic quarter crack.

the external layers and prevent them from becoming full thickness or deep cracks. The keratinized cells of the tubular and intertubular horn are firmly adhered to each other, creating an impermeable protective barrier. The inner hoof wall has no direct blood supply and therefore must receive its nutrients via diffusion from the dermis. Observing the healing pattern of a foot that has sloughed the entire hoof wall (Fig. 8A) demonstrates the different growth centers of the hoof and the different epidermal planes. Figure 8B shows the foot in the healing process in which the lamellar dermis is cornified over with the lamellar epithelium. This layer of epithelial tissue is generated by the lamellar dermis, and the cells grow outward in an abaxial direction. The stratum medium (pigmented layer) is produced by the coronary dermis and is produced in a proximal to distal direction. The stratum medium epidural layer is shown growing downward in Figs. 8B and C. Through proteases and remodeling enzymes, these two layers of epithelium combine as the stratum medium continues to grow downward past the lamellar epithelium.

Many products available to treat conditions of the foot are intended to be used on the hoof capsule, which is a thick, cornified tissue. When the underlying corium or dermis is exposed, it is important to educate the caregivers of the horse that this tissue is the same as sensitive tissue anywhere else in the body. Products intended to be used to treat thrush, white line disease, and other conditions of the hoof capsule (hoof wall, sole, and frog) are often not appropriate or safe for lesions involving structures deep to the hoof capsule.

3. Chemical Burns

Care should be taken in choosing the appropriate topical disinfectant or soaking solutions. Caustic materials containing strong iodine, formaldehyde, and chlorine can kill sensitive tissue and delay or even reverse the healing process. Figure 9 is a cadaver specimen from a chronic quarter crack. The lamellar dermis is scarred from overuse of caustic materials applied to the crack. Figure 10 is a case with a severe chemical burn from a mixture of strong iodine and formalin to treat thrush. The Eschar formation from the chemical burn involved the entire frog corium, digital cushion, deep digital flexor tendon, bursa, and navicular bone.



Fig. 10. A case with a severe chemical burn from a mixture of strong iodine and formalin to treat thrush.

4. Hoof Cracks

Hoof cracks are usually classified according to their location and/or origin (i.e., toe crack, quarter crack, heel crack.) A true quarter crack begins at the coronary band, is full thickness, and propagates distally. However, a sand crack in the quarter begins distally and is superficial. Generally, quarter cracks are the result of an imbalance in the frontal and sagittal planes. This imbalance places more stress on the quarter than it is designed to accommodate, resulting in vertical, proximal displacement of the coronary band. The displaced coronary band interferes with the abduction of the collateral cartilage, resulting in a quarter crack. These cracks usually start in the stratum internum and propagate externally.[5] Occasionally, a quarter will crack internally and have a delayed propagation to the external surface (blind quarter crack). These are usually sensitive as serum and hemorrhaging can build up slight pressure under the wall. Mending a quarter crack begins with trimming and shoeing first. The foot should be trimmed and shod to restore balance or more even weight distribution. Often, the use of a heartbar or arch support aids in taking some weight off the affected quarter. Ideally, the coronary band should be allowed to drop from its vertical displacement before patching, but this is not always possible. Methods to help the coronary band to settle are grooving, flotation, overnight poulticing, or just reestablishing balance and time. Going barefoot during this time if possible is very helpful. Once the foot is properly trimmed and shod, the bed of the crack should be packed off with antiseptic powder or paste and a drain. The drain can be any material that can be placed over the crack and then removed once the acrylic patch has cured, creating a tunnel or channel



Fig. 11. Example of a quarter crack that became infected beneath the patch because the bed of the crack was not packed off with an antiseptic or drain.

where the crack bed can be medicated or lavaged if needed. The crack can then be stabilized by various methods:

1. wire suture/lacing, acrylic, and epoxy
2. composite cloth, acrylic, and epoxy
3. metal plate and screws

Stabilization of a quarter crack should address both tensile and shearing forces. A metal band alone stabilizes tensile forces but does little for shear forces. Usually, sufficient stabilization requires a composite mesh cloth and resin or acrylic. Some cases require metal wire stitching and lacing as well.[6]

Toe cracks generally occur secondary to excessive tension on the anterior hoof wall. This tension is from the deep digital flexor tendon pulling on the coffin bone causing excessive rotational pull on the coffin bone and tensile strain on the anterior laminae and hoof wall. The dorsal hoof wall usually becomes concave or dished prior to the crack forming. Toe cracks are seen in flat feet with excessively long toes and break over too far forward or in club feet. Both hoof conformations have increased strain on the dorsal wall.

5. Treatment of Toe Cracks

Trimming and shoeing to rebalance the hoof and ease break over is the first step. Generally, the break over point should be set directly beneath the proximal aspect of the crack or directly beneath where the dish starts. The author is generally more aggressive and gently rolls the toe forward from a plum line dropped from the anterior coronary band. This alone heals most toe cracks. If the horse is lame from the crack or if the crack is unstable (opens and closes with weight bearing), then it needs to be stabilized. Usually, addressing tensile forces with a metal plate (aluminum plate glued across the crack) is sufficient. The toe crack opens when not weight bearing and closes excessively or has overlapping margins during weight bearing.[3] These cracks should be stabilized in the non-weight-bearing position as this best opposes the margins of the wall. Care should be taken not to cover any crack with acrylic or adhesive as this makes the perfect environment for a submural abscess. Crack beds should be packed off with antiseptic powder, cotton saturated with antiseptic, or a drain. Figure 11 is an example of a quarter crack that became infected beneath the patch because the bed of the crack was not packed off with an antiseptic or drain.

It is important to realize that even the best crack repair patch or stitching technique is useless without first addressing the trimming and/or shoeing. Common techniques to repair hoof cracks can be used to repair injuries to the coronary band. It is important to try to repair these injuries to prevent future abnormal wall growth. Techniques to stabilize and oppose the wound margins such as in Figs. 12 and 13 will help achieve normal healing and prevent future hoof capsule distortions.

6. Puncture Wounds

Foot infections are a common source of lameness in the horse. The sensitive structures of the foot are protected by the cornified hoof capsule (wall, sole, frog).



Fig. 12. A, Coronary band partial avulsion in which a flap of coronary band tissue is displaced proximally. B, C, After the granulation tissue was trimmed away, the flap of tissue was able to lie flat and was stabilized with wire suture/stents fastened to an acrylic patch/block on the dorsal hoof wall.

For an infection to occur, microorganisms must first breech this protective barrier in large enough numbers and invade the underlying sensitive tissue. This is a common complication of most hoof injuries as the sensitive structures are contaminated.

Puncture wounds can be classified as superficial or deep. Superficial infections involve the tissue just beneath the capsule (subsolar or submural). The infection only involves the underlying dermis or corium. Deep infections involve any of the structures deep to the underlying dermis (coffin bone, digital cushion, navicular bursa, bone, deep digital flexor tendon/sheath, coffin joint, collateral cartilage, etc.). Horses with foot infections usually present with acute severe lameness. The foot should be freshly pared, trimmed, and cleaned for inspection. A hoof tester exam will isolate the source of lameness, which is usually located at a hoof capsule defect. Most superficial infections are easily located and opened to establish drainage. If drainage cannot be obtained, the use of overnight foot poultices can be useful to hydrate the tissue and promote abscess maturation and eruption. Once drainage is established, the foot is kept in a poultice for 3 to 4 days and remains protected until the capsule defect has healed. It is not recommended to use antibiotics for superficial abscesses as this will only delay the maturation and resolution of the infection. Although superficial sounds benign, these infections can be life threatening or progress to create deeper infections. Therefore, all infections should be treated seriously. Superficial infections can undermine the entire sole or wall and make the foot unstable, slough, or create laminitis. If a superficial infection does not resolve soon after drainage is established, radiographs should be taken to evaluate the involvement of deeper structures. Deeper infections can manifest as constant drainage and severe lameness or intermittent episodes of lameness and drainage. This can be seen on some



Fig. 13. This is a similar case as in Figure 12. Before (A) and 6 months after (B) repair. The coronary band healed with a functional result and only minimal distortion.



Fig. 14. Various fistulograms. A, A fistulogram involving the distal interphalangeal joint and navicular bursa. B, Only involves the digital cushion and subcutaneous tissue. C, Shows a navicular bursa infection.

feet as horizontal cracks on the hoof wall where abscesses have erupted out of the coronary band and grown down. The seriousness of a puncture wound depends on the area and direction of entry.

Understanding the anatomy can help determine which structures may be involved.

Infections of the central region of the foot should be treated as an emergency. These wounds should be

radiographed, debrided, lavaged, and have a regional limb perfusion performed. These cases are usually placed on appropriate systemic antibiotic therapy, and regional perfusions are repeated once daily for 3 days. Tissue or fluid cultures should be obtained to help guide antibiotic therapy. Rarely will a case be presented within 24 hours of a puncture wound become an established infection if treated aggressively and early. Radiographs of puncture wounds should involve a fistulogram of the puncture tract. If the tract communicates with the coffin joint, navicular bursa, or tendon sheath, these structures must be thoroughly lavaged daily for the first 3 days and then as deemed necessary. Figure 14 demonstrates fistulograms involving various structures of the foot.



Fig. 15. Lower limb bandage cast to immobilize the fetlock joint.

Cases that present in the chronic stage of the infection are difficult to treat as these wounds are necrotic and established. These cases require an aggressive debridement procedure and prolonged therapy. The author finds it useful to take a culture on these wounds to help guide in the antibiotic selection. Most infections benefit from some type of shoe combined with a hospital treatment plate. Infections that involve the navicular bone/bursa or deep digital flexor tendon benefit from a raised heel shoe (Fig. 4C).[7] This allows the sole to be suspended and protected, encourages drainage, and improves comfort. Cases with sepsis of the navicular bone, bursa, or flexor tendon often respond well to temporary immobilization of the fetlock joint with a splint or cast bandage (Fig. 15).

If a bony sequestrum is present, it needs to be surgically removed and debrided to healthy bone margins, or swabbed out with gauze and the area thoroughly lavaged. For deep puncture wounds, establishing drainage is imperative. The use of Penrose drains can maintain an open drainage tract (Fig. 16A).

Debridement of serious infections of the foot can contribute to the damage of the delicate architecture of the foot. This structural damage to the foot can delay healing and prevent the foot from functioning normally again. For this reason, it is usually recommended to follow up with a light surgical debridement with larval therapy.[8] The medical-grade maggots can be used to provide additional nontraumatic debridement and speed healing (Fig. 16B).

The clinician can significantly affect wound healing in all phases, especially the debridement and repair phases. Having knowledge of foot anatomy and biomechanics can aid in formulating a mechanical plan to provide stability to aid healing. Tissue apposition and repairing wounds of the hoof capsule are imperative to prevent hoof capsule distortion and a dysfunctional result. Multiple diagnostic modalities are available to determine the extent of tissue involvement. The clinician has access to many treatment options to improve the outcome of complicated hoof injuries.

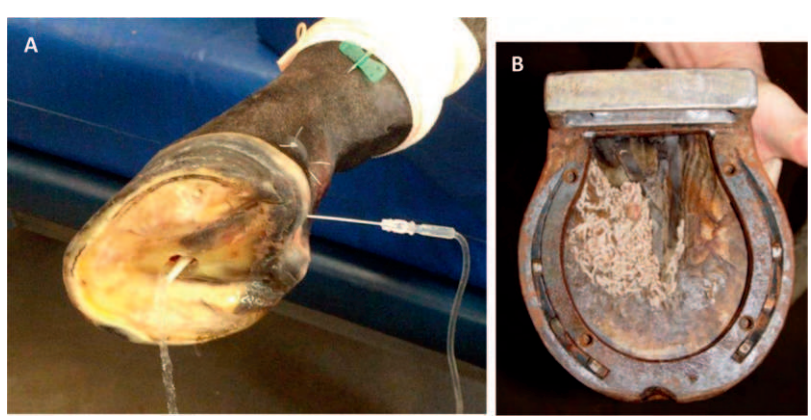


Fig. 16. A, A septic navicular bursa being lavaged and regionally perfused and a Penrose drain being placed into the puncture tract and sutured to the plantar pastern region. B, Larval therapy being used in a septic navicular bursa case.

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.

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Equine Postfixation Unilateral Twins Can Be Reduced by Fetal Compression

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Fetal compression is a successful technique for reducing postfixation, unilateral twins in the mare.
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1. Introduction

Management of postfixation twin pregnancy in the mare remains challenging because the success of most reduction techniques is disappointing.

2. Materials and Methods

Mares ($n = 16$) with twin pregnancies between 51 and 79 days of gestation were presented for twin reduction. Data regarding the mare (age, breed) and pregnancy (breeding technique: inseminated versus recipient of an *in vitro* produced [IVP] embryo, fixation: unilateral versus bilateral) was obtained from the owner/referring veterinarian. Twin reduction was performed by compressing the thorax of one fetus between the transrectal transducer and the ventral abdominal wall until the heartbeat slowed or stopped. Fetal compression was repeated on successive day(s) until the selected fetus was dead.

3. Results

Eleven of the submitted twins resulted after artificial insemination, while 5 mares carried monozygotic twins after transfer of an IVP embryo. The majority (94%) of the twin pregnancies were fixed unilaterally. The mean number of attempts required for fetal death was 4. The likelihood of success was significantly higher in artificially inseminated mares (73%) than in mares carrying IVP embryos (0%). None of the other factors examined had an influence on the outcome of fetal compression. To date, 7 mares in which the compression was successful have delivered a single healthy foal of normal size.

4. Discussion

Fetal compression appears to be more successful than other postfixation twin reduction techniques.

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.

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NOTES

Periovulatory Anticoagulant Therapy May Enhance Embryo Recovery Rates in Superovulated Mares: Preliminary Results

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A single periovulatory dose of 450 IU/kg of heparin sodium or 1 mg/kg of enoxaparin may enhance embryo recovery in superovulated mares. Authors' addresses: Department of Veterinary Surgery and Animal Reproduction, School of Veterinary Medicine and Animal Science, São Paulo State University "Júlio de Mesquita Filho," UNESP, Botucatu, Brazil (Rodrigues, Segabinazzi, Frasson, Dell'Aqua, Carmo, Wilmsen, Takahira, Alvarenga, Papa); Ross University School of Veterinary Medicine, PO Box 334, Basseterre, St. Kitts, West Indies (Segabinazzi); e-mail: lgseg@hotmail.com. *Corresponding and presenting author. © 2023 AAEP.

1. Introduction

Although protocols for superovulation have been described in mares, this technique has been discouraged due to low embryo recovery rates. The formation of a blood clot in the ovulation fossa following ovulation has been suggested as the reason for the frustrating results. Therefore, this study aimed to assess the effect of periovulatory anticoagulant therapy in superovulated mares.

2. Materials and Methods

In Experiment 1, 5 mares were assigned to receive 4 anticoagulant treatments in a crossover design: intravenous injections of 150 (H1)[22], 300 (H2), 400 (H3), 450 (H4), 600 (H5) IU/kg of heparin sodium.[a] Blood samples were collected sequentially (before to up to 24 hours after treatment) to test prothrombin (PT) and activated partial thromboplastin time (aPTT). In Experiment 2, 11 mares had 4 cycles randomly assigned to 4 different groups. In the control group, mares did not receive any treatment, whereas in groups G1, G2, and G3, mares were superovulated with equine pituitary extract and treated with placebo (sodium chloride 0.9%, G1), 450 IU/kg of heparin sodium[a] (G2), or 1 mg/kg of enoxaparin[b] 34 hours after the induction of ovulation. Mares in all groups had ovulation induced with human chorionic gonadotropin[c] plus histrelin acetate[d] and were bred with fresh semen from one stallion. Embryo flushing was

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performed 9 days postovulation. Data were analyzed with repeated-measures analysis of variance, Tukey's, and multivariate regression.

