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EQUINE VETERINARY EDUCATION

American Edition | October 2020

EQUINE VETERINARY EDUCATION/AMERICAN EDITION

VOLUME 32 NUMBER 10



The official journal of the
American Association of
Equine Practitioners, produced
in partnership with BEVA.

IN THIS ISSUE:

The conundrum of compounded drugs

Bilateral ovariectomy as a treatment for chronic pyometra in four horses

Use of a carbonated beverage to disintegrate a phytobezoar obstructing
the intrathoracic portion of the oesophagus of a horse

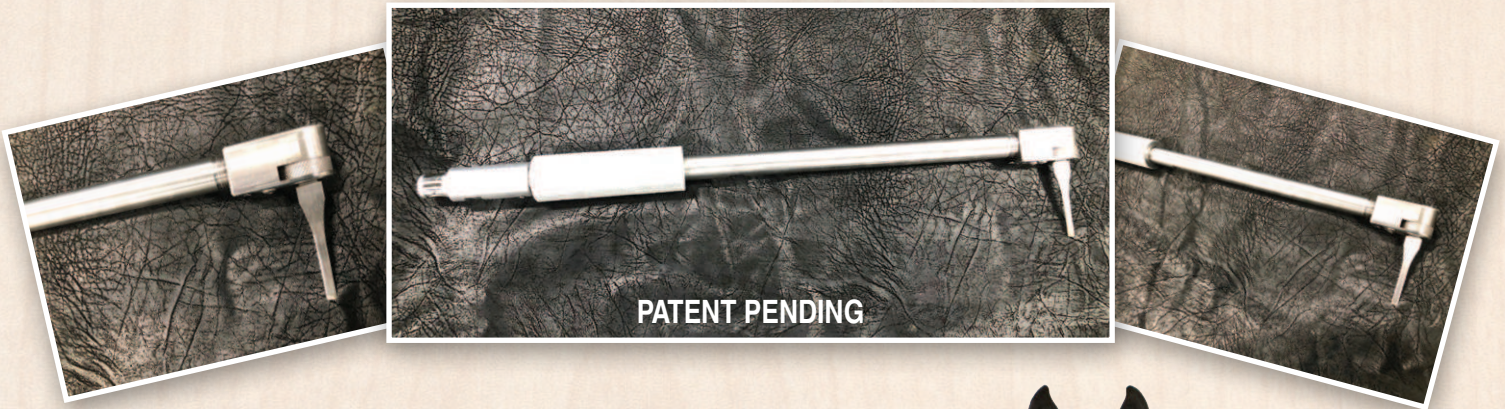
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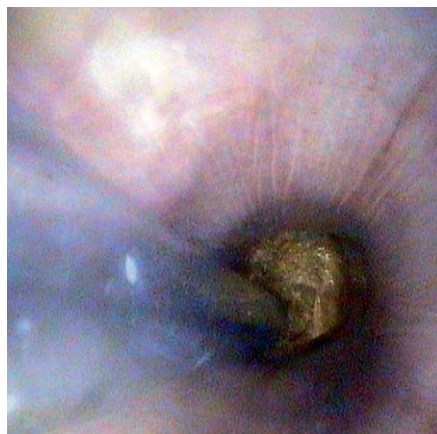
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CONTENTS



AAEP NEWS In this issue

The conundrum of compounded drugs	III
Longeing considerations for the competition horse.....	V
AAEP Virtual Convention & Trade Show: Prepare for a new practice era	VI

Highlights of Recent Clinically Relevant Papers

S. WRIGHT	506
-----------------	-----

Editorial

Environmental sustainability in the equine veterinary profession E. WEST AND F. MALALANA.....	508
--	-----

Case Reports

Reoccurrence of a paranasal osteoma following surgical removal in a 6-month-old Warmblood filly L. MCGLINCHEY, R. COLE AND F. J. CALDWELL	511
Use of a carbonated beverage to disintegrate a phytobezoar obstructing the intrathoracic portion of the oesophagus of a horse L. C. LIVESEY, E. YORKE, A. PARRA, Q. GRAY, C. DAVIES, D. WELDON, J. SCHUMACHER, S. KIMURA, C. HOWARD, T. SIERRA-RODRIGUEZ AND M. MORA-PEREIRA.....	514
Hand-assisted laparoscopic reattachment of a mesoduodenojejunal defect in a broodmare H. D. O'NEILL	518
Bilateral ovariectomy as a treatment for chronic pyometra in four horses A. R. E. JONES, C. A. RAGLE, N. A. HUGGONS AND A. A. TIBARY	519
Long-term successful outcome of a <i>Streptococcus equi</i> subspecies <i>equi</i> brain abscess H. C. SCHOTT II, M. M. ESSER, C. G. PIRIE, A. P. PEASE, J. S. PATTERSON AND S. M. REED.....	525
A two-step ovariohysterectomy with unilateral left flank laparoscopic assistance in a Quarter Horse mare D. T. N. KADIC AND A. G. BONILLA.....	526

Clinical Commentaries

Diagnostic imaging characteristics of sinonasal tumours in the horse R. E. MORGAN.....	512
Management of phytobezoars H. E. BANSE.....	515
Basic principles of intracorporeal suturing as applied during laparoscopy N. S. WOODFORD AND M. D. WHITTAKER.....	520

Original Articles

The influence of rider:horse bodyweight ratio and rider-horse-saddle fit on equine gait and behaviour: A pilot study S. DYSON, A. D. ELLIS, R. MACKECHNIE-GUIRE, J. DOUGLAS, A. BONDI AND P. HARRIS.....	527
Heineke-Mikulicz pyloroplasty for the treatment of pyloric stenosis secondary to gastro-duodenal ulcer disease in three foals A. V. KENT, D. E. SLONE, C. K. CLARK AND T. M. LYNCH	540

Review Articles

Eosinophils of the horse: Part I: Development, distribution, structure and biochemical mediators M. M. BROSNAHAN	545
Farriery for the foal: A review part 1: Basic trimming S. E. O'GRADY	553

Marketplace.....	560A-D
------------------	--------

Advertisers' Index	510
--------------------------	-----

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The conundrum of compounded drugs

By Dionne Benson, DVM, JD



Dr. Dionne Benson

A few weeks ago, while at the barn with my personal horse, a friend asked if I would administer a dose of Adequan® to her horse. Although I knew the horse, had examined him many times before, and knew that this class of medication would help based upon the horse's history, I did not prescribe the medication. When I asked if it is real Adequan or compounded, her response was not actual

Adequan but "generic." I apologized and said there is no generic Adequan and that I cannot administer a compounded drug when there is a legend drug approved by the FDA for the same purpose.

As it happened, a veterinary colleague was in the barn for her weekly chiropractic rounds. Out of the corner of my eye, I caught her giving me a thumbs up. This led to a discussion between the two of us about the difficulties we had encountered with compounded drugs. She revealed that she most often receives requests for compounded drugs when another veterinarian or the client's friend's veterinarian recommends a compounded version of a legend drug. The client then asks my colleague to prescribe or dispense the compounded drug. She believes that the FDA-approved product will work best for the horse and that the compounded drug may not be effective. Ethically, and based upon her best professional judgment, she refuses to prescribe these drugs, leading to an uncomfortable discussion with her client.

As a veterinarian working for a private company that owns racetracks, I often see veterinarians and vendors who want to sell and prescribe compounded drugs in lieu of FDA-approved medications at the racetrack. These drugs are marketed to horsemen who are usually unaware of the rules or the risks associated with compounded drugs. Often, state racing commission regulations specifically prohibit the sale of these compounded drugs but, like most things, the common argument in favor of compounded drugs is cost. I've seen many ethical veterinarians lose business to a vendor or another veterinarian willing to prescribe cheaper compounded versions of the same drug, which may be less effective or even dangerous. For me, this often leads to difficult conversations with veterinarians, trainers and vendors. In one memorable case, it led to another veterinarian shaking his finger at me while yelling, "Listen, little missy, you just don't know how things are done around here."

The use of compounded medications sometimes is indeed innocent, usually by veterinarians who lack the understanding of the differences between the classes of drugs and the applicable laws. The lack of clarity for compounding regulations is aggravated by unclear messaging from the FDA. Several years ago, the FDA began a revision of its guidance regarding the use of compounded drugs in veterinary practice; at that time, it pulled the existing guidance document. This left veterinarians without much direction on how the FDA would approach enforcement activities with respect to veterinary compounding, especially as it relates to compounding from bulk drug substances. The new FDA guidance is set to be released in the coming months and has been the subject of much debate among compounders, drug companies and veterinarians. The guidance document likely will lay out the criteria/circumstances whereby the FDA will exercise enforcement discretion with respect to compounding from bulk drugs.

Unclear guidance from the FDA and clients asking for cheaper treatment alternatives creates the perfect storm of incentive for the veterinarian to take the easy route by just providing the compounded drug. The client is happy to save money and the veterinarian is unlikely to face any legal consequences for prescribing a compounded version. But does that make it ethical?

American philosopher Aldo Leopold wrote, "Ethical behavior is doing the right thing when no one else is watching—even when doing the wrong thing is legal." This oft-quoted statement is particularly applicable to dealing with compounded drugs. For the most part, clients don't understand the difference between compounded, generic or legend drugs. Even if something goes wrong with a horse, the client may not connect it with the use of a compounded drug. Unless there is a specific complaint from a client or another regulatory body, the veterinarian runs little risk of enforcement by the FDA or the state pharmacy board. Quite simply, no one is watching our behavior when we make these decisions. Because of this, it is crucial that we, as veterinarians, act ethically when it comes to prescribing and administering medication.

The use of compounded medication should be limited to instances where it is absolutely necessary for the health and welfare of a horse when there are no other options available to the veterinarian. As veterinarians, it is our job to educate clients about the value of legend and generic medications so that they understand that with increased cost comes research, purity, consistency and other safeguards that protect their horse. Ultimately, if that doesn't work, it is our job to say we won't improperly prescribe a compounded drug.



ETHICAL PRACTICE
Every Day-Every Time

Dr. Benson is chief veterinary officer for The Stronach Group, which owns and operates Thoroughbred racetracks across the United States, and a member of the AAEP's Professional Conduct & Ethics Committee.