3. Results and Discussion

In Experiment 1, only mares in groups H4 and H5 had increased aPTT and PT ($P > 0.05$) for up to 12 hours, and in all groups, aPTT and PT values returned to baselines at 24 hours posttreatment ($P > 0.05$). However, 4 mares (80%, 4/5) in group H5 presented side effects (e.g., injection site bleeding and subcutaneous hematoma) immediately after treatment. In Experiment 2, more preovulatory follicles and ovulations per cycle were observed in G1-, G2-, and G3-assigned cycles compared to the control-assigned cycle ($P < 0.05$). Embryo recovery rate per cycle was greater in G2- (250%, 4.1-fold) and G3-assigned (260%, 4.3-fold) cycles ($P < 0.05$) compared to control-assigned cycles (60%), whereas G1-assigned cycles (160%) had intermediate embryo recovery ($P > 0.05$). In addition, when data were adjusted for the number of ovulations per cycle, embryo recovery was reduced in G1-assigned cycles (36%) compared with the control-assigned cycles (64%; $P < 0.05$). However, both G2- (50%) and G3-assigned (52%) cycles presented intermediate results statistically insignificant to the other groups ($P > 0.05$). In conclusion, periovulatory anticoagulant therapy may improve embryo recovery in superovulated mares.

Acknowledgments

Funding Sources

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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.

Footnotes

[a]Hemofol, Cristalia, São Paulo, Brazil.
[b]Versa®, Eurofarma, Brazil.
[c]Chorulon®, MSD Saúde Animal, São Paulo, Brazil.
[d]Strelin®, Botupharma, São Paulo, Brazil.

Effects of Feeding Oils and Supportive Nutrients on Skeletal Muscle and Oocyte Metabolism in Old Mares

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Feeding flaxseed or corn oil to old mares is associated with more oxidative stress in skeletal muscle; however, providing supplemental nutrients with the oils mitigates muscle oxidative stress and improves oocyte metabolism. Authors' address: Colorado State University, Equine Reproduction Lab, 3101 Rampart Road, Fort Collins, CO 80521; e-mail: giovana.catandi@gmail.com. *Corresponding and presenting author. © 2023 AAEP.

1. Introduction

Mare aging is associated with loss of body condition and impaired fertility. Oils are commonly fed to older mares, but effects on the ovarian follicle and oocyte are unclear. The present study tested the hypothesis that feeding old mares flaxseed oil, rich in omega-3 polyunsaturated fatty acids (PUFAs; N3), would be more beneficial than feeding corn oil, rich in omega-6 PUFAs (N6); but with either oil, optimal cell metabolism would require appropriate support nutrients.

2. Materials and Methods

Oocytes and granulosa cells from preovulatory follicles and skeletal muscle cells were collected from light-horse mares before they were divided into two groups and supplemented daily with 120 mL of N3 ($n = 6$ mares, 22.5 ± 1.2 years) or N6 ($n = 6$ mares, 23.2 ± 1.1 years) for 4 to 6 weeks before a second cell collection. The groups were then maintained on their respective oils with the addition of reproductive support supplements (RSS),[a] including a combination of omega-3 PUFAs, vitamins, trace minerals, amino acids, antioxidants, and probiotics, for 4 to 6 weeks before a third cell collection. Cellular metabolism was assessed by microsensors (oocytes) or high-resolution respirometry (granulosa cells and muscle). Comparisons were made among the three cell collections for N3 or N6 as repeated measures per mare.

3. Results and Discussion

Aerobic metabolism in oocytes did not change after feeding either oil; however, the addition of RSS with the oils resulted in greater oocyte aerobic metabolism for N3 ($p < 0.1$) and N6 ($p < 0.05$). Granulosa cells demonstrated wide sample variability, with inconsistent

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patterns in aerobic metabolism and ROS. Skeletal muscle aerobic metabolism was not affected by diet supplementations; however, reactive oxygen species (ROS) production was greater ($p < 0.05$) after feeding oils, although ROS was mitigated by the addition of RSS with either oil. Oils provide blends of fatty acids, which act as energy substrates that can affect cell metabolism and ROS. Support nutrients, such as RSS, help to optimize cell metabolic function in old mares. The benefits often associated with omega-3 versus omega-6 PUFAs were not assessed in the current study, and the inclusion of omega-3 PUFAs in RSS could have limited observable differences with short-term supplementation.

Acknowledgments

Disclaimer

An aqueous solution of deslorelin acetate[b] was used for induction of follicular maturation to maintain consistency with previous research. Compounded products can vary significantly in their respective potency.

Funding Sources

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Declaration of Ethics

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

Conflict of Interest

Some financial support was received from Platinum Performance for general research in our laboratory. However, they had no control over research in our laboratory, no control over the study design or implementation of this research, and no input as to publication content.

Footnotes

[a]Platinum Performance®, Inc., Buellton, CA 93427.
[b]Doc Lane, Lexington, KY 40511.

Non-Traditional (Emergency) Hormone Therapy Options for Embryo Transfer Recipient Mares

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Anestrus recipient mares administered estradiol and progesterone and diestrus recipient mares short-cycled with prostaglandins and immediately administered estradiol and progesterone have similar initial pregnancy rates and pregnancy loss rates as naturally cycling recipient mares.
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1. Introduction

Equine embryo transfer is a routine procedure in clinical veterinary practice. The dearth of recipient mares may necessitate the use of a hormone treated non-cycling mare or short-cycling a diestrus mare to be used as a recipient mare. The goals of this study were to 1) describe a hormone therapy protocol to set up an anestrus recipient mare to receive an embryo, 2) describe a hormone therapy protocol that can be used in an "emergency situation" to rapidly turn around a recipient mare in mid-diestrus to receive an embryo, and 3) report pregnancy outcomes in hormone treated anestrus mares, hormone manipulated cycling mares, and naturally cycling recipient mares.

2. Materials and Methods

The hormone therapy protocol for deep anestrus mares consisted of intramuscular administration of estradiol-17β (6.66 mg, IM, q 24 h) for 2 days (Day -2 and -1) beginning the day the donor mare ovulated. This was followed by administration of a compounded short-acting progesterone preparation (200 mg, IM, q 24 h) for 7 days (Days 0-6), starting two days post-ovulation in the donor mare. The day of the first dose of progesterone administration in the recipient mare was considered to be Day 0. The hormone therapy protocol for transitional mares was similar, but estradiol-17β is optional and may not be administered if ultrasound examination reveals the presence of moderate endometrial edema. In the event that a donor mare has just ovulated, and no qualified anestrus, transitional, or cycling mares in estrus are available, an "emergency" protocol can be utilized on a cycling recipient mare in mid-diestrus. A dose of cloprostenol (250 μg, IM, once) would be administered along with a dose of estradiol-17β (6.66 mg, IM, q 24 h) for two days in a

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row. The recipient mare would then be administered a short-acting progesterone preparation (200 mg, IM, q 24 h) for 7 days. A traditional synchronization protocol is to administer an ovulation induction agent, such as histrelin, deslorelin, or human chorionic gonadotropin (hCG) to a recipient mare with a large dominant follicle in the presence of uterine edema the day the donor mare ovulated. Reproductive records of embryo transfer recipient mares from five consecutive breeding seasons (2018 to 2022) were evaluated. Embryo transfers were performed using either a traditional manual transcervical technique or through a vaginal speculum with cervical forceps. Recipient mares were administered acepromazine (10 mg, IV, once) alone or a combination of acepromazine and xylazine (150 mg, IV, once), as well as flunixin meglumine (500 mg, IV, once) prior to transfer. Group I mares (anestrus or transitional) and Group II mares (short-cycled diestrus mares) were continued on short-acting progesterone (200 mg, IM, q 24 h) after transfer until pregnancy status was confirmed. Pregnant mares started on short-acting progesterone were switched to a compounded long-acting progesterone preparation (1,500 mg, IM, q 7 days). Group III mares (traditional cycling mares) were administered altrenogest (0.044 mg/kg, PO, q 24 h) after transfer until pregnancy status was confirmed. All pregnant mares remained on exogenous progesterone/progestin therapy until 120 days of gestation. Initial ultrasound pregnancy exams were performed between 12 and 16 days of embryo age. Additional pregnancy examinations were performed on days 25, 35, and 45 of gestation. Differences in pregnancy rates and embryonic loss rates were analyzed using χ^2 analysis. Data were considered significantly different at $p < 0.05$.

3. Results

The overall initial pregnancy rate combining all mares in all groups was 74.6%. Pregnancy rates at days 12 to 16, day 25, day 35, and day 45 were not significantly different ($p > 0.05$) between groups. Initial pregnancy rates were 79.8% for hormone-treated anestrus or transitional mares, 74.6% for hormone treated short-cycled diestrus mares, and 72.8% for traditional cycling mares. Pregnancy loss rates were not significantly different ($p > 0.05$) between groups during any of the time intervals. Embryonic loss was highest in every group between the initial pregnancy examination (day 12 to 16) and day 25 of gestation, with anestrus/transitional mares experiencing an early pregnancy loss rate of 12.3%, and short-cycled diestrus mares and normal diestrus mares experiencing early pregnancy loss rates of 6.4% and 11.9%, respectively. Thereafter, with all groups combined, the pregnancy loss between days 25 and 35 was 0.8%, and pregnancy loss between days 35 and 45 was 1.3%.

4. Discussion

If a cycling recipient is not available to synchronize with a donor mare, a mare in either deep anestrus or spring transition can be used as a recipient following hormone therapy. Sequential administration of estradiol-17β and progesterone will enable a deep anestrus mare to be a functional embryo recipient within 7 to 9 days. There was no difference in pregnancy rates or pregnancy loss rates between non-cycling (deep anestrus or transitional) recipient mares administered estrogen and progesterone, short-cycled diestrus mares administered estrogen and progesterone, and normal cycling recipient mares. A manual transcervical technique was used for transfer of embryos in the initial 4 years of the study. In the final year reported, all embryos were transferred using a stainless-steel Polansky vaginal speculum, light source, and cervical forceps. There was no difference in transfer success rate between the two techniques (75% vs. 73%). In summary, hormone treated deep anestrus or transitional mares can be successfully used as recipient mares. In addition, in an "emergency," the day a donor mare ovulates, a diestrus mare can be administered prostaglandins to lyse her corpus luteum and immediately started on a protocol of 2 days of estradiol followed by 5 to 7 days of progesterone. The pregnancy rates and pregnancy loss rates of hormone treated non-cycling mares and short-cycled diestrus mares are not different from those of normal cycling mares.

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.

Gonadotropin and Testosterone Concentrations in Response to Long-Acting Deslorelin Acetate in Stallions

Igor Canisso, DVM, MSc, PhD, DACT, DECAR

Deslorelin acetate stimulates the release of follicle-stimulating hormone, luteinizing hormone, and testosterone in a dose-dependent manner in stallions; however, the latter is significantly smaller than human chorionic gonadotropin administration. Author's address: University of Illinois, 1102 West Hazelwood Drive, Urbana, IL 61802; e-mail: canisso@illinois.edu. © 2023 AAEP.

1. Introduction

Testosterone-stimulation protocols (TSPs) to detect cryptorchidism and improve libido and testicular function have been primarily based on human chorionic gonadotropin (hCG) administration and less commonly using short-acting gonadotropin-releasing hormone agonists; however, the latter TSPs also stimulate gonadotropins to assess the hypothalamic-pituitary-testis axis. Deslorelin acetate is a long-acting gonadotropin-releasing hormone agonist labeled to induce ovulation and has been anecdotally used in stallions but not critically tested. This study aimed to compare (i) testosterone concentrations following administration of hCG and deslorelin acetate and (ii) concentrations of follicle-stimulating hormone (FSH), luteinizing hormone (LH), and testosterone in stallions receiving the mare-labeled dose (1.8 mg) and double-labeled dose (3.6 mg) of deslorelin acetate for induction of ovulation.

2. Materials and Methods

Eleven stallions (5–17 years old) were enrolled over 6 weeks during the breeding season to randomly receive TSP: (i) hCG (10,000 IU, IV) or (ii) deslorelin acetate (1.8 mg and 3.6 mg, IM). Plasma samples were collected before each TSP and then repeated 1, 2, 24, and 48 hours later. Concentrations of testosterone, FSH, and LH were determined by radioimmunoassay and results expressed as means ± standard error of the mean and mean percent change (MPC). Data were log-transformed and analyzed by mixed model with least significant difference as post hoc significance was set at $p < 0.05$.

3. Results and Discussion

Administration of hCG significantly increased testosterone concentrations throughout; specifically, by 1 hour, the MPC of testosterone increased 294% from baseline, and by 48 hours, the MPC was 608% above baseline. Testosterone reached peak at 2 hours after either dose of deslorelin and returned to baseline within 24 hours. Deslorelin of 1.8 mg increased the MPC of testosterone to 84%, whereas 3.6 mg of deslorelin caused a 168% increase. Deslorelin acetate increased testosterone, LH, and FSH significantly in a

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dose-dependent manner; peaking plasma concentrations were achieved at 2 hours. Deslorelin, 1.8 mg, induced a peak MPC of 168% for LH and 116% for FSH. Similarly, 3.6 mg deslorelin caused an MPC of 168% for LH and 167% for FSH. Levels of FSH and LH decreased by 24 hours and returned to baseline by 48 hours. This study demonstrates that deslorelin acetate stimulates the release of FSH, LH, and testosterone in stallions and could be used to assess the hypothalamic-pituitary-adrenal axis. However, deslorelin acetate induced a significantly smaller MPC in testosterone concentrations than hCG administration.

Acknowledgments

Declaration of Ethics

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Conflict of Interest

The author has no conflicts of interest.

Footnotes

[a]Chorulon®, Merck, Rahway, NJ 07065.
[b]Sucro-Mate™, Thorn Scientific LLC, Louisville, KY 40204.

Postbreeding Antibiotic Infusion Does Not Improve First-Cycle Pregnancy Rates in Selected Healthy Thoroughbred Mares

C. Scott Bailey, DVM, MS, DACT*; Thalita Leite, DVM; and Morgan Edwards, BS

Postbreeding antibiotic infusion can be omitted in healthy mares with "ideal" cycles. Limiting prophylactic treatment increases efficiency and preserves antimicrobial medications for animals with a higher risk for conception failure or early embryonic loss. Authors' address: Claiborne Farm, 707 Winchester Road, Paris, KY 40361; e-mail: csbailey@ncsu.edu. *Corresponding and presenting author. © 2023 AAEP.

1. Introduction

Veterinarians in large breeding centers are faced with a conundrum. The financial, scheduling efficiency, and emotional pressures inherent in these operations dictate that "everything possible" be done to maximize conception rates each cycle. To accomplish this, postbreeding antibiotic infusion has been an inexpensive tool that was first widely supported in two large retrospective studies by Pascoe in 1990 and then Pycock and Newcombe six years later. In these studies, mares treated with antibiotics (ABX) had a higher conception rate than untreated mares.[1,2] However, with the rise of antibiotic resistance, moral and regulatory imperatives direct veterinarians to limit routine prophylactic antibiotic use. Multiple sources predict that antibiotic resistant microbes will be a major cause of morbidity and mortality in humans and animals in the near future.[3,4] In response, public policy guidelines and regulations have progressively restricted veterinary antibiotic use, which may in turn limit conception rates and increase pressure on veterinarians and producers.

To accommodate these conflicting imperatives, the authors aimed to determine whether routine postbreeding infusions could be omitted in maiden and foaling Thoroughbred mares with predetermined "ideal" breeding cycles without affecting conception rates. Antibiotic infusions were therefore not performed in first-cycle mares that had ovulated prior to the first postbreeding check and had no evidence of previous or ongoing pathologic inflammation as determined by intrauterine fluid or excessive edema. In addition to avoiding unnecessary use of antibiotics, omission of a trans-cervical procedure had the potential benefit of avoiding cervical manipulation and potential contamination of the uterus during early diestrus. Although not studied in early diestrus, cervical manipulation is associated with an increase in oxytocin and prostaglandin and a reduction in the length of diestrus by day 7.[5] Additionally, it is well-recognized that the uterine response to bacterial contamination is impaired during diestrus and that antibiotic therapy is often not effective at eliminating infections while mares are under the influence of progesterone.[6]

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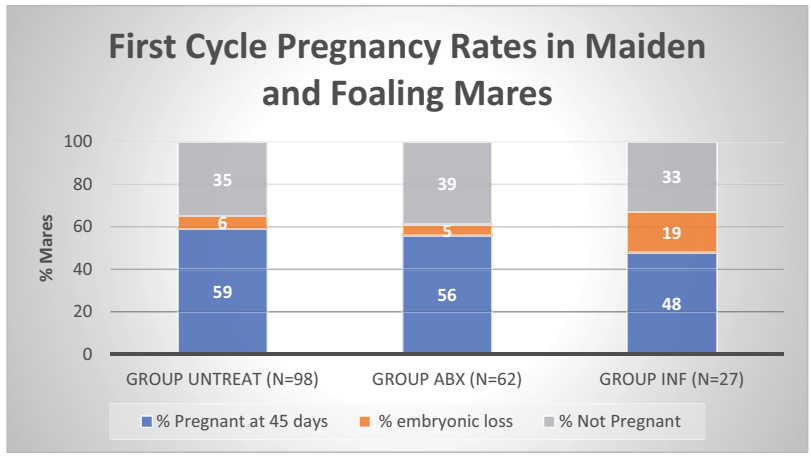


Fig. 1. First cycle pregnancy (1CP) and EED rates in maiden and foaling mares were not different between groups ($p > .2$). Group INF tended to have lower 1CP and higher EED rates than the other groups combined ($p = .06$).

2. Materials and Methods

The following protocol was developed for treatment of first-cycle maiden mares in 2021 and maiden and foaling mares in 2022. A negative culture was obtained from maiden mares but not required for foaling mares. All mares were monitored routinely via transrectal palpation and ultrasound. Mares were allowed to cycle naturally without hormonal treatment to induce estrus. Breeding was requested once the mare had a follicle of 35 mm or greater and grade 2 edema or greater on the second (postfoaling) cycle of the year. A GnRH analog was used as an ovulation inducing agent within 16 hours prior to scheduled breeding. Mares were then examined within 12–24 hours postbreeding. At this time, mares that had ovulated prior to the postbreeding examination, had <0.5 mm fluid throughout the breeding cycle, and had a uterine edema score of 2 or lower were passed over without a postbreeding antibiotic infusion (Group UNTREAT). Mares that had not ovulated by the first examination were treated with an infusion of 7.2 million IU procaine penicillin and 600 mg gentamicin, extended to 60 mL with lactated Ringers' solution (LRS; Group ABX). Mares that had evidence of persistent inflammation or infection (>0.5 mm fluid at any time in the cycle, or excessive edema postbreeding) were treated with an infusion of 7.2 million IU procaine penicillin and 600 mg gentamicin, extended to 60 mL with LRS and complementary therapy as deemed necessary (Group INF). Statistical analysis was performed prospectively between groups using a publicly available Chi Square calculator to compare first cycle pregnancy (1CP) and embryonic loss rates (EED) between groups. In addition, retrospective comparison of cycles per pregnancy (C/P), EED and seasonal pregnancy rate (PR) was performed in foaling mares that were bred in both the 2020 and 2021 breeding seasons.

3. Results

Out of 187 mares bred, 98 were not treated, 62 received a single postbreeding antibiotic infusion, and 27 were treated for inflammation or infection. First cycle pregnancy rate and EED were not statistically different between groups (59%,6% for UNTREAT; 56%,5% for ABX; 48%,19% INF: $p = .2$; Fig 1). However, Group INF tended to have higher EED and lower 1CP compared to the other two groups combined ($p = .06$).

One hundred and two mares foaled and were rebred in both years. Of those, 41 were in Group UNTREAT. There was no statistical difference in C/P, EED, or PR between the years. Mares had a numerically lower C/P but higher EED in 2022 compared to 2021 (C/P 1.47 vs 1.49; EED 8% vs 4%; PR 85% vs 100%: $p > .1$). This effect was independent of treatment group (Table 1).

4. Discussion

This is the first study designed to identify a group of mares that does not benefit from postbreeding

Table 1. Breeding Results in Mares That Foaled in Both 2021 and 2022 by Group and Year

	Group UNTREAT (n = 41)		GROUP ABX (n = 43)		Group INF (N = 17)	
Year	2022	2021	2022	2021	2022	2021
Cycles per pregnancy	1.325	1.571429	1.625	1.347826	1.5	1.647059
Early Embryonic Loss	0.05	0.02	0.1	0.07	0.14	0
Pregnancy rate	0.9	1	0.88	1	0.71	1

Cycles per pregnancy, EED, and seasonal pregnancy rate in foaling mares bred both in 2021 and 2022 were not different between years, regardless of treatment group.

treatment, as opposed to testing whether a treatment improves outcomes in a particular population. The findings of this study suggest that postbreeding antibiotic infusion can be omitted in healthy mares without evidence of inflammation and which have ovulated within 12-24 hours after ovulation. These findings support a recent comprehensive Cochrane-style review of reproductive treatments which failed to demonstrate strong evidence for any proposed treatment.[7] Omission of a postbreeding treatment in this group would conserve antibiotic use for a potential higher-risk population of mares and have the additional benefit of reducing time spent per mare for routine procedures.

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.

Disclaimer

Compounded products can vary significantly in their respective potency and stability.

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How to Discuss Transvaginal Aspiration with Clients: A Clinical Perspective

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Transvaginal aspiration (TVA) and shipment of oocytes is becoming a routine procedure in clinical practice. This paper will help practitioners discuss with their clients the costs associated with TVA versus embryo transfer, complications post-TVA, and time frames to return to work. Authors' address: Summit Equine, Inc., 6460 Highway 219 NE, Gervais, OR 97026; e-mail: rferris@summitequineinc.com. *Corresponding and presenting author. © 2023 AAEP.

1. Introduction

In the past few years, transvaginal aspiration (TVA) and intracytoplasmic sperm injection (ICSI) have become common in broodmare management.[1,2] The increased rate in TVA has been occurring at both facilities that offer TVA and ICSI onsite and at facilities where TVA is performed at one location and with the resulting oocytes being shipped to a separate ICSI laboratory. This increase in demand is likely due to the overall success of TVA/ICSI in many commercial programs, with an average of at least one embryo being produced in 70% of TVA procedures.[3]

While TVA and ICSI were initially used for problem mares, this technology has great demand in performance horses due to the decreased amount of time off work, the ability to schedule the TVA procedure weeks to months in advance, and the ability to perform this procedure in noncycling mares. With the overall success of TVA in clinical practices around the world, clients are asking many questions about the procedure: What is the cost compared to embryo transfer (ET)? Is TVA painful for my horse? When can my mare go back to work? The goal of this paper is to review pain following the TVA procedure in a clinical program, compare costs of TVA/ICSI versus ET, and survey clients on training and performance post-TVA procedure.

2. Materials and Methods

Medical records from 2021 and 2022 were reviewed for TVA procedures performed and notes on complications in the 24 hours post TVA. The TVA procedure is well described, but briefly,[4] mares were sedated with 0.04 mg/kg acepromazine[a] IM 20 minutes before being restrained in stocks and sedated with 0.01 mg/kg detomidine hydrochorlide,[b] 0.01 mg/kg butorphanol tartrate,[c] and 0.02 mg/kg acepromazine IV. Preprocedural medications include 0.9 mg/kg N-butylscopalammonium bromide[d] IV, 1.1 mg/kg flunixin meglumine[e] IV, 0.02 mg/kg dexamethasone[f] IV, 6.6 mg/kg gentamicin sulfate[g] IV, and 22,000 IU/kg penicillin IM[h] or IV.[i] The transvaginal TVA probe was placed into the vaginal vault and the ovary guided to the vaginal wall via rectal palpation. A 12-gauge double lumen needle[j] was

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advanced through the vaginal wall, ovary, and follicular wall into the center of the follicle. Once in the follicle, a vacuum was applied (flow of ~20–30 mL per minute) to aspirate the follicular fluid, the needle was rotated to scrape the follicular wall, and the follicle was flushed with an embryo flush medium[k] containing 5 IU heparin/mL. This was repeated until all follicles >5 mm aspirated on both ovaries. Recovered oocytes were placed into a commercial embryo holding media[l] and transferred to a 20°C temperature-controlled incubator with delivery of the oocytes to the ICSI laboratory within 24 hours of collection. Stallion selection for ICSI was based on client request; all horses in this study utilized frozen semen for fertilizing the oocytes, and resulting embryos were sent to 1 of 2 commercial recipient herds.

Mares were monitored postprocedure with walk-by evaluations at 2 and 4 hours post-TVA. If discomfort (based on subjective depressed appearance or horse grimace scale >8)[5] was identified, pain medications were administered and recorded. All mares received a full physical exam 6 to 8 and 22 to 24 hours post-TVA, and records were evaluated for changes in heart rate (>36 beats per minutes), respiratory rate (>16 breaths per minute), and body temperature (>101.5). Additional comments were evaluated for anything out of the ordinary for the horse (e.g., off feed, slow to eat, lack of manure production).

Client billing statements were reviewed for mares that had undergone a TVA procedure and for which a resulting pregnancy was obtained in a recipient mare. For comparison, the next ET mare being bred with cool shipped semen in the medical records by date from when the TVA procedure was performed was selected with the criteria of age (within ± 2 years) and similar breed. Only 2 recipient herds were utilized for pregnancy evaluation to control for this variable. Only TVA/ET donor mares in which a pregnancy was verified in the recipient resulting in a live foal or pregnancy confirmation at 7 months of gestation were included in this evaluation. The cost to produce a pregnancy by TVA/ICSI and ET was reported for the services rendered by the veterinary team to generate the embryo and the ICSI laboratory fees minus the cost of the recipients. The cost of the recipient was removed as the 2 commercial herds used in this study have different pricing structures making comparison difficult. To prevent issues arising from cost fixing, the costs were normalized to that of producing a pregnancy by embryo transfer. If the TVA value is <1, this indicates the cost for a TVA pregnancy was less expensive than an ET pregnancy; if the TVA value is >1, this indicates the cost for a TVA pregnancy was more expensive than an ET pregnancy. A second comparison looking at the total costs of ET versus TVA/ICSI was performed, with an estimated cost of $550 added to each required shipment of semen to the veterinary center for ET or ICSI laboratory.

Clients/trainers with performance mares that underwent TVA in 2021 to 2022 were surveyed with the following questions: How soon after TVA did you start riding/training? Did you notice any changes post-TVA in the horse's behavior or husbandry? Did you notice any changes in your horse's training post-TVA? Comparing show performance before and after TVA, did you notice a decrease/no change/increase in performance? What was the time interval between the TVA procedure and the next competition? Would you recommend TVA to other clients?

Statistical analysis was performed by a student's *t* test with a *P* value of 0.05 considered significant.

3. Results

In the period of 2021 and 2022, 112 TVA sessions were performed on 52 mares ranging in age from 2 to 26 years. The decision to perform TVA was at clients' request, semen availability, or clinician recommendations based on status of current reproductive performance.

Complications Post-TVA

In the 2 to 4 hours post-TVA, 11 of the 112 TVA (10%) procedure mares were observed to be uncomfortable (horse grimace scale >8, or depressed) as observed by the facility's horse care team. In all instances, 0.02 mg/kg of butorphanol tartrate was administered via subcutaneous injection. Alternations in the physical exam were found in 0 of the 112 mares (0%) at 6 to 8 hours and 0 of the 112 mares (0%) at 22 to 24 hours post-TVA. None of the 11 events observed 2 to 4 hours post-TVA had alterations to their physical exam or feeding charts at the later points.

Time to Return to Work

Follow-up for show mares (reining, cutting, dressage, and cowhorse) was provided for 6 trainers and 10 mares, representing 36 TVA procedures with a range of 1 to 10 TVA sessions in 2021 to 2022. These mares were put back into training 1.3 days (range 1–2) after the TVA session. In one mare, it was noted during the first training ride post-TVA that the mare was tight in the hind end. There were no recognized differences in training in the 9 other mares following TVA. No changes regarding soundness, appetite, or attitude were observed by the owners/trainers following TVA. All the surveys indicated the same level of performance at shows pre-TVA compared to post-TVA. The average range of days from TVA to next competition was 3 to 45 days. All the trainers (6 of 6) would recommend TVA as an option to their clients.

Costs Associated with TVA Versus ET

In the time frame of this study, 14 fresh pregnancies were established by ICSI in recipient mares, and 14 control ET cycles were identified. The average age for donors for ICSI and ET cycles was not statistically different (12.4 vs 12.1, respectively). For the 14 ICSI mares, 7 mares were classified as performance horses and 7 mares were classified as broodmares. For the ET control mares, 7 mares were classified as

Table 1. Average Results and Cost to Produce an ICSI or ET Pregnancy in a Recipient Mare

	Embryo Transfer				TVA/ICSI			
	Number of ET Cycles to Achieve a Pregnancy	Time at Facility (Days)	Veterinary Center Cost of ET to Achieve a Pregnancy	Total Cost of ET to Achieve a Pregnancy	Number of Cycles to Achieve a Pregnancy	Time at Facility (Days)	Veterinary Center and ICSI Laboratory Fees to Achieve a Pregnancy	Total Cost of TVA/ICSI to Achieve a Pregnancy
Average	1.7[a]	25.5[a]	X[a]	X[a]	1.4[a]	15.2[a]	1.7X[b]	1.2X[a]
Median	1	22[a]	Y[a]	Y[a]	1[a]	6[a]	1.8Y[b]	1.4Y[a]

Abbreviations: TVA, transvaginal aspiration; ICSI, intracytoplasmic sperm injection; ET, embryo transfer. These calculations do not include recipient mare lease agreements. Total cost of TVA/ICSI includes costs to ship semen for breeding/ICSI events. Differences in superscript indicate a statistically significant difference ($P < 0.05$).

performance horses and 7 mares were classified as broodmares. The average number of cycles to generate a pregnancy in a recipient was not different ($P > 0.05$) for ET (1.7) and TVA (1.4; Table 1). The duration that the mare was at the facility was not different ($p > 0.05$) for donors in the ET or TVA program (Table 1). The average cost for veterinary and laboratory services to generate a pregnancy in a recipient mare was significantly higher ($P < 0.05$) for mares undergoing TVA (1.7X) as compared to ET (X; Table 1). The average number of semen shipments was greater ($P < 0.05$) for mares undergoing ET (1.7) as compared to TVA (0.1). When factoring costs associated with semen shipments into clients' total average cost for a pregnant recipient, there was no difference ($p > 0.05$) between ET (X) and TVA/ICSI (1.2X). Additionally, of the 14 mares undergoing TVA, 6 of these mares had a combined 15 frozen embryos for future use.