5 things to know about AAEP this month

1. Register for the AAEP's Virtual Convention & Trade Show, which will conveniently incorporate live and on-demand sessions, at convention.aaep.org.
2. View the AAEP's new *Borrelia burgdorferi* Infection and Lyme Disease Guidelines or save them as a PDF to your mobile device at <https://tinyurl.com/aaepbldg>.
3. U.S. members: Be reimbursed for up to \$600 of free veterinary care for a financially distressed owner through Vet Direct Safety Net. Sign up at aaep.org/vet-direct-safety-net.
4. Seeking a new job opportunity or a qualified candidate for an open position? Make a career connection in the AAEP Career Center at jobs.aaep.org.
5. The Foundation for the Horse has provided hay, supplies and financial resources in support of equine disaster relief due to Hurricane Laura in Louisiana and wildfires in the Western U.S.

AAEP publishes *Borrelia burgdorferi* Infection and Lyme Disease Guidelines

Comprehensive guidelines to assist practitioners with identification, diagnosis and control of *Borrelia burgdorferi* infection and Lyme disease, an important tick-borne disease of horses in the northeastern United States and beyond, are now available on the AAEP website.

"*Borrelia burgdorferi* infection is common in horses residing in Lyme endemic areas and the geographic range for exposure appears to be increasing," said Dr. Sally DeNotta, who co-authored the guidelines with Dr. Thomas J. Divers. "Despite the high prevalence of exposure and seropositivity to *B. burgdorferi* in horses residing in endemic regions, confirming clinical Lyme disease remains a diagnostic challenge. We hope these guidelines help clear up confusion and provide useful information to assist equine veterinarians with the diagnostic approach and clinical management of horses suspected of having Lyme disease."

The *Borrelia burgdorferi* Infection and Lyme Disease Guidelines, available as a PDF file, were reviewed and approved by the AAEP's Infectious Disease Committee and board of directors. View the guidelines or save them



to your mobile device for future reference at <https://tinyurl.com/aaepbldg>.

In addition to *Borrelia burgdorferi* infection and Lyme disease, AAEP guidelines for 22 other equine infectious diseases are available at aaep.org/guidelines/infectious-disease-control. In addition, a Lyme disease Factsheet for horse owners may be found on the Equine Disease Communication Center website at equinediseasecc.org/disease-information.

Download AAEP member logo for use in your practice



Show your clients and prospective clients that you adhere to the highest ethical and professional standards by displaying the member version of the AAEP logo on your practice website, stationery, vehicle and elsewhere.

While you are welcomed and encouraged to signify your membership through display of the member logo, please refrain from using the AAEP logo in conjunction with any commercial product as such use may improperly infer an association endorsement of the product.

Download your desired logo format at <https://tinyurl.com/memlogoaaep>.

Longeing considerations for the competition horse

By Chris Newton, DVM

The practice of longeing horses for training and exercise is well based in the art of in-hand work of the horse. Throughout military history, horses have been worked in hand to develop communication between the trainer and the horse, develop the core fitness of the horse and prepare horses for higher levels of collection. In the present time, longeing continues to be used correctly by many, but the practice has been incorrectly used by some to fatigue and force submission in horses that are reticent to work correctly.

Longeing should be done with correct equipment, adequate experience and good footing. Equipment can range from a longe line, protective boots, a bridle and surcingle, or progress to more advanced devices such as a Pessoa and long lines for double longeing. The variation in equipment used depends on the ability of the handler, the horse and the goals trying to be accomplished.

Abusive longeing practices such as allowing horses to run wildly at the end of a longe line unbalanced is as harmful as forcing a horse into an uncomfortable position and having them refuse to move.

In general, horses should work in balance, proper rhythm and relaxed in the equipment being utilized. There may be moments of resistance, but the general period of exercise should progressively become more relaxed. Equipment used should be for protection of the horse as well as assistance in guiding the horse into a correct frame for exercise. Horses that fail to move forward, exhibit extreme misbehavior, or show lameness or difficulty breathing should be removed from the



equipment or placed in equipment that doesn't elicit that response. Progressive work through acceptance and relaxation is acceptable, but constant attention to the horse is required.

Abusive longeing practices such as allowing horses to run wildly at the end of a longe line unbalanced is as harmful as forcing a horse into an uncomfortable position and having them refuse to move. The AAEP Principles of Equine Welfare indicate that horses "should be cared for in ways that minimize fear, pain, stress and suffering." These are broad statements and can be interpreted as such. However, it should be clear that horses are working in a manner that exhibits relaxation, rhythm and balance quickly into the exercise session on the longe or long lines, and that horses don't exhibit excessive fatigue when the session ends. Horses that buck, rear, resist forward movement or run wildly throughout the session or for an extended period of time are not free of abusive practices.

It should be noted that competitions are a time of exhibiting horses at their best, and teaching is now considered a secondary focus of the competition. Horses working in hand at a competition should exhibit a much greater level of acceptance, rhythm, balance and relaxation than

they may at home. Horses at home may at times be more resistant, but the practice of working them on the lines should still proceed in stages that are acceptable to the horse and progress to greater degrees of difficulty through proper horsemanship and training. When horses are being handled in what appears to be abusive manners at a competition, it is not the veterinarian's role, in general, to confront the individuals, but the competition management and officials can be notified and they can take appropriate steps to deal with the situation.

In general, work in hand with a single longe line or double long lines is a tremendous technique to develop a horse's strength, training and relaxation. However, proper attention to humane treatment and proper horsemanship should always be maintained to accomplish the appropriate goals through humane techniques. The practice of working horses on lines should be understood by veterinarians, and the discussion of how to maximize the health and happiness of the horse should always be the primary goal.

Dr. Newton practices at Rood & Riddle Equine Hospital in Lexington, Ky., with primary interests in equine sports medicine, physical therapy, alternative medicine and reproduction.

AAEP comments on progress of Horseracing Integrity and Safety Act

Three weeks before the U.S. House of Representatives passed H.R. 1754, the Horseracing Integrity and Safety Act, on Sept. 29, U.S. Senate Majority Leader Mitch McConnell (R-KY) introduced companion legislation (S. 4547) in the Senate to help set national standards “to promote fairness, increase safety, and help preserve” the sport of horseracing.

The legislation would promulgate uniform performance and safety standards within the sport through creation of the Horseracing Integrity and Safety Authority, an independent, non-governmental regulatory body responsible for improving current regulations and bringing a new level of transparency. This authority would also address medication use, track conditions and other safety standards to protect equine athletes. The legislation would provide federal recognition and enforcement power for the Horseracing Integrity and Safety Authority to develop uniform, baseline standards for horseracing.

AAEP Racing Committee Chairman Dr. Jeff Berk issued the following statement on behalf of the association in early September, shortly after Sen McConnell announced his intention to introduce the legislation.

“Uniformity of therapeutic medication rules in United States horse racing is a goal long endorsed by the AAEP, and we are eager to evaluate the newly proposed Horseracing Integrity and Safety Act to understand how the legislation will address both anti-doping and therapeutic medication control. These two pillars require



Dr. Nat White

oversight by individuals with a high level of expertise. The AAEP urges the bill's sponsors to consider the requisite expertise needed within the sport's proposed governance structure in order to ensure successful implementation across the racing landscape.

“It is more important than ever that the AAEP work together with industry stakeholders to create a workable legislative vehicle that will achieve the uniformity, safety and integrity standards we all seek for racehorses and the racing industry. The AAEP welcomes the continued opportunity to contribute to this process.”





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AAEP Virtual Convention & Trade Show: Prepare for a new practice era

Reimagined event begins December 1; earn CE through June 2021

Adapt and evolve to new practice realities and opportunities during the 2020 AAEP Virtual Convention & Trade Show.

Through a blend of live and on-demand sessions, you'll enjoy the flexibility of earning CE hours at your own pace and on your own schedule. The virtual nature of this year's convention also makes it more affordable and accessible than ever before to acquire the sound medicine and disciplined management strategies that will help you and your practice shine through economic crisis and recovery.

See it all

Among the benefits of this year's convention being online: You'll literally be able to see it all if you so choose. While some educational sessions will be presented live, these and all other educational sessions will be recorded and made available for viewing on-demand until June 30, 2021. As such, there will be no need to take time off from practice or sit at your computer for extended hours at a time in December watching sessions. View sessions and earn CE when it is most convenient for you through the first half of next year.

How it works

The AAEP Virtual Convention & Trade Show will be hosted on Digitell's online digital platform. AAEP will send instructions and a link to the Digitell convention platform to all registrants approximately one week prior to the event. All you need to participate is a computer and Internet connection. Although a desktop computer is preferred, sessions can also be viewed on a tablet or other mobile device. A working microphone on your access device will be needed if you wish to interact during Table Topics, social events or with representatives from companies exhibiting in the virtual trade show.

December 1 kickoff

The virtual convention will start Dec. 1 with both on-demand educational sessions as well as live Table Topics, the popular collaborative outlet for convention attendees to work through common practice challenges together. A pair of Table Topics will be held each weekday through Dec. 18—one at noon and one at 8:00 p.m. ET.

Convention Prime Time

Several selected educational sessions will be presented live during the evenings from December 5–9 in a series called

Convention Prime Time. Among the featured sessions will be the Kester News Hour on Dec. 6 and the Milne Lecture with renowned equine anesthesiologist Dr. John Hubbell on Dec. 9. Attending live sessions will give you an opportunity to interact with the presenters and your fellow attendees using the chat and Q&A functions on the Digitell platform.

Trade show

Instead of browsing physical aisles this year, you'll instead use your browser to discover the latest products and services to improve your practice in the trade show. From Dec. 6–9, between 1:00–6:00 p.m. ET, you'll be able to visit virtual booths and read about show specials, download company resources, watch live demos and speak directly with sales representatives.

Social and wellness opportunities

Social events help maintain a sense of community, which is especially important during what has been an unusual year. In conjunction with the virtual convention, catch up with old classmates during alumni receptions, take advantage of on-demand yoga, and participate in a virtual 5K/10K Fun Run/Walk that can be completed in the weeks leading up to and through the virtual convention.

Register and learn more

View the educational program, including the schedule of live Table Topics and Convention Prime Time sessions, and register for the virtual convention at convention.aap.org. If among the first 1,000 registrants, you will receive a swag box in the mail containing helpful and fun items to enhance your virtual convention experience. If you have questions, please contact Kristin Walker, AAEP membership & event services coordinator, at kwalker@aaep.org or (859) 233-0147.

Members in the news



Dr. Marvin Beeman

Dr. Marvin Beeman honored by American Horse Council

The American Horse Council has bestowed the 2020 James J. Hickey Jr. Award upon AAEP Past President Dr. G. Marvin Beeman, for his longtime contributions to the AHC and the horse industry.