4. Discussion

The observed complication rates in this study were low, with 10% of horses experiencing an increase in pain in the 2 to 4 hours post-TVA, with no additional alterations to physical exam or behavior in the 24 hours post-TVA while at the veterinary center. Follow-up surveys from a small subset of clients did not report any complications following TVA about being off feed or restrictions from training. Previous studies have indicated that in the 24 hours post-TVA, 7% to 24% of mares will show signs of moderate to severe discomfort (fever, loss of appetite, lethargy, lying down, or pawing).[6,7] While the current study did have a 10% incidence of discomfort post-TVA, this was limited to discomfort detected by behavioral evaluation and increased horse grimace scale. None of the mares during the 112 TVA sessions exhibited fever, loss of appetite, lethargy, laying down, or pawing as observed in previous work. A study evaluating the use of TVA in field conditions did not note any change in the mares following TVA ($n = 66$).[8] The process of TVA is similar between the current study and previous work except that previous work utilized an epidural during the TVA procedure.[6] The current study did utilize pain relieving medication early postprocedure, potentially before signs of more serious discomfort developed. It is difficult to conclude exactly why the incidence of complications and severity was different from the published literature. Potentially, clinician experience or differences in aggressiveness in scraping the follicular wall leads to more pain in some mares post-TVA. However, based on this current evaluation, TVA is a safe procedure with minimal to no postprocedure discomfort.

Many clients are interested in using TVA as a replacement for ET because of the fact that the time off work is minimal and that these procedures can be scheduled weeks or months in advance. Trainers in this study put mares back into normal training 1 to 2 days after the TVA procedure. The only abnormal observation was in 1 of the 10 mares, represented by a stiffness in her back initially when starting to be put back into training. The trainer reported that this could be from the TVA, or it could be because the mare often does this when not in active training for a few days. The trainers (6/6) did not report any change in performance in this population of show mares, with 1 mare showing at the same level only 3 days post-TVA. The low rate of postoperative pain in the current study may explain why minimal complications were observed by trainers in the 1 to 2 days post-TVA.

Clients are always trying to determine if new technologies are less expensive as compared to traditional breeding methods. Based on the current study, TVA/ICSI may not always cost more as compared to ET. When evaluated for veterinary and laboratory services only, TVA/ICSI does cost significantly more to generate a pregnancy in a recipient on average as compared to ET. This is likely not surprising overall given the technological expertise needed to perform TVA and ICSI as compared to ET. However, when including $550 per shipment in costs for shipping semen as required for the mares in this study, the overall costs to the clients increased for ET but not for TVA/ICSI, resulting in costs of X and 1.2X, respectively. This observation is easily explained with the storage of frozen semen at the ICSI laboratory, which reduces clients' costs per TVA session. One limitation with this study is the limited number of cases due to the strict criteria of a pregnancy confirmation in a recipient at 7 months or birth of a live foal. This was done to confirm that pregnancies were well established as ICSI is associated with a higher embryonic

loss rate as compared to ET. Additionally, this study does not consider the overall costs in which a pregnancy via ET or ICSI was not established.

It was surprising that the final cost to generate a pregnancy in a recipient for a client was similar between TVA/ICSI and ET. Case selection is key in deciding ET versus TVA/ICSI. If the clinician's prognosis is that it will require 2 to 3 cycles to generate a pregnancy by ET, a better recommendation for success and cost to the client may be TVA/ICSI. If the prognosis for the client is that only 1 to 2 cycles will be required to generate a pregnancy by ET, this is likely to be the most cost-effective manner to generate a pregnancy. TVA/ICSI will have a distinct advantage over ET when clients are looking for ease in scheduling, especially with young show mares. An additional financial factor that is difficult to predict for clients is that 6 of the 14 TVA/ICSI mares had a total of 15 additional frozen embryos awaiting transfer into a recipient mare. This overall embryo production efficiency in some mares makes TVA/ICSI a much more lucrative procedure as compared to ET. Further work is warranted in predicting which mares will be better suited for ET as compared to TVA/ICSI.

In summary, TVA is going to continue to increase in frequency in many practices throughout the United States. These results indicate that TVA is a safe procedure with minimal to no postoperative pain or complications. With the low rate of complications, mares undergoing this procedure can enter training or even competition quickly following the procedure. The overall final cost to generate a pregnancy is similar for TVA/ICSI and ET, but case selection is key in determining which technology is best for individual mares and clients.

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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[a]Acepromazine maleate, Covetrus North America, Dublin, OH 43017.
[b]Dormosedan©, Zoetis, Florham, NJ 07932.
[c]Dolorex©, Merck and Co. Inc., Kenilworth, NJ 07033.
[d]Buscopan©, Boehinger Ingelheim Animal Health, Duluth, GA 30096.
[e]Flunixin meglumine, Covetrus North America, Dublin, OH 43017.
[f]Dexamethone 2 mg/mL, Covetrus North America, Dublin, OH 43017.
[g]Gentamicin sulfate, Covetrus North America, Dublin, OH 43017.
[h]Norocillin, Norbrook®, Lenexa, KS 66219.
[i]Penicillin G Potassium, WG Critical Care, LLC, Paramus, NJ 07652.
[j]Needle, cannula, and tubing setup, Minitube USA, Verona, WI 53593.
[k]Complete Flush Media, Vetoquinol USA, Fort Worth, TX 76137.
[l]ABT Holding, ABT360 LLC, Pullman, WA 99163.

Use of Time Lapse Imaging as a Prediction of Pregnancy Potential of in vitro Produced Embryos

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Timing from fertilization to cleavage and vitrification of in vitro produced embryos can help classify embryos according to their pregnancy potential and in return indicate pregnancy outcome.
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1. Introduction

The production of embryos by transvaginal aspiration of oocytes and intracytoplasmic sperm injection has become a routine procedure in horses worldwide. Despite advances in embryo production techniques, there are no standardized embryo evaluation protocols that can relate embryonic features to pregnancy outcome. To help solve this issue and improve in vitro embryo production, innovative methods for embryo analysis methods need to be explored.

2. Materials and Methods

Embryo morphokinetics and developmental parameters were evaluated retrospectively from in vitro produced embryos through time-lapse imaging. Developmental time points were associated with pregnancy rates and early embryonic loss.

3. Results

Embryos that yielded a pregnancy at 14 days after transfer had a shorter time interval from fertilization to cleavage ($p = 0.05$; $M \pm SD = 20.5 \pm 2.3$ hours vs. 24.6 ± 4.5 hours) as well as a shorter timeline to subsequent vitrification ($p = 0.04$; $M \pm SD = 197.5 \pm 28.9$ hours vs. 232.5 ± 39.9 hours). The percentage of excluded blastomeres on compaction was higher ($p = 0.04$) for nonpregnant (median = 45%; minimum = 10%; maximum = 60%) than pregnant embryos (median = 25%; minimum = 0%; maximum = 50%).

4. Discussion

According to these results, time-lapse imaging could be a useful tool for optimizing in vitro production of equine embryos. Embryonic morphokinetic features such as timing to cleavage as well as the

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level of blastomere exclusion, besides the previously known time-to-blastocyst formation, could be used as a routine method of embryo quality evaluation. Using a higher number of embryos could shed more light on the importance of the morphokinetics of embryos on the outcome of in vitro production programs.

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.

Anti-Müllerian Hormone and Testosterone Levels Are Not Often Associated with Persistent Stallion-Like Behavior in Supposed Geldings

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Persistent stallion-like behavior in supposed geldings is rarely associated with presence of testicular tissue as indicated by testicular hormones such as Anti-Müllerian Hormone (AMH) and testosterone. Authors' address: University of California – Davis, 1089 Veterinary Medicine Drive, Davis, CA 95616; e-mail: pdini@ucdavis.edu. *Corresponding author; †presenting author. © 2023 AAEP.

1. Introduction

Persistent stallion-like and/or aggressive behavior is a common symptom of cryptorchidism or incomplete castration in supposed geldings. Hormones secreted by Leydig and Sertoli cells in testicular tissues, such as testosterone and anti-Müllerian hormone (AMH), can be used to evaluate the possible presence of testicular tissues in suspected cases. This study aimed to determine the frequency of testicular tissue presence and its association to stallion-like behavior in supposed geldings.

2. Materials and Methods

Out of 4,050 submissions, 1,202 samples submitted with the words stallion/stud-like -behavior, -behave, -behavior, or -behaving in their history were analyzed. Association between reported behavior and concentrations of testosterone and AMH were assessed using a chi-square test of association.

3. Results

Significantly, a higher portion of the samples (82.8%) had serum concentrations of testosterone below the laboratory range for cryptorchids (<100 pg/ml). Similarly, 77.8% did not reach cryptorchid/stallion-like concentrations of AMH (>0.15 ng/ml), indicating an absence of any testicular tissue. A total of 54 samples were analyzed from horses that displayed aggression towards people or other horses, excluding any sexual or "stud-like" behavior. In 43 cases (79.6%), neither AMH nor testosterone reached cryptorchid-like concentrations. Among the remaining 11 horses, all had elevated AMH levels, and three cases showed elevated levels of both AMH and testosterone.

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4. Discussion

The results of this study highlight the complexity of behavior in horses and demonstrate that persistent stallion-like behavior in geldings could be related to factors different than the presence of testicular tissue and its biomarkers such as AMH and testosterone. A limitation is that this study relies on the reported behavior in the sample submissions and hormonal evaluation.

Acknowledgments

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Conflict of Interest

The authors have no conflicts of interest.

The Effect of Inhaled Ciclesonide Treatment on Systemic Markers of Immune Function in Horses

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A standard course of inhaled ciclesonide treatment did not result in messenger RNA changes indicative of systemic immunosuppression while a course of intravenous dexamethasone did. Authors' addresses: University of Kentucky Maxwell H. Gluck Equine Research Center, Lexington, KY 40546 (Page, Johnson, Parker, Jacob, Adam); University of Kentucky Veterinary Diagnostic Laboratory, Lexington, KY 40511 (Swan); e-mail: a.page@uky.edu. *Corresponding and presenting author. © 2023 AAEP.

1. Introduction

While environmental changes can augment successful management of equine asthma, medication is still the mainstay of treatment for airway inflammation. The use of dexamethasone to control equine asthma, especially during an acute crisis, is a common and effective treatment, supported both by its widespread clinical use and reports in the scientific literature. Although short-term systemic dexamethasone treatment has not been shown to induce systemic immunosuppression in the horse, this could reflect the lack of specific research to address this possibility. As such, the goal of this study was to determine whether inhaled ciclesonide, an FDA-approved drug for the treatment of equine asthma, exerts any systemic immunosuppressive effects when compared to dexamethasone-treated and untreated horses.

2. Materials and Methods

Eighteen light, mixed breed horses, ranging in age from 3 to 8 years of age, were used for this study and blocked by asthma status, as determined by bronchoalveolar lavage, prior to random allocation to one of three treatment groups: (1) non-treated controls; (2) ciclesonide treatment (8 actuations (343 mcg ciclesonide/actuation) q 12 h for 5 days, followed by 12 actuations q 24 h for 5 days); or (3) dexamethasone treatment (0.04 mg/kg IV q 24 h for 10 days). Blood was collected daily into a commercially available RNA stabilization blood collection tube[a] for steady-state messenger RNA (mRNA) analysis, as well as at days 0, 5, 10, and 15 of treatment for in vitro stimulation with Concanavalin A (ConA). Messenger RNA relative quantities were determined using RT-qPCR for *ALOX5AP*, *Granzyme B*, *Interferon-*γ, *IL-1*β,

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IL1RN, *IL-2*, *IL-4*, *IL-5*, *IL-10*, *IL-13*, *IL-17A*, and *TNFα*. Two-way, repeated measures analysis of variance was used to analyze qPCR data with the treatment group and treatment day used as covariates, and results considered significant at $P < 0.05$.

3. Results

There were significant decreases in the steady-state, whole-blood expression of granzyme B and interferon-γ due to dexamethasone treatment, when compared to the non-treated control group. As a means by which leukocyte function could be quantified and potential immunosuppression evaluated, ConA was utilized to stimulate heparinized blood samples due to its activity as a lymphocyte mitogen and T cell activator. Within ConA-stimulated samples, there remained a suppressive effect of dexamethasone treatment on granzyme B expression compared to non-treated control horses. Similar effects were not noted in the ciclesonide-treated horses.

4. Discussion

Although glucocorticoids, such as dexamethasone, are a commonly used treatment for equine asthma, the administration of systemic glucocorticoids raise concerns such as laminitis, suppression of the hypothalamic-pituitary-adrenal axis, and immunosuppression. Ciclesonide is a locally activated, anti-inflammatory, pro-drug glucocorticoid, which was recently approved by the FDA as an inhalant therapy for severe equine asthma and shown to be a safe and efficacious treatment for this challenging condition. Significant effects of ciclesonide treatment on markers of immune function were not noted in this study, suggesting that, while there remains a risk of immunosuppression with short-term dexamethasone treatment, a similar risk was not observed with inhaled ciclesonide treatment.

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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]Tempus®, Blood RNA tubes, Applied Biosystems/ThermoFisher Scientific, Carlsbad, CA 92008.

Review of Dietary Protein in Nutritional Management of Equine Insulin Dysregulation

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When feeding horses with insulin dysregulation (ID), the influence of dietary protein on disease control is not well understood. The use of high-protein ration balancers has historically been actively recommended when feeding ID patients. However, recent evidence suggests that high-protein meals may exacerbate postprandial hyperinsulinemia in equids with ID, calling into question the safety of this nutritional intervention in this population. Authors' address: The Ohio State University College of Veterinary Medicine, 1900 Coffey Road, Columbus, OH 43210; e-mail: thriffiley.1@osu.edu. *Corresponding and presenting author. © 2023 AAEP.

1. Introduction

Dietary management is the most important treatment for equine insulin dysregulation (ID).[1] Current recommendations are principally focused on two primary goals, namely encouraging weight loss where appropriate and minimizing postprandial hyperinsulinemia. As such, the amount of hydrolysable dietary carbohydrate in the diet is frequently manipulated to achieve these aims, and most dietary strategies recommended for equine ID patients involve feeding low nonstructural carbohydrate (NSC) forage and low-NSC, high-protein ration balancers to minimize the risk of trace mineral and vitamin deficiencies over time.[1,2] However, recent studies in rodents, humans, and horses have suggested that postprandial hyperinsulinemia can be exacerbated by a high-protein meal in individuals with ID, creating concern about the safety of this very common nutritional intervention.[3,4] This review describes the influence of protein on postprandial hyperinsulinemia and emphasizes why this should be considered when feeding horses, ponies, donkeys, and hybrids with ID.