A graduate of Colorado State University and Emeritus-original partner at Littleton Equine Medical Center in Littleton, Colo., Dr. Beeman is a former AHC trustee who also chaired the AHC Health and Regulatory Committee. He served as AAEP president in 1975 and has chaired or served on many AAEP committees and task forces during his career.



Dr. Larry Bramlage

Dr. Larry Bramlage elected Jockey Club steward

AAEP Past President Dr. Larry Bramlage, shareholder in Rood & Riddle Equine Hospital in Lexington, Ky., and recipient of The Jockey Club Medal in 1994 for his contributions to Thoroughbred racing, has been elected to the board of stewards of The Jockey Club.

Dr. Bramlage received his veterinary degree from Kansas State University. He served as AAEP president in 2004 and has participated as a member or chair of numerous committees and task forces through the years.



Dr. Mary Scollay

Dr. Mary Scollay elected Jockey Club member

Dr. Mary Scollay, executive director and chief operating officer of the Racing Medication and Testing Consortium in Lexington, Ky., has been elected to membership in The Jockey Club.

A graduate of the University of Illinois, Dr. Scollay serves on the AAEP's Racing Committee and Professional Conduct & Ethics Committee.



Dr. Bonnie Beaver

Drs. Bonnie Beaver, Anthony Blikslager recognized by AVMA

Several AAEP members received AVMA Excellence Awards during the association's virtual convention in August.

Dr. Bonnie Beaver, longtime professor of veterinary medicine at Texas A&M University, received the AVMA Award for her contributions to the advancement of veterinary medicine in its organizational aspects.

She served as AVMA president in 2004-05 and helped create the AVMA Animal Welfare Division and reorganize the AVMA Animal Welfare Committee. A graduate of the University of Minnesota, Dr. Beaver founded both the American College of Veterinary Behaviorists and the American College of Animal Welfare.



Dr. Anthony Blikslager

Dr. Anthony Blikslager, professor of equine surgery and gastroenterology and head of the Department of Clinical Sciences at North Carolina State University College of Veterinary Medicine, received the AVMA Clinical Research Award.

A graduate of Virginia-Maryland College of Veterinary Medicine, Dr. Blikslager has authored more than 180 peer-reviewed publications, and his research is focused on equine colic, recognition and treatment of pain, and mechanisms of intestinal repair. He serves as vice chairman of The Foundation for the Horse Advisory Council and chair of its Research Subcommittee.

Also honored during the convention and previously announced in *EVE* was Dr. Harry Werner, who received the AVMA Animal Welfare Award.

Auburn faculty clinician selected as August My Vet Rocks winner



Three AAEP members were selected from among several dozen nominations as the August honorees in the AAEP's My Vet Rocks Contest, which ran from June through August and celebrated the important relationship between veterinarian, owner and horse. Veterinarians were nominated by their horse-owning clients, and each month's overall winner received a prize package from the AAEP and contest sponsor American Regent Animal Health. In addition, the monthly winners remain eligible to win the contest's grand prize, which will be announced later this year in conjunction with the AAEP's Virtual Convention & Trade Show.



Dr. Alfredo Sanchez-Londoño



Dr. Lynn Gomes-Berkelaar



Dr. Anne Christopherson

As co-supervisor of Auburn University's equine field service, Dr. Sanchez-Londoño works with veterinary students to provide on-the-farm primary and emergency care within 35-miles of the J.T. Vaughan Large Animal Teaching Hospital.

Nominators praised Dr. Sanchez-Londoño's clinical proficiency, communication skills and deep-seated commitment to owner and student education. According to nominator Donna Tommelleo, "His approach to horses, horse owners and all things equine is rooted in constant learning, teaching and compassion. ... He is ever the teacher and, just as important, ever the student, always in tune with the latest

August Honorees

Win: Dr. Alfredo Sanchez-Londoño, associate clinical professor, equine field service, Auburn University College of Veterinary Medicine, Auburn, Ala.

Place: Dr. Lynn Gomes-Berkelaar, owner, Performance Equine Veterinary Services, Holly Springs, N.C.

Show: Dr. Anne Christopherson, owner, Western Skies Veterinary Services, Morriston, Fla.

research and best practice. As a horse owner, you know Alfredo's approach is at the forefront of what's new, what's next and what's best."

"I'm very honored that my clients thought that I provided good service to them and that they decided to nominate me," said Dr. Sanchez-Londoño, who joined Auburn in April 2019 after 14 years in a similar capacity at Tufts University in Connecticut. "Although I left Connecticut about 18 months ago, my clients from up there still call and keep me updated on their horses. I enjoy staying in touch with them and appreciate their recognition for this award."

Benefit: Practice to potential with an assist from *Proceedings*

The Annual Convention *Proceedings* book is traditionally ranked among the most valued benefits of AAEP membership—and for good reason. The handy compilation of scientific papers presented at the annual convention sheds light on the latest diagnostics and treatments that help you stay current with best practices and deliver the highest standard of care to your patients.

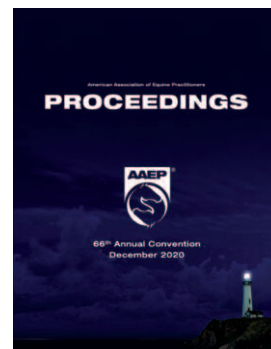
"The AAEP annual *Proceedings* is an invaluable source of useful information, not only academic but also practical," said Dr. Juan Martín Batistuta, an AAEP member in Buenos Aires, Argentina. "It keeps me updated with the latest advanced research and provides me with many new tools I can immediately use in my daily practice. I am always looking forward to getting the new edition at the end of the year."

The print edition traditionally is distributed on-site to convention attendees and mailed shortly thereafter to the

remainder of the membership; however, with this year's convention going virtual, the 2020 edition of *Proceedings* will be mailed to all members in mid-November.

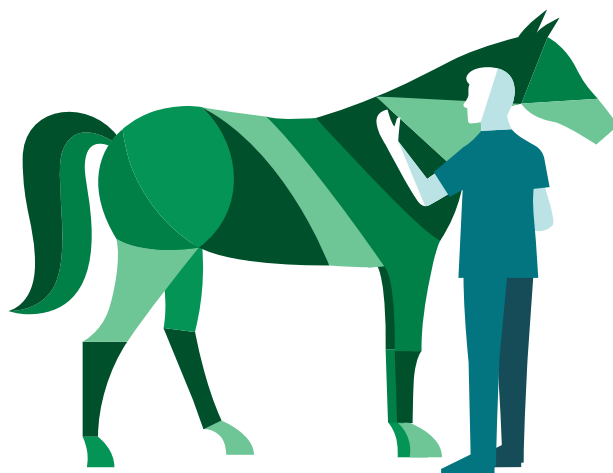
Digital editions of *Proceedings* since 2013 are also conveniently accessible within the Publications section of aaep.org and on the AAEP's Publications App. Search "AAEP Publications" at the App Store or Google Play to download the free app.

If you have questions about *Proceedings* or other benefits of your AAEP membership, contact Megan Gray, member concierge, at mgray@aaep.org.



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Be a hero to a horse owner in need with Vet Direct Safety Net

Foundation program reimburses for the cost of free veterinary care



With many Americans in the throes of pandemic-induced financial hardship, the fiscal reality for numerous horse owners can more accurately be described as distressing instead of idyllic.

If you have a client who struggles to pay for veterinary services, you can be “Dr. Clutch” through

enrollment in The Foundation for the Horse’s Vet Direct Safety Net. Managed in partnership with the AAEP and ASPCA, the program will reimburse you for up to \$600 worth of free compassionate veterinary services per horse. Eligible services include emergency stabilization procedures, euthanasia and disposal.

Among the first AAEP-member veterinarians to receive reimbursement through Vet Direct Safety Net is Dr. Charlene Noll, staff surgeon with Crossroads Veterinary Clinic in Anderson, Calif. Dr. Noll applied to participate in early May, soon after the program’s launch, and encountered an eligible case in late July.

Angel Marsh, a client of Dr. Noll’s who rescues horses and then raises money through social media for necessary veterinary care before adopting out healthy horses into forever homes, had just rescued and taken ownership of an 8-year-old mare named Sugar.

“She was so lame and in so much pain that we almost had to lift her up into the trailer,” said Marsh, who reached out to Dr. Noll upon arriving home and Sugar being unable to walk.

“She was messaging me asking whether there is anything she can do for the mare because it would probably take a few weeks to raise the needed funds,” said Dr. Noll. “I told her I thought we could use this new compassionate care program to at least triage the case, make sure the mare’s OK and, if not, figure out where to go from there.

“I took some foot radiographs and put some foam pads on her feet,” Dr. Noll added. “I think she just had really sore feet—she looked like she had had some bad trims before. We just wanted to make sure she didn’t have laminitis.”

A day after triaging the case on July 27, Dr. Noll submitted her invoice and client permission form online to the Vet Direct Safety Net program manager. A reimbursement check arrived in the mail two weeks later.



Dr. Charlene Noll

“I was expecting much longer and was surprised that it came so quickly,” she said.

According to Marsh, Sugar’s feet are trimmed regularly, and the mare has come a long way in her recovery. She shudders to think how the situation might have transpired without the immediate veterinary care enabled by the Vet Direct Safety Net program.

“Without the assistance, we probably would’ve had to euthanize her. Vet Direct literally saved her life,” said Marsh.

Up to 43% of horse-owning families earn less than \$75,000 per year according to prominent industry studies. If you are an AAEP-member veterinarian in the U.S. with clients who potentially could struggle to pay for veterinary care, put yourself in a position to help by enrolling in Vet Direct Safety Net. Sign up or learn more by visiting aaep.org/vet-direct-safety-net or contacting Sue Stivers at [sstivers@aaep.org](mailto:ssstivers@aaep.org).

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Highlights of recent clinically relevant papers

Retroperitoneoscopy

Surgical approaches to the kidneys and perirenal structures are uncommonly performed in horses and several complications have been described with the current procedures. This descriptive cadaveric study by Raymond Pujol and colleagues in France described the anatomy of the retroperitoneal perirenal space and a subsequently developed minimally invasive surgical approach to the area in horses.

Anatomical dissections of the retroperitoneal spaces of three equine cadavers were performed within 24 h of euthanasia, with the findings informing the subsequent surgical approach. Ten equine cadavers were then used to perform left or right side retroperitoneoscopy within 4 h of euthanasia, with the procedure being performed with cadavers in right lateral recumbency to explore the left retroperitoneal space or in a standing position to explore the left and right retroperitoneal spaces.

The dissections revealed that the kidneys are surrounded by a renal fascia which delimits a perirenal space between the kidney and the renal fascia, and a pararenal space between the renal fascia and psoas muscles or peritoneum. Anatomical landmarks for retroperitoneoscopic portals were established, and access to the area was successful in all horses, with the standing position being preferable. Division of the perirenal fat allowed access to the kidney and adrenal glands as well as individualisation of renal vessels and ureter in the renal hilus.

Large intestinal trocarisation in equids with colic

This study by Angelika Schoster and colleagues in Switzerland aimed to describe outcome and complications after large intestinal trocarisation in equids with colic and identify factors associated with nonsurvival and clinically relevant peritonitis (CRP).

Medical records over a 12-year period were reviewed and 228 equids with colic that had undergone large intestinal trocarisation were identified (198 horses, 24 ponies, and 6 donkeys and mules). Factors associated with nonsurvival in surgically and medically treated equids and with CRP in medically only treated equids were identified. Medically only treated equids with a high peritoneal fluid cell count ($>10,000$ cells/ μL) after large intestinal trocarisation were classified as having CRP if they met ≥ 2 of the following criteria: anorexia, fever, lethargy, abnormal oral mucous membrane colour, abnormal WBC count, or high blood fibrinogen concentration (>5 g/L).

Transabdominal large intestinal trocarisation was performed in 190 (83%) equids, transrectal trocarisation in 17 (7%), and both procedures in 21 (9%). Of 228 equids, 167 (73%) survived to hospital discharge. None died or were euthanised because of complications from large intestinal trocarisation. Nonsurvival was associated with an increasing number of trocarisation procedures and diagnosis of a large intestinal strangulating lesion. A diagnosis of nephrosplenic ligament entrapment of the large colon decreased the odds of nonsurvival. Twelve of 60 (20%) equids that received

medical treatment only had CRP following large intestinal trocarisation.

Large intestinal trocarisation could be considered for equids with colic and large intestinal gas distension. More than one trocarisation procedure was associated with an increase in nonsurvival, which should be considered for equids for which consent for surgery has been obtained.

Cervical facet osteoarthritis

This retrospective study by Judith Koenig and colleagues in Canada compared degenerative changes of the facet joints of the cervical vertebrae on radiographs of horses with clinical signs of cervical facet osteoarthritis (CFA) with healthy cohort-matched horses. The study also compared clinical findings between groups, and obtained follow-up information on the long-term outcome in treated horses.

Thirty horses diagnosed with CFA and treated with intra-articular injection of corticosteroids were included. Follow-up information on recovery from treatment was obtained via telephone survey of owners/trainers. Thirty healthy horses with no clinical signs of CFA were matched to treated horses by breed, sex, age, and sport as the control group. Two radiologists, blinded to the horses' groups, reviewed cervical spine radiographs for each horse and recorded CFA score and intravertebral/intervertebral measurements. Clinical and radiographic parameters were compared between treatment and control groups.

There was a significant difference in CFA grades for C5–6 and C6–7 between horses with clinical signs and healthy horses. However, interobserver agreement between radiologists for grading CFA was moderate and only 56% of values were identical for both observers. Atrophy of the neck was present on clinical examination in most cases in the treatment group.

The clinical diagnosis of CFA based on radiographic grading alone is questionable because of the lack of agreement between the radiologists. To strengthen the diagnosis, clinical signs of facet disease, in particular atrophy of the neck muscles, need to be present to make this diagnosis. Intra-articular corticosteroid injection was effective at allowing most treated horses to return to athletic use.

Cannabinoid receptors

This study by Roberto Chiocchetti and colleagues in Italy investigated the expression and location of cannabinoid receptors in the dorsal root ganglia, which may be potential therapeutic targets for pain.

The cervical (C6–C8) dorsal root ganglia were collected from six horses (1.5 years old) at an abattoir and processed to obtain cryosections. Immunohistochemistry was used to localise the cellular distribution of cannabinoid receptors 1 (CB1R) and 2 (CB2R), and three other putative cannabinoid-related receptors: nuclear peroxisome proliferator-activated receptor alpha (PPAR α), transient receptor potential ankyrin 1 (TRPA1) and serotonin 5-HT1a receptor (5-HT1aR).

Cannabinoid and cannabinoid-related receptors were widely distributed in the sensory neurons and satellite glial cells of the dorsal root ganglia. The neurons showed immunoreactivity for CB1R (100%), CB2R ($80 \pm 13\%$), PPAR α (100%), TRPA1 ($74 \pm 10\%$) and 5-HT1aR ($84 \pm 6\%$). The neuronal satellite glial cells showed immunoreactivity for CB2R, PPAR α , TRPA1 and 5-HT1aR.

Cannabinoid receptors are present in the sensory neurons and glial cells of the dorsal root ganglia, which could be relevant for future functional studies assessing the effects of cannabinoids in horses to manage pain.

Needle arthroscopy of the carpal joints

In this study Dimitri Kadic and colleagues in Canada described a technique for diagnostic needle arthroscopy of the radiocarpal and middle carpal joints in standing sedated horses.

In phase 1, six cadaveric forelimbs were used to assess needle arthroscopic evaluation of both joints. Six healthy horses were then enrolled in phase 2 to validate the procedure in live animals. The joint was maintained in flexion with a custom-made splint and base.

In phase 1, needle arthroscopy allowed thorough evaluation of the dorsal and palmar recesses of both joints with traditional arthroscopic portals. In phase 2, joint evaluation was also thorough but only dorsal approaches were performed. All horses underwent radiocarpal joint arthroscopy, whereas the middle carpal joint was evaluated in only three of six horses because of limb movement. The technique was quickly performed and well tolerated by all horses. Complications included moderate movement, mild iatrogenic cartilage damage, and mild haemarthrosis.

This technique offers an alternative diagnostic tool for radiographically silent intra-articular lesions of the carpus while initially avoiding the cost and risks associated with general anaesthesia. Arthroscopy of a single joint is recommended to minimise risks associated with movement during the procedure.

Nephrosplenic entrapment of the large colon

This study by Alex Gillen and colleagues in the UK and USA provides a systematic meta-analytical assessment of the efficacy of different treatment strategies in horses with confirmed or suspected nephrosplenic entrapment of the large colon.

A comprehensive literature search was performed from 1970 to 2017. Inclusion criteria were retrospective studies involving horses with confirmed and suspected nephrosplenic entrapment. A meta-analysis was performed using a random effects model, with the effect size calculated as an odds ratio (OR) with 95% confidence intervals. Out of 84 peer reviewed publications that met the search criteria, 19 relevant studies were identified. Using an OR as the effect size, the meta-analysis noted that the choice of medical or surgical therapy had no statistically significant effect on survival. Patients treated via the rolling technique were no more likely to resolve with medical management than those treated via jogging. Patients treated with phenylephrine were no more likely to exhibit medical resolution than patients that

did not receive phenylephrine, either when all medical treatment methods were considered, or when rolling under general anaesthesia was used.

Treatment strategy, including medical versus surgical therapy, does not affect the likelihood of resolution of nephrosplenic entrapment. However, the lack of randomised trials means the results should be treated with caution and case selection remains important.

Plasma iron concentrations and SIRS in foals

This study by Júlia Sanmartí and colleagues in Spain aimed to determine the physiological plasma iron concentration in neonatal foals and to assess its utility as an inflammatory marker to predict systemic inflammatory response syndrome (SIRS) and as a prognostic marker.

Forty-seven sick neonatal foals admitted to a referral equine hospital were divided into two groups based on the SIRS criteria (24 SIRS and 23 non-SIRS). Two control groups of healthy neonatal foals (43 hospital and 135 stud farm) were also included.

Plasma iron concentrations in neonatal foals with SIRS were not significantly different compared to the non-SIRS and stud farm control groups. Plasma iron concentration had a large variability in healthy neonatal foals, and was negatively correlated with age in hospital controls and sick neonatal foals. The authors concluded that plasma iron was not a useful marker of SIRS in neonatal foals and was not associated with outcome.

S. WRIGHT

EVE Editorial Office

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Editorial

Environmental sustainability in the equine veterinary profession

"Pour ce qui est de l'avenir, il ne s'agit pas de le prévoir, mais de le rendre possible"

"As for the future, it is not a question of foreseeing it, but of making it possible"
Antoine de Saint-Exupéry

Introduction

We are becoming increasingly aware of the environmental harm humans cause, and we realise there are limits to natural resource extraction. The climate crisis is a major cause of the social, economic and ecologic disruption which we face. Our future currently holds more extreme weather events, air and water pollution, loss of biodiversity, water and food insecurity and altered vector-borne disease patterns.

Sustainable development has been defined by the UN Brundtland Commission as 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs'. The UN published 17 sustainable development goals to target by 2030; goals include reduced inequalities, clean water and sanitation, responsible consumption and production, and life on land and below water.

Sustainable thinking reflects good governance and future-proofs organisations by identifying how global megatrends will affect them. We can utilise it to improve financial, social and ecologic resilience in the face of legislative, resource availability and societal changes in response to the climate crises. In this editorial, we explore the role for engagement with sustainability within the equine veterinary sector.

Greenhouse gases

The current crisis stems from the introduction of large quantities of greenhouse gases into the atmosphere, mostly carbon dioxide (CO₂) from industrial burning of fossil fuels since the 1800s. The current global increase in temperature since the pre-industrial era is around 1°C. In 2015, an international treaty was signed in Paris committing the signing 195 countries to remain within 2°C of the pre-industrial era. The Intergovernmental Panel on Climate Change (IPCC) estimates that if global warming continues at the current pace, we will reach 1.5°C between 2030 and 2052 (Intergovernmental Panel on Climate Change 2018). Even at 1.5°C, the IPCC predicts extreme weather events and changes in sea levels. Additional risks may result, including forced migration, damage to vital infrastructure and increased conflict. These will have catastrophic and additive effects on all global communities, and the developing countries which have contributed least are likely to suffer most. It is easy to imagine the impacts on equestrian activities, including the need to adapt to more extreme weather events such as flooding.

Equestrian activities can also produce carbon emissions. Both energy and transport are widely used in the equine sector, and in 2017, these represented the top two sources of

UK carbon emissions at 27 and 24%, respectively. We do not have a carbon footprint of the veterinary sector, but the UK's National Health Service (NHS) healthcare emissions contributed around 6.3% of the total carbon footprint (27.12 million tonnes CO₂ equivalents, MtCO₂e) of England in 2017. Volatile anaesthetic agents, including isoflurane and sevoflurane, are also potent greenhouse gases (Jones and West 2019). The NHS's current 5-year plan includes reducing emissions from anaesthetic gases by 50%; translated to our sector, this could impact on the provision of hospital equine anaesthesia.