2. Feeding Horses and Ponies with ID

Glycemic and insulinemic responses to various feedstuffs vary between ID and non-ID horses.[4] NSCs include starch, monosaccharides (such as glucose and fructose), disaccharides (such as sucrose), and fructans. Pasture grass, cured hay, and other forages can contain high amounts of NSCs that are associated with significant elevations in postprandial blood glucose and, consequently, postprandial hyperinsulinemia.[5] Therefore, the type of forage fed to horses with ID can

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influence postprandial insulin and glucose concentrations and is a well-described target for nutritional management.[6,7] Current feeding recommendations for ID horses include feeding low-NSC grass hay (<10% NSC on a dry matter basis) at 1.25% to 1.5% of body weight.[1] Soaking the hay can decrease water-soluble carbohydrate content, but this will also leach other water-soluble components, such as vitamins and trace minerals. In combination with the fact that forages are low in protein, ration balancers are recommended to supplement vitamins, minerals, and protein.[1,8] Given the importance of glucose as the most well characterized and important secretagogue of insulin, most empiric research on feeding horses, ponies, and donkeys with ID has focused on the carbohydrate composition of the diet and its effects on glycemic and insulinemic control; managing the NSC content of the equine diet is now common practice, and information related to low-NSC feeding has now become quite established within the industry. In fact, most companies marketing equine feeds have at least one commercially available feed product formulated for ID equids currently on the market.

Dietary protein requirements for horses with ID are not known to be different from those of metabolically healthy horses. For an adult horse in light work, crude protein requirements are estimated to be 0.76 kg/day with 33g/day of lysine.[9] These requirements are increased when the horse is in heavy work, pregnant, lactating, or growing. Protein deficiency is uncommon in horses, although one or more amino acids may be deficient based on a horse's individual diet. Essential amino acids in the horse's diet include histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine; arginine is often included in this list for growing animals as well. When considering the source of protein in the horse's diet, protein quantity and quality vary with forage type/maturity and specific concentrate products; for example, cereal grains do not contain high-quality protein, and more mature forages usually have lower crude protein content. Whenever possible, high-quality protein sources, such as vegetative legume forages, fertilized cool-season grasses (also vegetative), and soybean meal should be considered for fulfilling this nutritional requirement. However, there is no benefit to be gained by exceeding the daily requirement and overfeeding protein; protein deficiency is uncommon in adult horses, and excessive dietary protein must be excreted as urea (requiring additional metabolic energy).[9]

3. The Role of Dietary Protein and Amino Acids

While glucose is the primary stimulus for insulin synthesis and secretion from the pancreatic β-cells, arginine and other amino acids also play a role. The magnitude of insulin secretion stimulated by amino acids and dietary protein is relatively small compared to the effects of glucose, but this paradigm applies to healthy animals and may not be an accurate assessment of what happens in individuals with ID. Most of the research effort in humans is focused on the role of dietary protein and amino acids in improving systemic insulin sensitivity, encouraging weight loss, and improving gain or retention of lean muscle mass. In fact, several studies in humans with type II diabetes mellitus (DM) suggest that high-protein diets result in significantly enhanced insulin secretion over time, an effect that is independent of weight loss (which also often occurs in this population eating high-protein diets); this was considered a beneficial effect in these patients, allowing for reduction in exogenous insulin dosing.[10,11] However, enhanced insulin secretion is not a therapeutic goal in equine ID patients; actually, the opposite goal is almost always the case (minimizing postprandial insulin secretion), as type II DM is very uncommon in this species and hyperinsulinemia is the most important risk factor for endocrinopathic laminitis. An additional consideration to bear in mind when extrapolating results of studies in humans to equids is the potential influence of the dietary protein source on metabolic outcomes. Animal protein has been linked to higher levels of tissue and systemic insulin resistance and diabetes risk in humans when compared to isocaloric amounts of plant protein;[12] however, this may not be a relevant concern for equine nutrition (in which diets are almost exclusively plant based, with the exception of occasional incorporation of milk proteins).

In humans and rodents, branched-chain amino acids (BCAA; valine, leucine, isoleucine), the aromatic amino acids (phenylalanine, tyrosine), C3 and C5 acylcarnitines, glutamic acid, and alanine are strongly associated with insulin sensitivity.[13] When considering healthy humans specifically, epidemiologic studies repeatedly show that long-term consumption of a high-protein diet (50% or more above the recommended daily intake of 0.8 g/kg/day) is associated with development of systemic insulin resistance and, over time, increased risk of type II DM.[10,11] A study using rats fed a high-fat diet compared to a high-fat diet supplemented with BCAA revealed that rats fed the diet with BCAA were just as insulin resistant as the rats fed the high-fat-only diet, even though the BCAA-supplemented rats ate less and had lower weight gain.[13,14] Evidence is accumulating that dietary protein ingested in excess of nutritional requirements over time has negative effects on systemic insulin and glucose dynamics and is associated with an increased incidence of metabolic disease in all species evaluated to date.

In humans, therefore, there is an increasingly well-established association between dietary protein content, altered protein and amino acid metabolism, and systemic insulin resistance.[10,15] In equids, relatively little attention has been given to the effect of dietary protein on insulin and glucose dynamics, but this is an active area of investigation for several research groups currently. While NSC also appears to be the principal nutritional factor driving the postprandial insulin response in equids, high-protein meals have

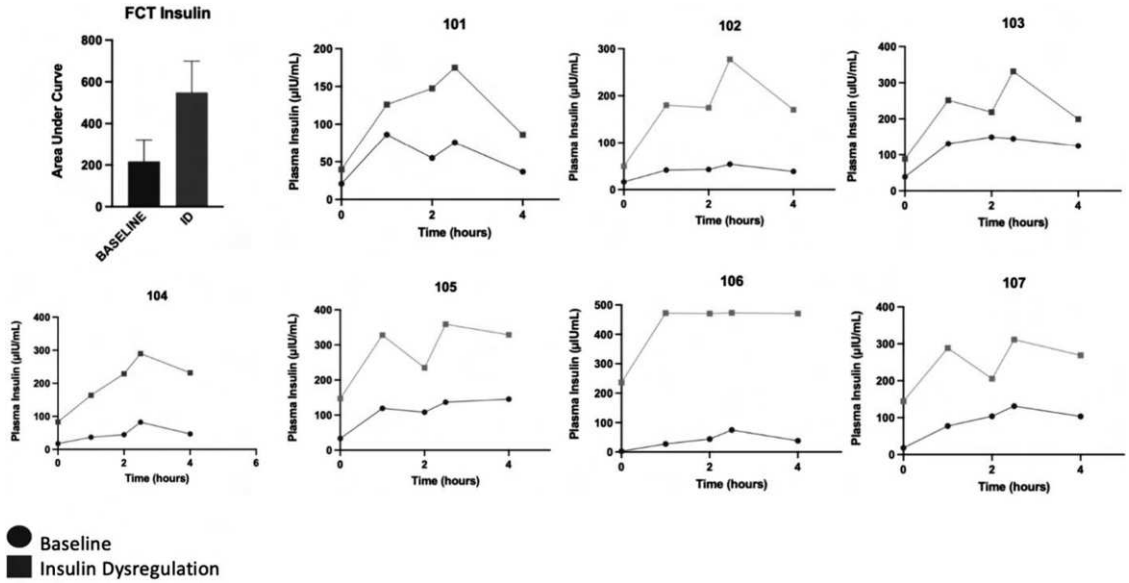


Fig. 1. The top left graph displays the area under curve after consumption of a high-protein meal at baseline and after insulin dysregulation (ID). Plasma [insulin] during the 4-hour postprandial period is displayed for 7 individual horses at baseline (circles) and ID (squares). FCT, feed challenge test.

also been associated with exacerbated insulin responses in horses with ID.[3,4] When the insulinemic response to a high-protein meal (31% crude protein, 4 g/kg) was compared between normal and ID horses, there was a 9-fold greater insulin response observed in the ID horses over a 4-hour postprandial observation period.[3] Horses with experimentally induced ID (induced with dexamethasone, 0.08 mg/kg PO q 24 hours for 7 days) displayed significantly higher glycemic and insulinemic responses to a high-protein meal (32% crude protein, 1 kg meal) than the same individuals did at baseline[a] (see Fig. 1). These studies strongly suggest that high-protein ration balancers may exacerbate insulinemic responses in the setting of equine ID.

Mechanistically, there are several ways that dietary protein and amino acids can influence pancreatic insulin secretion. As mentioned above, several individual amino acids (such as glutamine, glutamate, alanine, arginine, leucine, isoleucine, and homocysteine) can alter β-cell insulin secretion directly in multiple ways. The magnitude and direction of these effects on secretion can vary not only with the prevailing concentration of glucose (for example, arginine only stimulates insulin release in the presence of glucose, while leucine-induced insulin secretion is inhibited by high [glucose]) but also with the relative concentrations of other amino acids.[16] Four amino acids appear to be particularly important for stimulating electrical activity within β-cells (which is required for insulin secretion): leucine, isoleucine, alanine, and arginine. Three of these (arginine, leucine, and isoleucine) are often considered essential amino acids in equids, and two are particularly glucogenic (isoleucine and alanine). This capacity to support gluconeogenesis and increase blood [glucose] is yet another mechanism by which specific amino acids can promote hyperinsulinemia.[16]

Finally, and perhaps most importantly, when considering the consequences of metabolic disease in equids, dietary protein and amino acids have been shown to be robust activators of mechanistic target of rapamycin (mTOR) signaling at the tissue level. This highly conserved pathway is responsible for activation of a broad array of anabolic functions in response to nutrient ingestion, resulting in cell and tissue growth, energy storage, and protein synthesis, which ostensibly is an adaptive response to nutrient availability. However, prolonged mTOR activation also results in insulin resistance, both locally at the tissue level and systemically. Further, mTOR activation has been associated with changes in epithelial phenotype associated with epithelial-to-mesenchymal transition, which has received considerable attention in human medicine as a risk factor for and driver of metastasis in the setting of epithelial neoplasms (such as breast and pancreatic cancers). In horses, however, this change in epithelial phenotype may occur in a more rapid and readily identifiable fashion, with decreased epithelial polarity and basement membrane adhesion within the digital lamellae and, often, clinical laminitis.[17] Activation of mTOR signaling has been demonstrated within the digital lamellae in horses subjected to experimental models of all three forms of equine laminitis (sepsis-related laminitis,[18] hyperinsulinemia-associated laminitis,[19] and supporting limb laminitis[b] [Fig. 2]). In a model of supporting limb laminitis, lamellar tissue harvested from supporting limbs contained higher concentrations of phosphorylated ribosomal protein S6, a central downstream target of the mTOR complex 1 signaling pathway that functions as a biomarker of mTOR activation. Figure 2 displays data for two different phosphorylation (activation) sites on ribosomal protein S6; however, both demonstrate evidence

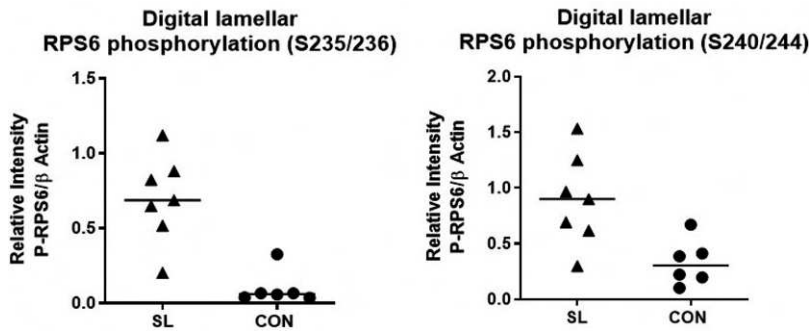


Fig. 2. Activation of mTOR signaling (indicated by ribosomal protein S6 phosphorylation) within the digital lamellae of horses subjected to prolonged unilateral weight bearing as a model for supporting limb laminitis. CON, control; RPS6, ribosomal protein S6; SL, supporting limb.

of activation of mTOR signaling in the digital lamellae of the supporting limb. Similar findings have been published for other experimental models of equine laminitis, suggesting a central role for mTOR signaling in the pathophysiology of this condition (and a potentially sound rationale for avoiding situations that might enhance mTOR signaling, such as high-protein feeding, which warrants further exploration). The role that dietary protein and amino acids might play in the laminitis risk associated with equine metabolic disease requires further investigation, but preliminary studies suggest that this is a valid concern.[20]

4. Discussion

As nutritional intervention is one of the most important facets of managing equine ID, the role of protein in feeding affected horses warrants additional investigation. Based on recent studies, the role of high-protein ration balancers should be re-evaluated when feeding affected horses, as high-protein meals have been consistently associated with undesirable amplification of postprandial insulinemic responses.[3] Ration balancers are offered to supplement vitamins, minerals, and protein in horses being fed a predominantly forage-based diet.[2,8] Ration balancer products with lower protein contents (12–15% crude protein) may be a better option when feeding horses with ID in order to decrease the risk of exacerbation of hyperinsulinemia. Further, patients receiving high-protein ration balancers whose ID is currently poorly controlled should have this facet of their management critically evaluated.

When managing a patient whose ID is poorly regulated in the face of a tightly controlled, low-NSC diet, other aspects of the patient's diet should be carefully scrutinized to assess their influence on the animal's persistent hyperinsulinemia. A feed trial can be performed in order to evaluate the degree of postprandial hyperinsulinemia in response to various components of the diet, including a particular ration balancer, if appropriate. This test can be approached in much the same way as the oral sugar test currently in widespread use for the diagnosis of equine ID. Briefly, the horse should be fed one flake of grass hay the night before the test and then muzzled until beginning the test the following morning. A blood sample should be collected at baseline, and then the horse is fed the dietary component (for example, a meal of a ration balancer in the amount recommended by the manufacturer or an amount already being regularly fed to the horse). Additional blood samples should be drawn at 30 and 60 minutes postprandially in order to explore the horse's insulinemic response to the feedstuff. Exaggerated insulinemic responses (suggested evaluative criteria could be >45 mIU/L at either time point in horses with normal baseline insulin concentrations or a >30–40 mIU/L increase in insulin concentration from an abnormal baseline concentration) should warrant modification of this portion of the diet (elimination, substitution, alteration of amount, etc.).

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.

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Accuracy of a Point-of-Care, Species-Specific Blood Glucose Monitoring System for Use in Horses

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Point-of-care blood glucose monitoring hand-held devices allow for stall-side clinical decision-making and frequent monitoring and are a preferred alternative to more costly and time-consuming standard reference laboratory methods. Authors' address: Veterinary Medicine Research and Development, Zoetis, Kalamazoo, MI 49007-9970 (Velineni); Equine Technical Services (Cowles), Global Diagnostics (Wilson), Zoetis, Parsippany, NJ 07054; Tyson Bioresearch Inc., 5F, #22 Ke East Road III Chu-Nan Miao-Li Hsien, Taiwan (Chang, Peng); William Woods University, 1 University Avenue, Fulton, MO 65251 (Schiltz). e-mail: bobby.cowles@zoetis.com. *Corresponding and presenting author. © 2023 AAEP.

1. Introduction

The objective of this study was to determine the accuracy of an equine algorithm on the AlphaTrak 3 (AT3) in measuring blood glucose levels in whole blood samples.

2. Materials and Methods

Accuracy in measuring equine blood glucose levels was evaluated in two study populations, 60 horses (Group 1) and 100 horses (Group 2). Venous blood samples were collected in ethylenediaminetetraacetic acid tubes for both studies. Laboratory reference assays were performed. The bias by AT3 device measurements as compared to reference analyzers was estimated per International Organization for Standardization (ISO) 15197:2013 specifications.