There is currently little literature identifying the carbon emissions emitted by horses. One study assessed the carbon emissions of draught horses used for forestry work and estimated emissions of 48.1 tonnes CO₂e during the 20-year lifespan of a horse, including basic veterinary care (but not including transport; Engel *et al.* 2012). For an average 500-kg horse carrying out lighter work, we estimate roughly 1 tonne CO₂e per equine life-year. Included in this total is methane, and whilst horses emit around three times less methane than ruminants, global equine methane emissions are estimated at 26.5 MtCO₂e per annum (Elghandour *et al.* 2019). Methane has a high heat absorption capacity but a lower duration in the atmosphere, which may reduce its impact if the concentrations remain stable over time. Agricultural and livestock land-use has the potential to increase overall carbon sequestration and biodiversity, but transformation to sustainable systems will be needed to mitigate greenhouse gas emissions (Costain 2019).

Per capita, the UK produced around 6.7 tonnes CO₂e in 2018 (data source: UK government and Office for National Statistics, 2018). The UK government has committed to net zero carbon emissions by 2050. Horse ownership could occupy an increasingly large part of an owner's carbon budget; however, this should be balanced with the social value of equine activities as well as potential for lower carbon emissions resulting from active lifestyles and less travel from home.

Biodiversity

The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services recently reported that 'nature and its vital contributions to people, which together embody biodiversity and ecosystem functions and services, are deteriorating worldwide' (IPBES 2019). They also reported an accelerating extinction rate of 10–100 times higher than baseline rates. This will cause losses of essential natural services including reducing vulnerability to extreme climate events, carbon sequestration, promoting mental and physical health, medicines, genetic resources, livelihoods, cultural services, food and energy. Ecosystems may also be destabilised; for example, some UK vector-borne diseases such as Lyme's disease are showing increasing incidence, which may relate in part to climate changes (Tulloch *et al.* 2019).

Air, water and soil pollution

Grazing horses are capable of damaging natural ecosystems causing soil erosion and compaction, vegetative damage and increased movement of sediment, nutrients and pathogens into nearby surface waters (Bott *et al.* 2013). Equestrian activities may also be in direct conflict with other users of natural capital. The UK sustainable development principles state that 'any plan should take into account how the environment can be protected and enhanced'. Pasture management such as rotating paddocks and avoiding overstocking may mitigate negative impacts and also improve biodiversity and soil fertility, increase CO₂ sequestration and reduce feeding costs. Owner-oriented programmes offering sustainable management systems are already available. Veterinary surgeons will be expected to be conversant in the concerns and regulatory requirements of their clients, including the local authority and Natural England guidance on land management.

Horse manure is rich in nutrients; a 450-kg horse produces around 7 tonnes per year of nitrogen and phosphate-rich faeces (Bott *et al.* 2013). In the UK, horse manure may not be classed as waste if used as soil fertiliser. However, it must not be spread near water or stored where there is a risk of run-off into watercourses, as the nutrients can cause eutrophication. Compliance with nitrate vulnerable zones and groundwater legislation may also be required, including for wastewater run-off from stabling areas.

Horse waste may also be rich in veterinary pharmaceutical residues (VPR). The benzimidazoles (e.g. fenbendazole) may be less harmful, but the macrocyclic lactones (e.g. ivermectin) are highly toxic to coprophagic invertebrates (Horvat *et al.* 2012) and persistent; after oral administration in horses with ivermectin, moxidectin and doramectin, faecal contamination persisted for 4 days (Gokbulut *et al.* 2001). In addition, VPR may not be removed by wastewater treatment. In a French agricultural region, researchers found VPRs in 20% of tap water samples (Charuau *et al.* 2019). Further research is needed to establish the ecosystem toxicity of equine pharmaceuticals and establish appropriate stabling periods after treatment, but selective deworming, faecal worm counts in adults and sound pasture management should be standard practice.

Sustainable procurement and waste management

Around 25% of the NHS carbon footprint comes from procurement of pharmaceuticals and medical equipment. Understanding the resource costs of pharmaceuticals can help to target emission reductions; during manufacture, up to 100 kg of waste per kg of pharmaceutical may be generated, and the lifecycle carbon emissions for 20 common anaesthetic drugs were calculated as between 11 and 3000 kg CO₂e per kg of drug (Parvatker *et al.* 2019). Reducing resource use is also the first step of the waste hierarchy within The Waste (England and Wales) Regulations 2011. Next, re-use and recycling should be addressed; up to 40–60% of medical perioperative waste can be recycled to join the circular economy. A robust waste segregation policy will ensure legal compliance, including adherence to the waste hierarchy which promotes the most environment friendly means of waste disposal. Avoiding incineration of

plastics (particularly PVC) can reduce respiratory pollutants such as dioxins. Lastly, legally-compliant disposal is necessary for hazardous waste streams to avoid harm to aquatic and soil ecosystems.

Engaging with sustainability

A recent British Veterinary Association (BVA) survey found that '89% of vets said that they would like to play a more active role in sustainable animal agriculture', and it is a key ambition in the 2015 BVA/Royal College of Veterinary Surgeons Vet Futures report for the UK veterinary profession to be clear about its wider role in society, including environmental sustainability. The 2019 BVA position statement on sustainable animal agriculture recommended that at individual, community and national levels 'the veterinary profession is well-placed to advise and influence sustainable animal husbandry practices at whole system levels and ... all veterinary surgeons should be able to articulate the contributions that the profession can make to the sustainable agriculture agenda'. More resources are becoming available, including from the recently formed Vet Sustain group (www.vetsustain.org accessed on 4 October 2019).

Moving forward at a rapid pace is essential. We must demand leadership from our professional institutions and seek support from sustainability professionals. Our practices must develop bold and robust policies which reflect environmental and social values. As the relevance of sustainability increases for younger generations, sustainability should be included in teaching curricula (as it is for medical schools). Most importantly, individuals should engage within their own sphere of influence; we can utilise telemedicine and teleconferencing, we can avoid flights, and we can demand that sustainability remains high on the political agenda.

Conclusions

An alternative definition of sustainability was proposed by Newcastle University: 'Enough, For All, Forever'. We must only take what can be replaced. We must pay the true social and environmental cost of resource use, and we must not do so at the expense of others. Horse-owners will look to the veterinary sector to assist in providing low carbon care as standard practice. Meeting these challenges will require transformative change within individuals, businesses and institutions. There are frightening prospects ahead, but also outstanding opportunities for our sector, communities and world.

We can foresee the future for our world, and now our task is to make better outcomes possible.

E. WEST*  and **F. MALALANA†** 

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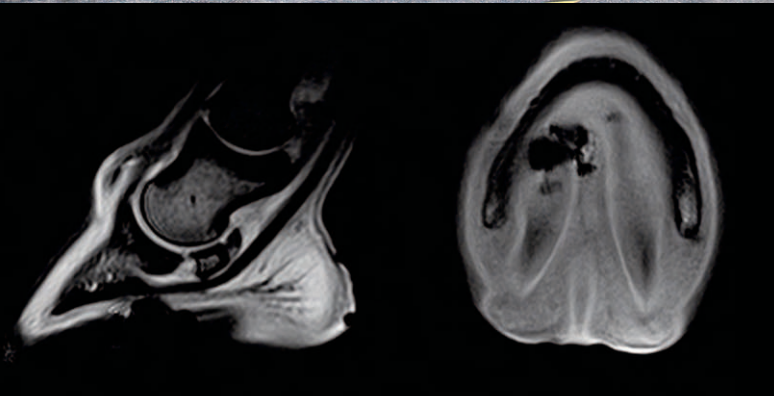
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Case Report

Reoccurrence of a paranasal osteoma following surgical removal in a 6-month-old Warmblood filly

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Keywords: horse; osteoma; paranasal sinus; surgery; nasolacrimal duct; computed tomography

Summary

Tumours of the sinonasal region are relatively uncommon in horses. Osteomas are benign tumours of the bone that occur more commonly in younger horses. It has been suggested that regrowth is uncommon even after incomplete removal of the mass. Of the few reports with long-term follow-up,

none describe reoccurrence following surgical removal. This report describes the recurrence of an osteoma in a weanling horse following surgical removal under general anaesthesia. A 6-month-old Warmblood filly presented for evaluation of a left sided unilateral mucopurulent discharge of 5 weeks' duration. Upper airway endoscopy revealed a large, smooth mass in the region of the ethmoturbinates. Dorsoventral and lateral radiographs of the head revealed a large osseous mass in the left sinus area. A biopsy was performed under general anaesthesia and an osteoma was diagnosed. A computed tomography (CT) examination was performed to guide surgical removal. Surgery was performed under general anaesthesia and a large mass was removed $\sim 12 \times 9$ cm. A CT examination 3 months following surgery revealed three small areas of mineralisation (**Fig 1b**). It was difficult to differentiate if these were areas of regrowth or were not entirely removed. A CT examination 8 months later revealed one of the areas had increased moderately in size (**Fig 1c**). A second surgery was performed standing to remove the growth. A final CT 8 months later revealed no further evidence of a bone growth (**Fig 1d**). This report describes the successful removal of an osteoma regrowth following initial surgical removal and, to the best of the authors' knowledge, is the first to describe the recurrence of an osteoma after surgical intervention. It also describes a successful rhinotomy in the standing equine patient. This case highlights the importance of serial follow-up imaging after surgical removal as osteoma regrowth occurred in this case.

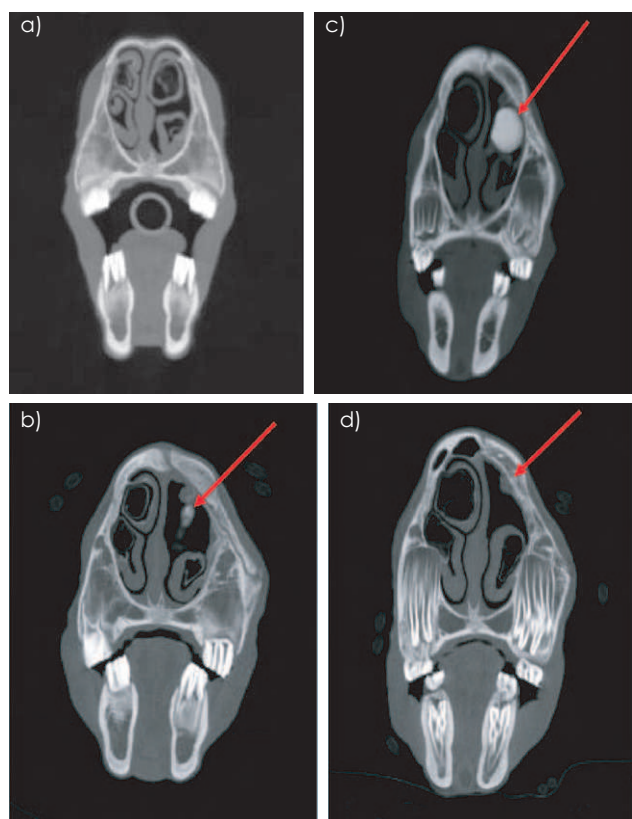


Fig 1: Serial axial CT images of the rostral paranasal sinus/caudal nasal region showing the progression of the osteoma following surgical removal. a) Pre-operative. b) 3 months post first surgery. c) 11 months post first surgery. d) 8 months post second surgery.

Key points

- This case highlights the importance of serial imaging follow-up after osteoma removal as regrowth is possible.
- Detailed serial imaging, such as CT, is important in a young horse to monitor permanent dental structure development.
- This case highlights the feasibility of performing a standing rhinotomy, in this case, a young equine patient (18 months old).



Clinical Commentary

Diagnostic imaging characteristics of sinonasal tumours in the horse

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Many different types of sinonasal tumours have been reported in the horse, the most common being the squamous cell carcinoma (Dixon and Head 1999; Head and Dixon 1999). Sinonasal tumours can be classified into surface epithelial, glandular epithelial and undifferentiated carcinomas (Stünzi and Hauser 1976), which Head and Dixon (1999) used to describe equine nasal and paranasal sinus tumours. These tumours can produce clinical signs similar to sinus disease caused by an infectious or traumatic aetiology (Dixon and Head 1999), and facial swellings similar to those seen with sinus cysts (Tremaine and Dixon 2001). They are frequently presented in the advanced stages of the disease process; often making their prognosis hopeless.

Radiography has been shown to identify pathology in 82% of horses with sinonasal neoplasia (Tremaine and Dixon 2001), making this modality valuable in localisation to the head. However, the same study found radiographs to be diagnostically useful in only 23% of cases combined with historical and clinical findings (Tremaine and Dixon 2001). Sinonasal neoplasia can be associated with an increase in soft tissue/fluid opacity or space occupying lesions distorting surrounding osseous structures. However, radiography cannot distinguish between different types of tumours, or between sinonasal tumours and more common non-neoplastic space occupying lesions such as sinus cysts or progressive ethmoid haematomas. Radiographs may also underestimate features of malignancy (Cissell *et al.* 2012), such as the degree of osteolysis or periosteal reaction, and radiographic characteristics can, in some cases, be similar to those of osteomyelitis (Butler *et al.* 2017) with distorted outlines, associated osteolysis and new bone production (Cissell *et al.* 2012; Butler *et al.* 2017). Radiographs have been found most accurate at identifying sinonasal tumours within the maxillary sinuses (Cissell *et al.* 2012), which is the most common site of tumour origin (Dixon and Head 1999). Radiography appears to be less sensitive for tumours located in the sphenopalatine sinuses, cranium and retrobulbar space when compared with computed tomography (CT) (Cissell *et al.* 2012). Due to the complicated anatomical configuration of the nasal cavity and paranasal sinuses, the ability to detect the degree of tumour expansion is limited when solely using radiography.

Computed tomography can provide a detailed examination of the osseous structures of the head (Manso-Diaz *et al.* 2015), mitigating the superimposition that occurs with radiographs, and offers more information pertaining to the size and extent of tumour extension. This can be invaluable in preoperative planning of biopsy and surgical resection of tumours. CT characteristics of equine sinonasal tumours can include aggressive patterns of osteolysis, erosion of the cribriform plate and invasion of the cranial vault; all features of sinonasal neoplasia (Davis *et al.* 2002; Cissell *et al.* 2012). These findings are usually associated with a negative

prognosis, and the fact that they are not readily apparent on radiographs (Cissell *et al.* 2012) highlights the importance of CT examinations. Furthermore, most sinonasal tumours exhibit destructive changes to adjacent nasal turbinates, the nasal septum and/or the infraorbital canal, alongside moderate to marked osteolysis of adjacent cortical bone and variable periosteal proliferation (Cissell *et al.* 2012). One study found the extent and character of bone destruction revealed by CT examinations was more severe than assumed radiographically in cases of sinonasal tumours (Veraa *et al.* 2009). Some sinonasal tumours can be variably mineralised; seen as regions of hyperattenuation on CT. For example, focal mild mineralisation has been associated with cases of undifferentiated carcinomas (**Fig 1**) and myomas, multifocal mineralisation has been seen within osteosarcomas and nasal adenocarcinomas, and extensive mineralisation occurs within ossifying fibromas (Veraa *et al.* 2009; Cissell *et al.* 2012). Mineralisation has also been identified within melanomas which can be found within the nasal cavity (Dixon and Head 1999), as well as other structures of the head. Melanomas can appear as well-defined homogenous masses that are hyperattenuating (median 113.5 Hounsfield units [HU]) compared to masseter muscle (median 69HU), which is thought to be due to the high metal ion binding affinity of the melanin pigment (Dixon *et al.* 2016). One of the main limitations of CT is the difficulty in distinguishing the tumour margin from adjacent soft tissues. The attenuation of sinonasal tumours was found to increase by eight times that of the masseter muscles in two horses administered positive contrast media i.v., which may improve the accuracy in identifying tumour margins (Cissell *et al.* 2012).

Magnetic resonance imaging (MRI) provides high soft tissue contrast, allowing good differentiation of tissue types and can also identify space occupying lesions (Manso-Diaz *et al.* 2015). Two previous studies have identified aggressive characteristics of sinonasal tumours on MR examinations, including a high degree of infiltration of surrounding structures, marked destruction of adjacent osseous structures, such as the ethmoturbinates, cribriform plate and the globe, and intracranial tumour extension (Tessier *et al.* 2013; Manso-Diaz *et al.* 2015). Both low- and high-field MRI systems can provide diagnostic quality examinations to assess sinonasal tumours (Manso-Diaz *et al.* 2015). This imaging modality allows distinction between more common paranasal sinus and nasal cavity conditions such as sinus cysts and progressive ethmoid haematomas, due to the comparable differences in signal intensity detected on different sequences, and between tumour margins and surrounding fluid within the paranasal sinus cavities (Manso-Diaz *et al.* 2015). This modality was, however, found to be suboptimal in evaluating small osseous lesions of the skull, such as lysis and thinning, especially of the maxillary and nasal bones. This was likely due to the poor



Fig 1: Transverse CT image of the head of a 17-year-old Cob mare, at the level of the 108 tooth (right side of the head is on the left side of the image). There is an expansile, mainly soft tissue attenuating mass, expanding into the right rostral maxillary and ventral conchal sinuses, causing thinning and lysis of the adjacent right maxillary bone (white arrows), and nasal turbinates. The mass effect is causing compression of the right ventral meatus (white arrowhead). There are multiple small focal areas of mineral attenuation throughout the soft tissue of the mass (black arrows). This was confirmed to be an undifferentiated carcinoma on histopathology examination (Window level: 839, Window width: 3220).

signal intensity produced by flat bones containing no medullary cavity (Manso-Díaz *et al.* 2015).

To conclude, radiographs of the head can provide visualisation of sinonasal tumours within both the nasal cavities and paranasal sinuses. However, they often underestimate the impact on surrounding structures, do not provide accurate localisation of the tumours, especially within the caudal aspect of the head, and cannot distinguish between some of the more common pathological conditions and sinonasal tumours. Three-dimensional cross-sectional imaging allows a clear assessment of the complex anatomical detail of the head, provided by both MRI and CT

(Manso-Díaz *et al.* 2015). CT offers excellent evaluation of osseous structures and tumour extension, although it does not allow delineation between tumour margins and adjacent soft tissue, whereas MRI provides optimum soft tissue contrast but lacks definition of small bone lesions.

Author's declaration of interests

No conflicts of interest have been declared.

Ethical animal research

Not applicable.

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Case Report

Use of a carbonated beverage to disintegrate a phytobezoar obstructing the intrathoracic portion of the oesophagus of a horse**L. C. Livesey*[†] , E. Yorke[†], A. Parra[†], Q. Gray[†], C. Davies[†], D. Weldon[‡], J. Schumacher[§] , S. Kimura[§], C. Howard[¶], T. Sierra-Rodriguez[§] and M. Mora-Pereira[§]**[†]Tuskegee University College of Veterinary Medicine, Auburn, Alabama; [‡]Southeast Equine Veterinary services, Phenix City, Alabama; [§]J.T. Vaughan Large Animal Teaching Hospital, Auburn University College of Veterinary Medicine, Auburn, Alabama; and [¶]Bluegrass Animal Clinic, Grayson, Kentucky, USA*Corresponding author email: llivesey@tuskegee.edu**Keywords:** horse; phytobezoar; carbonated beverage; oesophageal obstruction; disintegration**Summary**

This report describes treatment of a 17-year-old American Quarter Horse gelding presented with signs of oesophageal obstruction for approximately 24 h. An intraluminal oesophageal mass resembling a phytobezoar, located close to the cardia, was observed during endoscopic examination of the horse's oesophagus. An intrathoracic oesophageal diverticulum, filled with fluid, was observed about 40 cm proximal to the obstruction. With the aid of the endoscope, a nasogastric tube was guided beyond the diverticulum, so that its tip rested close to the obstruction (**Figs 1 and 2**).

Despite vigorous and prolonged lavage, the obstruction failed to disintegrate or move. With the horse's head elevated, 0.5 L of cola was administered on to the obstruction, through the nasogastric tube. After the horse's head had been maintained elevated for an hour, it was lowered and oesophageal lavage was resumed. The nasogastric tube was able to be passed into the stomach within 3 min of resuming lavage.

The successful use of a carbonated beverage to treat human patients for oesophageal or gastrointestinal obstruction caused by a phytobezoar is well-documented. Carbonated beverages have also been reported to be effective in treating horses for gastric and enteric impactions caused by persimmon seeds.