3. Results

AlphaTrak 3 results for Group 1 horses showed that 98.9% of measurements ranging from 29 to 479 mg/dL fell within the ISO accuracy threshold of ± 15 mg/dL or ± 15% of the average reference value. In Group 2 horses with blood glucose levels of 65 to 105 mg/dL, 98.4% of AT3 measurements were within the ISO accuracy threshold. It was observed that 100% of AT3 measurements from blood samples derived from Group 1 horses fell in consensus error grid Zone A, whereas 99.2% from Group 2 horses were within Zone A.

4. Discussion

The analytical performance of the hand-held AT3 device is comparable to the reference glucose analyzer results in measuring blood glucose levels of equine blood samples and is a reliable and cost-effective

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device for accurately monitoring equine blood glucose levels on the farm or in a clinical setting.

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

Drs. Velineni, Cowles, and Wilson are employed by Zoetis, LLC.

Effect of Procaine Penicillin G and Flunixin Meglumine on Serum Amyloid A Response in Premedicated Healthy Adult Horses

Jurica Trsan, DVM*; Nicola Pusterla, DVM, PhD, DACVIM, DAVDC-Equine; and Bridget F. Nottle, BVSc, DACVS-LA

Local tissue injury caused by 3-day intramuscular procaine penicillin G administration in multiple altering injection sites, intravenous flunixin meglumine administration, or both did not elicit a significant serum amyloid A response, which would impact postprocedural monitoring of equine patients. Authors' addresses: William R. Pritchard Veterinary Medical Teaching Hospital, School of Veterinary Medicine, University of California, Davis, CA 95616 (Trsan, Pusterla, Nottle); Department of Clinical Sciences, College of Veterinary Medicine and Biomedical Sciences, Colorado State University, Fort Collins, CO80523 (Nottle); e-mail: jtrsan@ucdavis.edu. *Corresponding and presenting author. © 2023 AAEP.

1. Introduction

Serum amyloid A (SAA), an acute phase protein, is a monitoring tool for acute infectious or inflammatory diseases in horses. SAA is often used to monitor complications after elective procedures. To the authors' knowledge, there is no information of the inflammatory effect of procaine penicillin G (PPG) and flunixin meglumine when used at clinical dosing regimens on the SAA response in premedicated healthy adult horses.

2. Materials and Methods

To observe at least a 20% difference in SAA levels between horses, 6 healthy adult horses were used in crossover design study. In this case, the probability (power) is 80% that the study will detect differences at a two-sided $P = 0.05$ significance level. Further, SAA area under the time curve amongst the various horse groups was compared using a test of the null hypothesis. A P value under 0.05 was considered statistically significant. There was one control and three treatment groups: control (no treatment), PPG (intramuscularly q 12 h for 72 h), flunixin meglumine (intravenously q 24 h for 72 h), and PPG (intramuscularly q 12 h for 72 h) with flunixin meglumine (intravenously q 24 h for 72 h). Whole blood was collected at 0, 24, 48, 72, 96, and 120 hours after initial drug administration to measure SAA. The washout period between treatments was 30 days.

3. Results

Throughout the course of this research, daily temperatures remained within the normal range for the duration of the study. The complete blood count and fibrinogen screenings remained within normal references before

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each cycle. Individual SAA values were within the reference range of ≤ 20 μg/mL for almost all horses in the control group. One control horse displayed an SAA value of 28 μg/mL at 72 hours. All horses from the PPG group showed normal SAA values throughout the study. Except for one horse (SAA of 24 μg/mL at 96 hours) from the flunixin meglumine group, all horses showed normal SAA values. For the PPG and flunixin meglumine group, five horses had SAA values within the reference range. One horse displayed SAA values from 32 to 45 μg/mL between 48 and 96 hours after drug administration. There was no statistical significance in area under the SAA time curve amongst the control and three treatment groups ($P > 0.05$).

4. Discussion

There was no statistical significance in area under the SAA time curve amongst control and treatment groups ($P > 0.05$). The routine administration of intramuscular PPG in multiple altering injection sites and/or intravenous flunixin meglumine does not trigger an inflammatory response that induces SAA value above reference range in most adult healthy horses.

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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.

Transdermal Flunixin Meglumine as a Pain Relief in Donkeys: A Pharmacokinetics Pilot Study

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Transdermal flunixin meglumine in donkeys appears to produce sufficient systemic concentrations to induce anti-inflammatory effects for 24–72 hours and could be further explored as a means of pain relief in this species. Authors' address: University of California – Davis, School of Veterinary Medicine, One Shields Avenue, Davis, CA 95616; e-mail: acmclean@ucdavis.edu. *Corresponding and presenting author. © 2023 AAEP.

1. Introduction

Donkeys are difficult to medicate, which poses challenges for their treatment and care. The objective of this study was to compare the pharmacokinetics and effects of flunixin meglumine (FM) on anti-inflammatory biomarkers in donkeys following administration by three routes (oral [PO], intravenous [IV], and transdermal [TD]). The authors hypothesized TD FM pharmacokinetics and effects on inflammation biomarkers would be comparable to IV FM and PO FM in donkeys.

2. Materials and Methods

Six healthy donkeys were administered FM[a] dosed at 1.1 mg/kg BW PO and IV and 3.3 mg/kg (per label) TD in a three-way crossover design with a two-week washout. Whole blood samples collected over 96 hours to evaluate FM, 5OH FM, and eicosanoids (TXB2, and PGF2 alpha) using LC-MS/MS and pharmacokinetic parameters (C_{max}, and t_{max} were determined). Data were checked for normality using histogram in Stata and analyzed using mixed-effects analysis, with animals as a random effect and route, time points, and their interactions as fixed effect with significant P value of <0.05.

3. Results

Both flunixin and 5OH flunixin reached detectable levels in blood collected during the transdermal trial. Average FM C_{max} was 1279, 161, and 45 ng/mL for IV, TD, and PO, respectively. Results showed reduction in inflammation biomarkers post TD FM administration started at 1 hour and continued until 24 hours for

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PGF2$_\alpha$ and 72 hours for TXB2 compared to the baseline, which was longer than other routes.

4. Discussion

Findings indicate that therapeutic doses of FM, administered PO and IV at a rate of 1.1 mg/kg, and TD dose of 4.4 mg/kg, are effective in controlling inflammation in donkeys. More studies are needed to detect the safe withdrawal periods and effect of TD FM in pain mitigation.

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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[a]Banamine®, Merck Animal Health, Rahway, NJ 07065.

How to Improve Management of Acute Kidney Injury in Horses

Daniel Jean, DMV, PhD, DACVIM (LA)

Hemodynamic and nephrotoxic conditions are the most common causes of acute kidney injury in horses. Primary therapeutic approach for acute kidney injury (AKI) includes elimination of nephrotoxic drugs, control of predisposing disorders, and fluid therapy to promote diuresis. In more complicated cases with inadequate urine production, several drug treatments are also available. The survival rate has increased during the three last decades and is likely explained by the improvement in therapeutic management of AKI and comorbidities over time. The survival rate is significantly decreased in AKI Stage 3 equine patients. While survival rates seem independent of age, there is a trend for horses over 15 years old to have a less favorable prognosis. Finally, the survival rate negatively correlates with associated orthopedic, muscular, or respiratory diseases. Author's address: University of Montreal, 3200 Sicotte, St-Hyacinthe, QC J2S 7C6, Canada; email: daniel.jean@umontreal.ca. © 2023 AAEP.

1. Introduction

The term acute kidney injury (AKI) has been proposed and introduced to increase awareness of renal injury (subclinical and clinical) that accompanies sudden and significant decreases in renal blood flow (RBF), glomerular filtration rate (GFR), and urine output (UO). Recently, the terminology of clinical renal failure was modified to AKI to more closely reflect more modern and accurate medicine. The magnitude of increase in serum creatinine (sCr) concentration within 48 hours and lasting up to 7 days, combined with duration and severity of oliguria, is assessed to classify AKI from Stage 0 to Stage 3: Stage 0 is defined as an increase in sCr $<$ 150% from baseline (136–200 μmol/L; 1.53–2.26 mg/dL), Stage 1 (S1) as defined by an increase in sCr of 150% to 199% from baseline (201–270 μmol/L; 2.27–3.0 mg/dL), Stage 2 (S2) by an increase in sCr from 200% to 299% from baseline (271–400 μmol/L; 3.1–4.52 mg/dL), and Stage 3 (S3) by an increase in sCr of more than 300% from baseline (> 400 μmol/L; > 4.52 mg/dL). AKI has been documented to develop in 7% to 18% of hospitalized human patients and approximately 50% of patients admitted to intensive care units. Mortality rates among hospitalized patients with more severe AKI (Stages 2 or 3) remain high (approximately 50%). Consequently, early detection of AKI and interventions to limit or even prevent the progression of kidney damage are crucial to improve the survival rate and prevent long-term complications.[1–2]

2. Acute Kidney Injury in Horses

The Veterinary Acute Kidney Injury (VAKI) staging system was used to determine the prevalence of AKI in 325 hospitalized horses that had at least 2 serum Cr measurements (between 24 hours and 7 days of

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hospitalization).[3] Savage et al. reported a retrospective study of 325 equine patients (mostly gastrointestinal emergencies), and 4.3% ($n = 14$) had baseline azotemia (mean Cr 2.4 mg/dL, range 1.9–3.5 mg/dL) that normalized during hospitalization, whereas 14.7% ($n = 48$) developed AKI (44 VAKI Stages 1 and 4 VAKI Stage 2).[3] Mortality rates were 29% for horses with baseline azotemia versus 12% for horses developing reversible AKI during hospitalization.[3] In a retrospective study performed at the author's veterinary teaching hospital in 233 equine patients with AKI, 9.7% and 24.8% were respectively in AKI Stages 2 (survival rate at 56.5%) and 3 (survival rate at 28.8%). Previously, several studies had reported survival rates and prognostic factors of patients with clinical renal failure in different clinical contexts (colic/colitis, red maple leaf intoxication, and hemodynamic causes).[4–7] In colic- or colitis-affected horses, prognosis for survival for horses in which AKI resolves within 72 hours of treatment appears to be better than for horses with persistent AKI.

3. Assessment of Horses for Renal Disease

Early detection of AKI should limit morbidity and improve outcome in patients with secondary renal disease. If dehydration and/or compromised hemodynamic status are present, the expected physiologic response would be acute reductions in RBF, GFR, and UO. Healthy horses deprived of water for 3 days have several urinary impacts: urine output decreased to 1.25 to 2.5 mL/min (0.15–0.30 mL/kg/hour), urine specific gravity increased to 1.040 to 1.050, and urine osmolality increased to 1,500 to 2,000 mOsm/kg. Finally, a complete history can provide clues as to the duration of decreased renal perfusion and identify the use of potentially nephrotoxic medications. Asking owners about long-standing excessive drinking and urination habits may provide further evidence for pre-existing chronic kidney disease, especially for equine patients with weight loss.

Once hospitalized, observation for urination (and sample collection) when a horse is initially moved into a stall should be considered an essential component of the initial physical examination. Even dehydrated horses may void a small amount of urine when placed into a stall with fresh bedding. Although often overlooked, collection of the first urine sample can provide valuable information and should be done before treatment because alpha-2-agonists and/or fluid therapy can decrease urine tonicity. If urine is not voided spontaneously, a simple collection device can be suspended below the prepuce in male horses or a bladder catheter can be passed in mares to collect an initial sample.[2–8]

4. Estimation of Glomerular Filtration Rate

Serum/plasma urea nitrogen (UN) and Cr concentrations are indirect estimates of GFR and are commonly used to assess renal function. It is important to note that UN and Cr are imperfect indicators of decreased renal function because values typically do not increase above upper limits of reference intervals until GFR is reduced by at least 75% or more. Once above the upper reference limit, small increases in UN and Cr become more sensitive indicators of further deterioration of GFR, with doubling of values indicating a further 50% decline in renal function. Changes in renal function are better reflected by changes in Cr than UN because the latter can be affected by nonrenal factors including liver disease and upper gastrointestinal hemorrhage. However, measuring Cr also has limitations because Cr is released as a degradation product of skeletal muscle creatine, and breed and sex differences in muscle mass may affect serum concentrations. The commonly used test known as Jaffe reaction also measures non-Cr chromogens that may account for up to 45% to 50% of the Cr concentrations. A small amount of Cr can be eliminated by tubular secretion; thus, Cr can overestimate GFR. Despite the fact that the serum creatinine concentration is an imperfect glomerular parameter, it can be used with efficiency in the follow-up of horses with elevated values.[2–8] Measurement of symmetric dimethylarginine (SDMA) concentration to estimate the GFR has recently been evaluated in different clinical contexts and is readily available as IDEXX Laboratories includes this parameter on their equine biochemical profile. So far, there is insufficient data available to validate SDMA as a superior parameter to creatinine in AKI equine patients. The clinical potential of this parameter would most likely be more prompt detection of early stages of AKI.[9]

5. General Considerations of Management of AKI in Horses

Treatment of horses with AKI should focus on reversing/controlling the inciting or underlying cause and correcting fluid and electrolyte imbalances. The importance of prevention is crucial in the management of AKI in horses and is a major predictor of the prognosis.[2]

6. Fluid Therapy

While the exact fluid therapy plan will be somewhat clinician dependent and must also be tailored to the needs and parameters of the specific patient, the main goals of therapy are outlined here. Early identification of equine patients at risk and prevention of problems lies in rapid and accurate restoration and maintenance of intravascular fluid volume, glomerular filtration, and urine production (with fluids and sometimes diuretics). These tenets are the medical keys for survival and, if provided early enough, will minimize necessary treatments. The fluid deficits should initially be corrected as soon as possible, ideally over the first 6 to 12 hours of treatment. Equine patients with AKI may require large intravenous fluid volumes, and the cost may present a financial limit for owners; hence, this is a limit for medical success. Physiologic saline or a balanced electrolyte solution such as lactated

Ringer's solution are the fluids of choice unless the patient is hypernatremic. In this specific clinical context, solutions of 0.45% sodium chloride and 2.5% dextrose may be alternative options. The use of 0.5 to 2 mg/kg/minute of dextrose helps to cover the caloric needs of any anorectic horses and can be given by adding dextrose to fluids or by using a continuous rate infusion pump. Diuresis should be present if fluid administration is begun early in the course of the disease or if the AKI is mild. When diuresis occurs, intravenous fluid therapy should be maintained at least at approximately twice the maintenance level (100 mL/kg/day or more) until the normalization of intravascular volume and blood pressure as well as significant reduction in serum creatinine concentration have occurred. If the horse or foal urinates a moderate to large volume after receiving fluids, one can assume intravascular volume and systemic pressures are adequate for kidney function. In a favorable clinical context, the rate of fluid therapy may be gradually reduced (50–100 mL/kg/day) until the serum creatinine concentration is normal or stabilized during at least 3 consecutive days. The withdrawal of fluid therapy is variable depending on the clinical context (level of drinking, stabilization of the cause) and the stabilization point of serum creatinine concentration. In an unfavorable clinical context, the fluid therapy dosage must be adapted to the variation of serum creatinine concentration, the cardio-vascular parameters, and the presence or absence of overhydration signs (abnormal distension and pulsation of jugular vein and other peripheral veins, pulmonary and tissue edema).[2] The intensity of monitoring must be adapted to the cardiovascular status of the patient and should include repeated evaluation of body weight, hematocrit, serum total protein concentration, central venous pressure, and arterial blood gases as essential early indicators of overhydration or other complications. If creatinine rises when fluids are discontinued, an option is to restart fluid therapy at the initial management rate for 2 to 3 days or until creatinine stabilizes for 3 consecutive measurements 12 hours apart. The decision to continue fluid therapy is often based on the degree of creatinine increase, whether the creatinine continues to increase or stays stable, as well as owner finances. Throughout treatment, the horse must be carefully supervised for adequate food and water intake as well as to ensure that it urinates appropriately in response to fluid therapy (normal baseline urine output is between 5 and 15 L in a 500-kg horse with normal renal function). Urology examination 36 to 48 hours after stopping fluid therapy is recommended to obtain some indication of the horse's natural capacity to concentrate urine (specific gravity > 1.020) and to identify urinary sediments suggestive of renal injury.