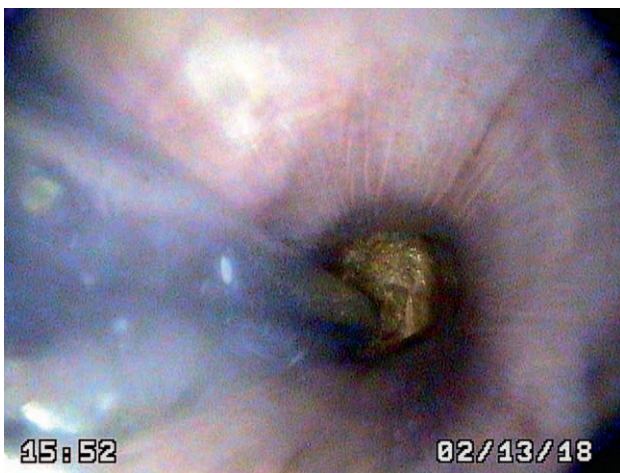


Fig 1: Endoscopic image of the phytobezoar lodged immediately cranial to the cardiac sphincter confirmed correct placement of a nasogastric tube for irrigation.

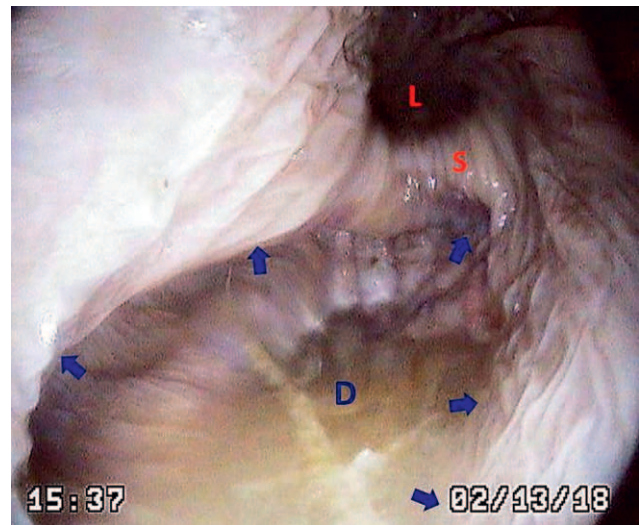


Fig 2: Endoscopic view of the intrathoracic oesophageal diverticulum. The margins (blue arrows) of the diverticulum (D), the oesophageal lumen (L) caudal to the diverticulum and the partial stricture (S) are visible.

When horses are refractory to other treatments, administering a carbonated beverage into the oesophagus may aid in resolution of oesophageal obstruction caused by a phytobezoar or impacted feed.

Supplementary Item 1 contains details of four subsequent cases of intraluminal oesophageal obstruction in which the impacted feed material rapidly underwent disintegration after administering a carbonated beverage by nasogastric tube.

Key points

- For intraluminal oesophageal obstructions in horses that resist disintegration, administration of a carbonated beverage by nasogastric tube may provide effective treatment that is inexpensive and atraumatic.
- The use of carbonated beverages such as cola to disintegrate intraluminal oesophageal obstructions has been described extensively in medical literature.



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Clinical Commentary

Management of phytobezoars

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A bezoar is an indigestible conglomeration within the gastrointestinal tract. Bezoars can be found throughout the gastrointestinal tract, although they are most commonly identified in the stomach. Approximately 0.4–0.8% of people undergoing endoscopic evaluation of the upper gastrointestinal tract (oesophagus, stomach, duodenum) had bezoars (Iwamuro *et al.* 2015). Bezoars may be comprised of a variety of substances, including plant material (phytobezoar), milk (lactobezoar), hair (trichobezoar) or medications (pharmacobezoar) (Iwamuro *et al.* 2015).

Bezoars are uncommonly reported in horses, although exact incidence of formation is unknown. The most commonly reported bezoar is the persimmon phytobezoar or diospyrobezoar (Honnas and Schumacher 1985; Wilson and Scruggs 1992; Cummings *et al.* 1997; Kellam *et al.* 2000; Hurtado *et al.* 2007; Banse *et al.* 2011), although other phytobezoars, pharmacobezoars and trichophytobezoars (hair and plant-derived) have been previously reported (Turner 1986; Bohanon 1988; Bridges *et al.* 1993; Yvorchuk-St-Jean *et al.* 1993; Mair 2002; Gillen *et al.* 2015; Manneveau *et al.* 2017; Bergstrom *et al.* 2018).

Phytobezoars are composed primarily of cellulose, hemicellulose, tannin and lignin (Holloway *et al.* 1980). In cases of diospyrobezoars, the polymerisation of tannin monomers following contact with hydrochloric acid appears important to the formation of the persimmon phytobezoar. Treatment modalities depend on phytobezoar location and include dissolution, endoscopic fragmentation and retrieval or surgical removal.

Oesophageal bezoars are rare. In human subjects, oesophageal bezoar treatment primarily consists of endoscopic fragmentation and removal (Qureshi 2005; Kim *et al.* 2010). However, cola with or without pancreatic enzymes has been demonstrated to be effective in bezoar dissolution (Yaqub *et al.* 2012). Furthermore, oesophageal obstructions of other aetiologies have been successfully treated with administration of carbonated soda water (Mohammed and Hegedüs 1986). In horses, an oesophageal bezoar was successfully treated via gastrotomy (Orsini *et al.* 1991). Oesophagostomy has occasionally been used for oesophageal foreign body retrieval (Craig *et al.* 1990; Koenig *et al.* 2016). However, due to the risk of complications with oesophageal (Craig *et al.* 1990; Koenig *et al.* 2016) or gastric (Freeman 2011) surgery, investigation of other treatment options is warranted. The present report 'Use of a carbonated beverage to disintegrate a phytobezoar obstructing the intrathoracic portion of the oesophagus of a horse' by Livesey *et al.* (2020), is the first to use cola to resolve an episode of oesophageal obstruction from a phytobezoar that was unresponsive to standard medical management. In this report, a dose of 0.5 L of cola was used effectively to promote dissolution. Carbonated beverage administration appears to be an inexpensive treatment method for oesophageal

phytobezoars that may be less likely to result in complications, compared with surgical approaches.

In the stomach, dissolution is the treatment of choice for phytobezoars due to low risk of complications. Dissolution may be achieved with cola (Coca-Cola¹), cellulase or papain, acetylcysteine or pancreatic enzymes combined with hydrochloric acid and bicarbonate (Iwamuro *et al.* 2015). Cola¹ was initially reported as a successful treatment for dissolution of phytobezoars in 2002 (Ladas *et al.*). A systematic review of the use of cola¹ in dissolution of phytobezoars indicated that Coca-Cola alone was effective in 50% of patients (Ladas *et al.* 2013). The mechanism of cola-mediated phytobezoar dissolution remains unknown, but it may be associated with the mucolytic effect of sodium bicarbonate, the acidifying effect of carbonic and phosphoric acid, or penetration and breakdown by carbon dioxide bubbles (reviewed in Iwamuro *et al.* 2015). Other carbonated beverages are effective in phytobezoar (diospyrobezoar) dissolution (Iwamuro *et al.* 2018), suggesting that carbon dioxide bubbles may be the key mechanism contributing to dissolution. Endoscopic fragmentation with or without retrieval may be pursued in conjunction with dissolution, or in cases where dissolution fails. Methods for endoscopic bezoar breakdown and removal include snaring, lithotripsy or disintegration with biopsy forceps. In the systematic review by Ladas *et al.* (2013), combining cola¹ dissolution with endoscopic fragmentation and retrieval increased the therapeutic success rate to 91%. In cases where endoscopic methods and dissolution fail, gastrotomy can be performed. For enteral obstructions with phytobezoars, surgical removal is indicated (reviewed in Iwamuro *et al.* 2015).

Gastric diospyrobezoars are more difficult to dissolve than other phytobezoars (Ladas *et al.* 2013). In equine cases of diospyrobezoars, dietary management (pelleted diet), cellulase, intrabezoar acetylcysteine and enteral cola administration >20 L/day have been reported to be effective in their management (Banse *et al.* 2011). Mineral oil and dioctyl sodium succinate were not effective in one case of gastric diospyrobezoar, suggesting that treatment with dissolving agents, such as cola, should be considered before laxatives (Kellam *et al.* 2000). The volume of cola administered appears to be important, as those horses administered smaller volumes of cola (<4 L/day) did not resolve with medical management and required surgical intervention. Smaller volumes (700 mL) may be effective when injected directly into the diospyrobezoar (Hurtado *et al.* 2007). Endoscopic fragmentation of gastric diospyrobezoars may be less effective in horses compared with people due to the larger mass of equine diospyrobezoars. If dissolution and endoscopic methods fail, surgery may be performed, and

dissolution attempted by massage of the stomach (Honnas and Schumacher 1985; Banse *et al.* 2011). Finally, gastrotomy may be performed, but is generally considered to be a last resort due to the difficulty in obtaining surgical access to the stomach and the risk of peritonitis (Banse *et al.* 2011). For enteral obstructions, surgical removal is indicated (Kellam *et al.* 2000). Enteral diospyrobezoars can be treated successfully (Kellam *et al.* 2000) but appear to have a poorer prognosis than gastric diospyrobezoars, in part due to challenges in diagnosis (Banse *et al.* 2011).

Complications of phytobezoars include gastrointestinal ulceration and perforation, incomplete dissolution or fragmentation of gastric phytobezoars, resulting in subsequent enteral obstruction (Kilam and Cohen 1986; Ha *et al.* 2007). Oesophageal obstruction by a gastric phytobezoar after regurgitation has also been reported (Seggie and Knottenbelt 1981). Papain, a proteolytic enzyme, may precipitate hypernatremia or gastrointestinal tract perforation (Holsinger *et al.* 1968; Dugan *et al.* 1972; Zarling and Moeller 1981), so its use is no longer recommended. Caffeine toxicosis was suspected in one horse that had received high doses of caffeinated products (24 h) in one day (Banse *et al.* 2011). In cases of oesophageal phytobezoars, digestion in the stomach may decrease the risk of more distal gastrointestinal obstruction. However, administration of cola into the oesophagus carries the additional risk of aspiration pneumonia. Using small volumes (500 mL) and elevating the head during and after the procedure, as described in the present case report, (Livesey *et al.* 2020) may help minimise this risk. In the future, consideration of other carbonated beverages (i.e. a sugar-free alternative) may help decrease the severity of secondary bacterial colonisation in case the carbonated beverage is accidentally aspirated.

In conclusion, bezoars are challenging to treat. Dissolution with cola and other carbonated beverages appears effective in cases of gastric phytobezoars in both subjects and horses. Oesophageal phytobezoars and other oesophageal obstructions (i.e. choke) provide a new application for this treatment modality in horses.

Author's declaration of interests

No conflicts of interest have been declared.

Ethical animal research

Not applicable.