7. Diuretic Agents

The successful use of diuretic agents such as furosemide and mannitol in a clinical context of AKI is variable and questionable. Furosemide and ethacrynic acid are the loop diuretics most commonly used. Furosemide is a particularly potent short-acting agent that acts by blocking the Na/K2Cl- cotransporter in the ascending limb of the loop of Henle. However, loop diuretic administration may also exacerbate or induce volume depletion in cases of AKI that are characterized by isosthenuria or polyuria, thus making the condition worse and rendering the patient more susceptible to nephrotoxic effects. To minimize the complications of diuretics on AKI patients, small doses may be used (furosemide at 0.5 mg/kg, once daily or as needed). In any clinical context, urine production should first be stimulated using fluid therapy rather than by use of diuretics. Mannitol (20%, 0.25–1.0 g/kg) given over 15 to 20 minutes may help to improve oliguria by increasing RBF and GFR. Once filtered, it also acts as an osmotic diuretic, thus decreasing urine solute concentration and increasing urine volume. Consequently, mannitol also can be effective in treating conditions characterized by tubular obstruction and swelling of tubule cells. The cost of this drug may limit use in equine patients.

8. Renal Vasoactive Drugs

In a clinical context of an oliguric period of 6 to 12 hours after beginning fluid therapy, administration of dopamine mixed in 5% dextrose administered slowly (3–5 μg/kg/min, IV) may theoretically improve renal blood flow and urine output. During dopamine infusion, blood pressure should be monitored because the drug can induce significant hypertension. Administration of dopamine should be discontinued if blood pressure starts to rise, and the infusion can be restarted at a lower rate when blood pressure has returned to normal. Blood pressure also may increase because of overhydration of oliguric/anuric equine patients. Again, regular monitoring of body weight, hematocrit, serum total protein concentration, central venous pressure, and arterial blood gases are essential for early detection of overhydration and for following complications. To the author's knowledge, there is no significant documentation or clinical experience that this drug improves outcome on renal function or the prognosis of equine patients.

9. Electrolyte Imbalances and Dietary Management

Different electrolyte imbalances may be observed in AKI equine patients and vary depending on the cause. Hyperkalemia is uncommon except in some postrenal contexts and usually responds to administration of potassium-free intravenous fluids, glucose (up to 10% solution), sodium bicarbonate, or both. In the context of incomplete response, insulin may be necessary. Potassium supplementation (potassium chloride 20–40 mEq/L, IV) may be indicated in horses with polyuric status during the recovery period. Hypercalcemia, if present, usually resolves with a switch to a grass or grass-hay diet (avoid

legumes) and time. Hypocalcemia may be corrected by intravenous fluid therapy with calcium salt supplements and feeding alfalfa. A possible complication following renal injury is renal tubular acidosis, which is characterized by severe metabolic acidosis, marked hyperchloremia, and often hypokalemia. Treatment of the condition in horses is associated with HCO3− therapy, sometimes long term, to correct acid-base imbalance and K+ replacement therapy if hypokalemia is present. This condition may reoccur even after initial correction and should be considered in horses displaying vague signs of depression, weight loss, and anorexia, especially with a history of renal insult.

In comparison to human and companion animal literature where extensive information is available regarding dietary management following renal injury, little information has been documented in horses. One case report described successful nutritional management of a horse with AKI by limiting protein, sugar, starch, and calcium intake as well as supplementing with omega-3 polyunsaturated fatty acids for their kidney protective properties. The goals of the diet were to optimize tissue healing and minimize risk for the development of chronic renal failure by supporting optimal kidney function, achieving weight gain, decreasing retention of renal toxic solutes from protein catabolism, avoiding gastric ulcer development by limiting sugar and starch per meal, and restricting dietary calcium uptake to avoid hypercalcemia.[10] To the author's knowledge, these diet benefits have not been evaluated objectively in several case series in horses.

10. Nephrotoxins and AKI

Amongst the therapeutic drugs used in horses, several have undesirable nephrotoxic side effects. Aminoglycoside toxicity is one of the more common causes of AKI in equine patients. The management of an AKI equine patient that requires an aminoglycoside antibiotic should undergo therapeutic drug monitoring in order to maintain desired concentration, prevent significant toxicity, and assess GFR. When toxicity is documented, it is recommended to discontinue the therapy until renal parameters have normalized. The re-initiated treatment should be administered with a prolonged dosing interval or reduced dose. Administration of other potentially nephrotoxic drugs should follow the same recommendations as those proposed for aminoglycosides. The benefit of using nephrotoxic therapeutic medication should be evaluated against the complications of the used drug as well as the survival rate with different comorbidities. Whichever the nephrotoxin involved, the renal impact should be mitigated by maintaining or increasing intravenous fluid therapy to prevent or limit renal hypoperfusion together with an appropriate adjustment of the dosing interval of the nephrotoxic drugs if indicated. Ideally, nephrotoxic agents should be discontinued entirely during treatment for AKI.

11. Hemodialysis and Peritoneal Dialysis

Hemodialysis is an excellent ancillary therapy in a clinical context of toxin-induced AKI if the materials and expertise are available. Another dialysis technique that may be more practical is continuous-flow peritoneal dialysis. Continuous-flow peritoneal dialysis can be performed by placing two catheters, one in the flank and one in the ventral abdomen, and continuously or intermittently infusing a dialysate solution. The challenge of this technique is the capacity to recover a significant amount of the dialysate solution by the ventral catheter. To the author's knowledge, the benefit of peritoneal dialysis is not reported and likely varies with different coexisting comorbidities.

12. Primary Urinary Contexts

Urinary obstruction is a rare cause of AKI in horses (prevalence of 0.1%), and the obstruction site may be located in the urethra(s), bladder, ureters, and/or kidneys. Cystoliths and urethroliths are more commonly recognized and represented 3/4 of all uroliths in Laverty et al.'s study of 68 horses, whereas ureteroliths represented less than 4%.[11] This urinary tract comorbidity may have potential and variable renal impacts depending on the urolithiasis location. The presence of cystoliths usually has few renal impacts, whereas urethrolithiasis, ureterolithiasis, and nephrolithiasis may have significant effects on renal function. Early detection and rapid/minimally invasive therapeutic intervention should be undertaken as soon as possible. The development of ultrasonographic imaging as a diagnostic tool for equine medicine has improved the detection of ureterolithiasis and nephrolithiasis. The long-term impact on renal function must be determined. Different surgical options have been described to remove cystoliths, urethroliths, as well as uretero-renoliths. Ureteral/renal obstructions by stones may be challenging, and recent developments in minimally invasive intervention with intracoporeal lithotripsy adds another therapeutic option to improve renal function in horses.[12] The real consequence of ureteral/renal obstruction on kidney function in horses remains unknown, but specific cases seem to be reversible and have a fair prognosis. The renal function benefits with minimally invasive procedures must be confirmed with a more significant number of equine patients. Future studies are needed to better elucidate the ideal protocol and management of associated kidney disease in horses with upper urinary tract stones. Early detection of ureteroliths and rapid implementation of the safest and most accurate procedure to remove the stone decreases the risk of complications including AKI, bladder rupture, and peritonitis.

13. Prognostic Factors

Despite the presence of some studies, specific data on the various factors that influence the survival rate of equine patients with AKI are poorly documented. The literature reports general points of AKI prognosis in equine patients that depend on the underlying cause, the duration of renal injury, the response to initial treatment, and the development of secondary complications. The presence of severe ischemia and acute interstitial nephritis likely carries the worst prognosis. On the other therapeutic hand, AKI induced by nephrotoxic agents carries a more favorable prognosis when tubule basement membranes remain intact. Additional and more specific parameters must be taken into consideration to further determine prognosis. These parameters include the maximum creatinine concentration value effect, patient age, cause of renal injury, effect of fluid therapy duration and volume, effect of comorbidity, and recovery time. In a retrospective study using a large number of hospital cases at the author's veterinary teaching hospital (233 equine patients with AKI), the average survival rate was 66%, which has increased over the last three decades, likely attributable to improved therapeutic management. Survival rates decreased with higher AKI stages, were independent of age (although there was a trend for horses over 15 years old to have a less favorable prognosis), and were negatively correlated with associated orthopedic, muscular, or respiratory disease comorbidities.

Whichever the cause of AKI in equine patients, a successful outcome may be incomplete, and a return to previous normal renal function may not occur. Horses with low-grade renal dysfunction probably live long after an AKI episode, but this point is not well documented and remains to be validated.

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.

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Association of Vitamin E-Responsive Myopathy and Equine Neuroaxonal Dystrophy/Equine Degenerative Myeloencephalopathy

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Sacrocaudalis dorsalis medialis mitochondrial alterations consistent with vitamin E-responsive myopathy were identified in >40% of horses diagnosed with equine neuroaxonal dystrophy/equine degenerative myeloencephalopathy. Vitamin E-responsive myopathy diagnosis may be used to increase suspicion of equine neuroaxonal dystrophy/equine degenerative myeloencephalopathy antemortem.
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1. Introduction

Equine neuroaxonal dystrophy/equine degenerative myeloencephalopathy (eNAD/EDM) is a common postmortem diagnosis in neurologic horses. Though temporal vitamin E deficiency is etiologically implicated, eNAD/EDM remains a diagnosis of exclusion in live horses. Vitamin E-responsive myopathy (VEM) is diagnosed through observation of mitochondrial alterations in highly oxidative muscle fibers within the sacrocaudalis dorsalis medialis (SCDM). These alterations might be a proxy for central nervous system oxidative damage. The objective was to determine the percentage of horses with concurrent eNAD/EDM and VEM. Percentages of horses with eNAD/EDM exhibiting low serum [vitamin E] and increased serum and cerebrospinal fluid [phosphorylated neurofilament heavy subunit (pNF-H)] were also compared.

2. Materials and Methods

In this descriptive case series, SCDM biopsies were obtained from 43 horses presented to the University of Pennsylvania School of Veterinary Medicine's New Bolton Center Large Animal Hospital between 2021 and 2023 with postmortem lesions compatible with eNAD/EDM. Biopsies were histopathologically evaluated for mitochondrial alterations. Serum [vitamin E] was determined with high-performance

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liquid chromatography and [pNF-H] with sandwich enzyme-linked immunosorbent assay.

3. Results

Twenty eight out of 68 (41%) horses exhibited comorbid VEM. Three out of 36 (8%) exhibited elevated serum [pNF-H], and 8/36 (22%) exhibited increased cerebrospinal fluid [pNF-H]. Eleven out of 59 (19%) had low serum [vitamin E].

4. Discussion

SCDM mitochondrial alterations were identified in >40% of horses with eNAD/EDM and can increase antemortem suspicion of neurodegenerative disease. Investigation of VEM frequency in normal horses and those with other neurologic conditions will enable estimation of specificity.

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 Submit a Neurologic Horse for Postmortem Examination: Submission, Interpretation, and Expectations

Rebecca Ruby, BVSc, MS, DACVP, DACVIM*; Jennifer Janes, DVM, PhD, DACVP; and Julie Engiles, VMD, DACVP

This paper will aid practitioners submitting a neurologic horse for postmortem examination by summarizing the necessary information and logistical considerations needed to maximize the diagnostic value of a postmortem examination related to clinical disease. Authors' addresses: University of Kentucky Veterinary Diagnostic Lab, 1490 Bull Lea Road, Lexington, KY 40511 (Ruby, Janes); University of Pennsylvania, New Bolton Center, 382 West Street Road, Kennett Square, PA 19348 (Engiles); e-mail: rebecca.ruby@uky.edu. *Corresponding and presenting author. © 2023 AAEP.

1. Introduction

The complete neurologic postmortem examination in horses is a time-consuming and effort-laden event that requires an appropriate facility with necessary equipment and skilled personnel with knowledge of equine musculoskeletal and nervous system anatomy. This presentation will mostly focus on diseases affecting the cervical spinal segment, but much of the information can be applied to other equine neuropathologies. Neurologic disease in horses can result from a variety of causes including developmental malformations (e.g., cervical vertebral compressive myelopathy), degenerative processes (e.g., vertebral articular process joint arthropathy [Fig. 1] or intervertebral disc disease), trauma, infectious/inflammatory processes (i.e., osteomyelitis) Vitamin E associated diseases (e.g., equine degenerative myeloencephalopathy or equine motor neuron disease), vascular insults, or rarely neoplasia. In most cases of disease related to the equine cervical column, the historical onset and progression of disease is chronic, and, with the exceptions of equine protozoal myeloencephalitis or neuroborreliosis that often have more long-term, insidious neurologic manifestations, infectious disease (i.e., bacterial or viral encephalomyelitis) is less likely. Therefore, a comprehensive history including duration of clinical signs and vaccination history will help to avoid delays in processing if infectious pathogens can be ruled out. Of note, in all cases of acute onset neurologic disease, zoonotic causes of encephalitis in countries where they exist (rabies virus, eastern equine encephalitis, Hendra virus) are considered differential diagnoses that require specialized testing prior to commencement of mechanical sectioning and evaluation of the spinal column. Moreover, all personnel in contact with the animal both ante- and postmortem should implement biosecurity measures to avoid exposure to blood or body fluids or, if exposed, contact local health and regulatory authorities to determine the need for postexposure prophylaxis.

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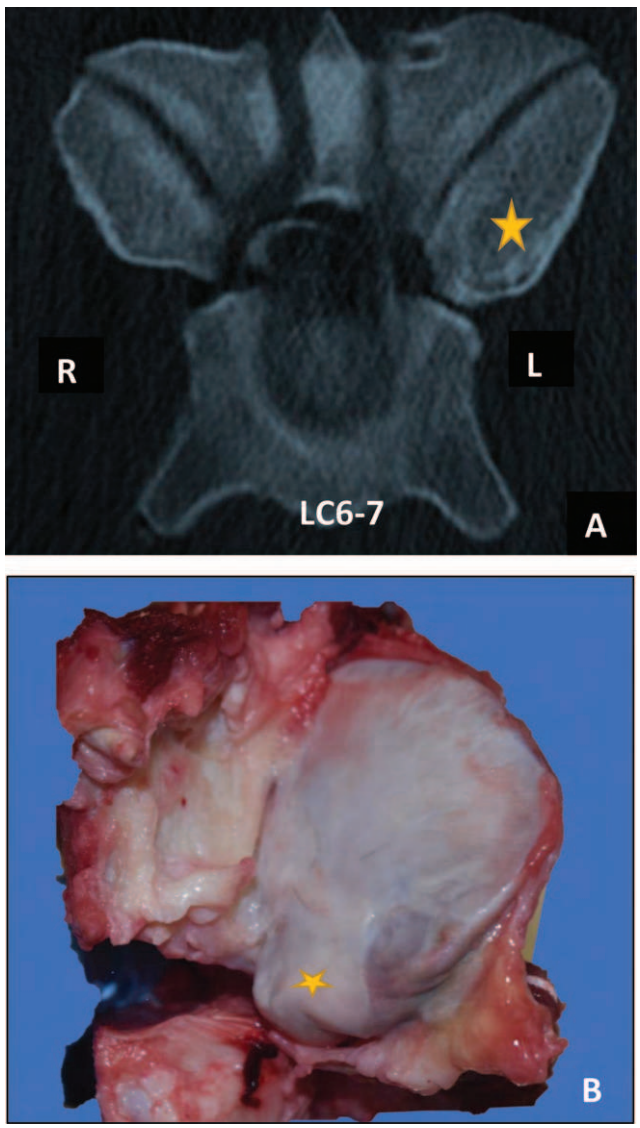


Fig. 1. Computerized tomography-macroscopic correlation of cervical osteoarthropathy. A, Left cranial articular process of C7 (star) is enlarged with evidence of narrowing of the intervertebral foramen. (Image courtesy of Dr. Katherine Garrett.) B, On macroscopic examination, the left cranial articular process of C7 is enlarged with thinning of the articular surface and an irregular margin (star) along the ventral aspect that is obstructing the view of the intervertebral foramen.

2. Materials and Methods

When planning to submit a horse for neurologic postmortem examination, the authors recommend contacting the laboratory prior to euthanasia if this is not a routine submission from one's practice. Important considerations and logistical questions to ask the lab are included below:

- Can the laboratory perform a complete neurologic necropsy? This includes removal of the brain and all of the spinal cord and examination of the spinal column for bone or soft tissue abnormalities. Large, commercial-grade bandsaws are typically required to perform these tasks in a systematic and efficient manner.
- What are the hours/days that necropsies are performed, and what is the ideal time for the horse to arrive? Since disease with infectious or herd-health implications often take priority in a diagnostic laboratory, depending on staffing constraints, cases of elective euthanasia may be scheduled based on anticipated laboratory case load to minimize postmortem interval and autolysis of central nervous system tissues.
- Communication of specific clinical questions to ensure that these areas of interest are addressed at the time of postmortem examination. This is particularly important if the case is complex and there are multiple clinical problems/questions such as suspected cervical vertebral disease but also chronic forelimb lameness.
- If the horse is insured or there are potential medical-legal implications, information regarding the anticipated turn-around time from submission to a final report is helpful, as well as information on the laboratory's policy on holding both glass slides and tissue blocks. In some cases, these may be disposed of within months of the case. Relaying any information that will be needed from the insurance company or for potential legal action is ideal before the postmortem examination.

Once the lab is identified for submission, a complete but concise history should be provided to the pathologist prior to or at the time of the submission of the animal. All information should be in writing and submitted with the laboratory submission paperwork to ensure it is available to the attending pathologist. Check with the laboratory to see if submission history can be emailed or entered electronically through an online portal. If diagnostic imaging has been performed, then access to these reports or a summary of the findings is incredibly helpful to direct the postmortem examination. Remember that pathologists are not equine clinicians; avoid use of abbreviations or colloquial terms. The most pertinent information is included below:

- Known onset, duration, and progression of neurologic disease
- Neuroanatomic localization
- Imaging study findings with emphasis on the presence of lateralizing lesions if applicable
    - This is particularly important if osteoarthritis or abnormalities of the articular processes are a concern as disarticulation is typically not performed throughout the entire column.
- Vaccination status of the horse
- Any other clinical concerns

- Desire for gross photographs or plan to publish the case
    - Photographs are not obtained in all postmortem cases; therefore, if a submitter requires or requests photographs, this should be requested prior to the postmortem.
- It is rarely recommended to limit the neurologic examination to only one section of the spinal cord. Unless there is a specific need, collection of the brain and all spinal cord sections is encouraged. This will allow for examination of further sections if a primary diagnosis is not found in the original area of interest.

Autolysis occurs rapidly in the spinal cord due to the large size of horses and presence of adipose tissue surrounding the cord. Unlike other tissues, autolysis may mimic several common processes in the spinal cord and brain, making histologic interpretation challenging, and thus will often inhibit making a definitive diagnosis. As mentioned above, it is extremely important to perform the neurologic necropsy the same day as euthanasia whenever possible. This may necessitate scheduling of the euthanasia or transport for early morning. In warm/hot climates, prohibitive autolysis may occur within less than 12 hours of euthanasia. Antemortem pyrexia can also advance tissue autolysis.

3. Results

Neurologic postmortem examinations often take a longer time to process, evaluate, and interpret gross and histologic lesions; acquire ancillary diagnostic tests if applicable (e.g., microbiologic, molecular or toxicologic tests); and produce a finalized report compared to non-neurologic postmortem evaluations. This is due to the inherent complexity of many of these cases that requires radiologic correlation and extensive gross and histologic subsections, as well as the preference of allowing neural tissue to fix in formalin for an additional 24 hours or longer depending on the nuances of a particular case. If microscopic evaluation of bone lesions is required, this requires additional steps to decalcify the bone prior to histologic tissue processing. Although labs often communicate anticipated delays to the veterinarian to help manage expectations, these potential delays should also be conveyed to the client and insurance company.

The components of a postmortem report include the gross examination, microscopic examination, morphologic diagnoses, final diagnoses, and possibly a comment summarizing the findings in context of the provided clinical history if needed. The convention is that normal findings are not typically reported unless there is a specific justification (e.g., historical reference of a suggested abnormality that lacks gross or histologic correlation). The gross examination portion is a description of the findings observed while performing the examination on the postmortem floor including all accompanying dissections of the equine head and spinal column. It is implied that all abnormalities of significance will be described. There is variation between laboratories and pathologists with gross examination of a case released first in some, while in others it is not available until microscopic examination is completed. The microscopic/histopathologic examination of the report describes microscopic abnormalities of significance (Table 1). These microscopic findings will be listed according to tissue/organ examined. Ideally, specific locations in the brain and spinal cord, where appropriate, will be indicated in this description. Typically, a list of other organs that were examined and determined to be normal is also included within this section. While gross and histologic descriptions are objective (i.e., true "data points"), morphologic diagnoses are subjective to pathologic interpretations of the gross or histologic lesions, which often summarize the detailed pathologic findings. The "morphologic diagnosis" or "pathoanatomic diagnosis" is the section of the report where most abnormalities will be listed in bulleted form. In some laboratories, the morphologic diagnosis and microscopic examination will be combined into one section. If a final diagnosis section is present, this is typically considered the main cause of disease or death based on all pertinent findings. Finally, a comment may be included to address any specific clinical questions or further describe the observed disease processes if needed.

4. Discussion

From both a clinical and pathologic perspective, diagnostic workup of equine neurologic disease is an involved and often time-consuming process. Reaching a final diagnosis often requires collaboration between the submitting veterinarian, diagnostic imaging specialists, and anatomic pathologist. Providing complete histories, neuroanatomic localizations, and advanced imaging results to the pathologist are incredibly useful to help direct the postmortem examination. Being mindful of logistical issues (i.e., transportation, reduction of the postmortem interval, etc.) will greatly help the ability to achieve a postmortem diagnosis. Of note, in a subset of cases, lesions that correlate with clinical signs may not be observed, e.g., botulism is a "rule-out" diagnosis from a pathologic perspective and is not associated with gross or histologic lesions. Given the amount and diversity of tissue that makes up the central nervous system, it is impossible to process all tissue for microscopic examination; thus, sections from standard sets of representative areas are evaluated first, with additional samples from other areas if indicated. This reiterates the importance of relaying clinical information and neuroanatomic localization to help direct the postmortem examination. The neurologic postmortem examination is a great resource for understanding various disease processes in the horse and can be confirmatory of the clinical diagnosis or provide alternative etiologies that advance understanding of neurologic manifestations of disease. With effort from both the submitting veterinarian and veterinary anatomic pathologist, these cases can be valuable experiences. The goal of this how-to paper is to provide

Table 1. Common Terminology Within the Neurologic Postmortem Examination[1,2]

Term	Definition	Clinical Correlation
Axonopathy	Degenerative processes resulting in degeneration and die-back of axons and eventually neuronal cell bodies	Equine degenerative myeloencephalopathy (EDM) or neuroaxonal dystrophy (NAD)
Chromatolysis	Degenerate or necrotic neurons characterized by perikaryon hypereosinophilia, nuclear pyknosis/karyorrhexis/karyolysis	Gray matter degeneration associated with compressive myelopathy (CVCM), EDM/NAD, neurotoxicity
Compressive myelopathy	Spinal cord compression resulting in microscopic lesions	Damage to the spinal cord that can result in clinical deficits (i.e., ataxia)
Digestion chambers	Wallerian degeneration with dilated myelin sheaths and phagocytosis of axonal/myelin debris by phagocytic "foamy" macrophages	Degenerative diseases (CVCM, EDM/NAD)
Gemistocytic astrocytes	Reactive population of astrocytic glial cells with swollen to streaming, hypereosinophilic cytoplasmic processes	CVCM, necrotizing infectious encephalomyelitis, vascular disruption (e.g., infarcts), central nervous system trauma
Gliosis	Increased infiltrates and activation of glial cells (combinations of reactive astrocytes and microglial/Gitter cells)	Degenerative or infectious/inflammatory processes, metabolic encephalopathies (i.e., Type 2 astrocytosis with hepatic encephalopathy)
Gitter cells	Myelomacrophages, i.e., phagocytic macrophages of the central nervous system that have vacuolated "foamy" cytoplasm	CVCM, necrotizing infectious encephalomyelitis, vascular disruption (e.g., infarcts), central nervous system trauma
Lipofuscin	Intracellular pigment accumulation thought to occur with oxidative damage	"Aging change," oxidative stress (e.g., Vitamin E deficiency)
Malacia	Necrosis of central nervous system tissue resulting in parenchyma "softening," cavitation, and inflammation including myelomacrophages (Gitter cells), spheroids, neuronal chromatolysis, and reactive astrocytosis (gemistocytes)	CVCM, necrotizing infectious encephalomyelitis, vascular disruption (e.g., infarcts), central nervous system trauma
Nonsuppurative	Nonneutrophilic inflammation, typically includes a mix of lymphocytes, plasma cells, macrophages; often noted if eosinophilic component is involved	Most viral encephalitidies (West Nile virus, rabies), equine protozoal myeloencephalitis (often with an eosinophilic component), a component of chronic suppurative inflammation
Spheroids	Swollen axons	Traumatic, degenerative, or inflammatory diseases
Subluxation	Partial dislocation of a synovial joint or intervertebral disc	Traumatic events, intervertebral disc disease herniation
Suppurative	Neutrophilic inflammation	Meningoencephalitis/myelitis associated with bacterial or fungal pathogens, eastern equine encephalitis (mild neutrophilic component)
Synovial cyst	Collection of synovial fluid within a cystic invagination of the synovial membranes of an articular process joint, often associated with compressive radiculopathy or myelopathy	Articular process arthropathy, compressive radiculopathy/myelopathy
Vacuolation/spongiosis	Myelin sheath dilation associated with Wallerian degeneration (i.e., axonal die back)	Degenerative myeloencephalopathies (CVCM, EDM/NAD)
Vascular hyperemia	Vasodilation or congestion (can be active or passive)	Associated with inflammatory or reactive processes, which can be secondary to primary process

a framework to enlighten submitters to the process, reduce questions and complications regarding neurologic postmortem submissions, set expectations, and maximize diagnostic value.

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.

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Synovial Fluid Concentrations of Morphine and Its Major Metabolites After Intravenous Regional Limb Perfusion in Horses Performed Under Standing Sedation

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Synovial morphine concentrations were measurable following intravenous regional limb perfusion and were not affected when used concurrently with amikacin. Administration of morphine via intravenous regional limb perfusion may be beneficial as an analgesic technique while limiting potential serious systemic side effects. Authors' address: University of California – Davis, School of Veterinary Medicine, One Shields Avenue, Davis, CA 95616; e-mail: ikilcoyne@ucdavis.edu. *Corresponding and presenting author. © 2023 AAEP.

1. Introduction

Addition of morphine to the perfusate while performing intravenous regional limb perfusion (IVRLP) may help in treating painful infectious orthopedic conditions of the distal limb. The main objective of this study was to determine synovial morphine concentrations following IVRLP with morphine alone or in combination with amikacin.

2. Materials and Methods

This was a randomized cross-over study. Six horses underwent IVRLP with 0.1 mg/kg morphine sulfate diluted to 60 mL using 0.9% sodium chloride (M-group) or combined with 2 g amikacin and 0.9% sodium chloride (MA-group) with a 2-week washout period between treatments. Synovial fluid was collected from the radiocarpal joint at 10, 20, 30, 120, 240, 480, 720, and 1,440 minutes after IVRLP. The tourniquet was removed after the 30-minute sample was collected. Synovial concentrations of morphine and major metabolites were measured using liquid chromatography-tandem mass spectrometry. Amikacin concentrations were quantified by a fluorescence polarization immunoassay.

3. Results

Measurable concentrations of morphine were apparent in the radiocarpal joint of all horses. The

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NOTES

mean ± standard deviation C_{MAX} of morphine was 5,925.7 ± 4,864.3 ng/mL in the M-group and 5,042 ± 1,556.2 ng/mL in the MA-group ($p = 0.46$). The mean ± standard deviation C_{MAX} of synovial amikacin was 522.3 ± 467.5 μg/mL.

4. Discussion

IVRLP using morphine is a feasible technique. Higher synovial morphine levels were achieved compared to those previously reported following intravenous administration. Similar concentrations of amikacin were measured compared to previous studies, indicating neither drug was affected by coadministration.

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.

Clinical and Safety Evaluation of a Novel Drug (SOCS1-KIR) for the Treatment of Horses with Uveitis

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The SOCS1-KIR novel drug is effective at treating equine recurrent uveitis (ERU) and is a potential treatment option for other autoimmune diseases. Authors' address: University of Pennsylvania, New Bolton Center, 382 West Street Road, Kennett Square, PA 19348; e-mail: scherrer@vet.upenn.edu. *Corresponding and presenting author. © 2023 AAEP.

1. Introduction

ERU is reported in up to 25% of horses, and standard medical and/or surgical treatment often does not control disease, so novel therapies are warranted.

2. Materials and Methods

Horses were randomly assigned to be treated with topical SOCS1-KIR or 0.1% diclofenac ointment twice daily during the study period of one month. Three ophthalmic examinations were performed at 2-week intervals, and an ocular inflammatory score was given at each exam. The total inflammatory score is created by combining the following individual scores: ocular discharge, ocular hyperemia, chemosis, corneal edema, hyphema, and aqueous flare.

3. Results

There was no statistical difference at any time point between horses treated with diclofenac and SOCS1-KIR. There was also no difference in ocular complications between the two groups (corneal ulcer = 2, blepharospasm = 1). Horses with bilateral disease were more likely to have increased scores (OR 6.96). Overall inflammatory scores were lower at appointments two and three compared to appointment one (OR appt 2 0.30, appt 3 0.18). Horses that had uncontrolled inflammation at the final visit were offered a low dose gentamicin injection, and there was no difference between groups in injections performed (n = 11).

4. Discussion

The SOCS1-KIR novel drug is as effective as topical diclofenac for horses with ERU, evidenced by similar inflammatory scores throughout the study between treatment groups and a similar progression to surgical intervention (low dose intravitreal gentamicin injection).

Acknowledgments

Disclaimer

Compounded products can vary significantly in their respective potency and stability.

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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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