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None.

Manufacturer's address

¹The Coca-Cola Company, Atlanta, Georgia, USA.

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Case Report

Hand-assisted laparoscopic reattachment of a mesoduodenojejunal defect in a broodmare**H. D. O'Neill***

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Keywords: horse; duodenum; jejunum; mesentery; laparoscopic; barbed suture**Summary**

An 8-year-old Thoroughbred mare at 318 days of gestation was admitted with signs of sudden onset, severe colic. Pertinent history included an admission 2 years previously for acute post-parturition haemoabdomen, with a presumptive uterine artery origin. A second period of hospitalisation occurred the following year, with acute, severe colic 2 months post-foaling. Small intestinal thickening was noted on ultrasound examination but the mare responded favourably to medical therapy, was discharged and successfully bred with no specific diagnosis reached.

Following initial triage, a decision was made to proceed with emergency exploratory laparotomy due to the level of discomfort. Findings revealed several feet of mid-jejunum incarcerated through a chronic mesenteric defect involving the proximal mesojejunum and extending approximately 20 cm oral to the duodenocolic pilca. Attempts to perform a blind, hand-sewn reattachment of the mesenteric defect were deemed unsafe at this time. The mare made an uneventful recovery and was discharged from the hospital 5 days post-operatively. Twelve days following hospital discharge, the mare had an uneventful foaling under precautionary veterinary supervision. Eighteen days post-foaling, the mare returned for elective standing laparoscopic examination with a view to reattachment of the mesentery. Initial attempts to visualise the mesenteric defect with laparoscopic instruments proved unsuccessful, both with and without carbon dioxide insufflation. The procedure was then converted into a hand-assisted approach; with careful digital manipulation of the duodenum

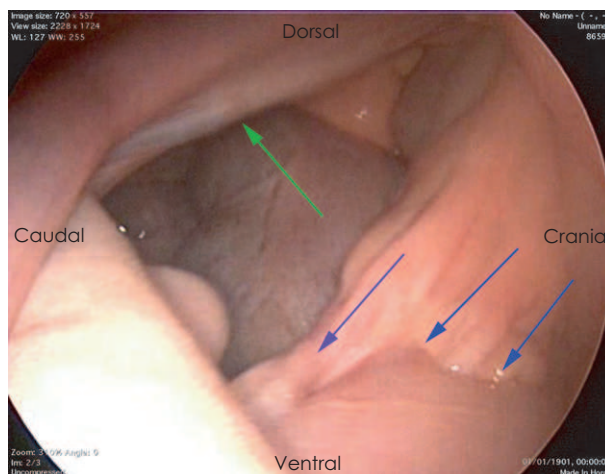


Fig 2: With a hand manipulating the aboral limit of the avulsion, the normal (blue arrows) and avulsed (green arrow) portions of the small intestine are noted.

and then onto the jejunum, the mesenteric defect could be detected and visualised with the telescope (**Figs 1 and 2**). Using a 43 cm long SILS Endostitch® device⁴ loaded with 2-0 V-LOC 180 8" (VLOCA208L) suture⁴, the torn mesentery was reattached onto the small intestine in an oral to aboral direction. Upon completion, digital palpation revealed excellent apposition of the defect. The mare made an uneventful recovery and was discharged from the hospital 72 h post-operatively. Dehiscence of the skin closure had occurred at the ventral portion of the hand portal by the time of suture removal. The mare was subsequently bred at 28 days post-discharge and a singleton pregnancy was confirmed 15 days post-ovulation and 46 days following laparoscopy. No further abdominal discomfort was noted in the first 8 months post-operatively.

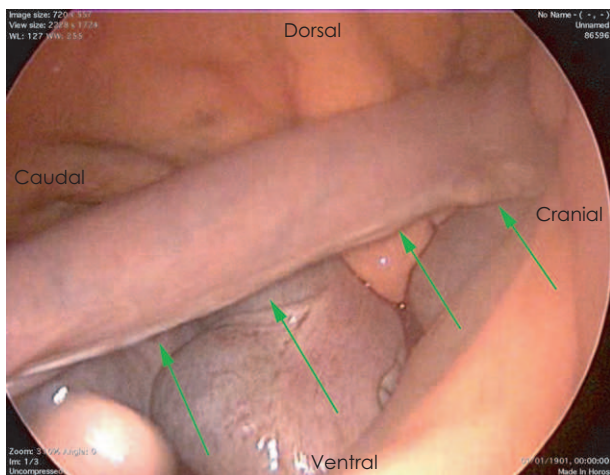


Fig 1: The green arrows indicate the site of previous mesenteric attachment onto the affected portion of small intestine.

Key points

- Trauma to the mesentery of the mesoduodenojejunal region should be considered as a differential for haemoabdomen in the post-parturient mare.
- Surgical access to the mesentery of the proximal jejunum and distal duodenum can be obtained by a standing, hand-assisted laparoscopic approach as an alternative to a midline laparotomy under general anaesthesia.
- The use of a barbed, knotless suture can be used for reattaching the mesentery to the intestinal serosa.



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Case Report

Bilateral ovariectomy as a treatment for chronic pyometra in four horses

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Keywords: horse; ovariectomy; pyometra; laparoscopy

Summary

Four horses presented for chronic pyometra that had been unresponsive to medical treatment, including serial uterine lavage and instillation of intrauterine antimicrobials. On presentation to the hospital, all horses had a fluid-filled uterus on ultrasonographic examination. All horses had persistent fluid accumulation that cultured *Streptococcus spp.*, and one case additionally cultured *Pseudomonas aeruginosa* from the fluid. Uterine lavages were performed with instillation of antimicrobials at the end, and N-acetyl-cysteine was used in one case and Tris-EDTA was used in one case. Two cases had cervical pathology (Cases 1 and 2), one case had an open cervix (Case 3) and one case most likely had poor uterine contractility and clearance (Case 4). Surgical management was pursued due to the chronic timeline and repeated uterine fluid accumulation in the face of treatment.

Standing bilateral laparoscopic ovariectomy with morcellation was performed as previously described, and the last uterine lavage was performed either 24 h before or after the ovariectomy. There were no complications with any of the surgeries. Cases 1 and 2 had histologically normal ovaries, histopathology was not performed on Case 4 and Case 3 had a vestigial testis on the left side and an ovotestis on the right side, thus was likely a true hermaphrodite. No horses had any vulvar discharge or evidence of pyometra, nor clinical signs associated with the reproductive tract on follow-up of 3–4 years post-ovariectomy; all owners were extremely satisfied with the procedure and outcome.

It was hypothesised that fluid accumulation within the uterus of mares with abnormal uterine and cervical conformation is primarily due to the repeated exposure to ovarian steroids. Progesterone reduces the local uterine immunity and can make mares more susceptible to infection. Thus, by removing the hormone source via (laparoscopic)

ovariectomy, resolution of clinical signs could be achieved as an alternative treatment option to ovariohysterectomy. Ovariohysterectomy is a more invasive and technically demanding surgery than ovariectomy and, although the survival rate can be good, is associated with more potential complications including haemorrhage, peritonitis, post-operative pain and death. Additionally, ovariectomy is a minimally invasive, familiar and somewhat common procedure to many equine surgeons. The other published technique for pyometra is cervical wedge resection, which would only be appropriate for cases of cervical pathology and/or adhesions and again might be less familiar than ovariectomy; complications were inadvertent penetration of the vagina and persistent fluid accumulation.

A larger case series needs to be compiled; however, with consideration of the influence of the hormones, the cases in this manuscript act as a successful 'proof of concept'. Bilateral ovariectomy without hysterectomy was a viable option for chronic pyometra in four horses.

Key points

- Ovarian steroids affect the intrauterine environment and are involved in the pathogenesis of equine pyometra, as well as cervical dysfunction or presence of foreign material.
- Ovariectomy is a viable alternative to ovariohysterectomy in cases of chronic pyometra unresponsive to conventional treatment.
- A minimally invasive surgical treatment led to resolution of clinical signs with no recurrence or complications in 3–4 years and had high owner satisfaction in this limited case series.



Clinical Commentary

Basic principles of intracorporeal suturing as applied during laparoscopy

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Introduction

In this edition of Equine Veterinary Education there are two publications describing unusual clinical conditions best served by helpful laparoscopic solutions (Jones *et al.* 2020; O'Neill 2020). The aim of this commentary is to accompany these two articles with an explanation of the major intracorporeal suturing principles as used routinely by experienced human surgeons with equine applications in mind. These principles are straightforward and the skills readily attained. In addition, The Royal College of Surgeons has a website which contains a guide to laparoscopic suturing.

Patient set up

The surgeon's position should be approximately in line with the intended visceral incision. Suturing in line with the laparoscope is easier than suturing an incision which is orientated obliquely/transversely. As experience increases, it can then be useful to turn the visceral incisions obliquely or transversely in the pelvitrainer and suture, to further improve technique. The intent should always be to position the needle holders directly above the visceral incision to achieve closure. The further from the incision, the more off perpendicular you become.

The surgeon should stand facing the monitor with the patient between surgeon and monitor. The scope is held by the assistant surgeon, and the surgeon stands to one side of the assistant, with a needle holder in each hand achieving triangulation, facing the monitor. So, on a clock face the dorsally recumbent horse is placed with the head at 12 o'clock and the tail at 6 o'clock, the scope is held at 6 o'clock pointing cranially. The surgeon is stood at approximately 7 o'clock with the principal needle holder (PNH) in the right hand at 7 o'clock and the assistant needle holder (ANH) in the left hand is at 8 o'clock and the monitor is at 1 o'clock; moving the screen from this axis, increases the degree of difficulty. Avoid placing the instrument ports too close together; you need easy 'triangulation', rather than chopsticks. Other set ups are described (Fischer 2002). Posture is important to reduce surgeon fatigue with the arms kept as low as possible during suturing.

Suture needle introduction into the abdomen

If a needle can be introduced directly down a cannula then this is the easiest way. Grasp the thread 1–2 cm from the needle and introduce. However, if larger needles are required then the following is useful.

To introduce any sized/shape needle into the abdomen using an existing 5 or 10 mm port. Pull the cannula out of the

incision in the abdominal wall and slide the needle holder into the cannula. Fold the length of suture material into 3–4 cm lengths and grasp the bundle with the needle holder several centimetres from the needle attachment. Introduce the needle holder, with the bundle in its jaws through the already created portal in the abdominal wall and on into the abdomen; the curved needle will follow into the abdomen. Then slide the cannula back down over the shaft of the needle holder back into the abdominal wall and the abdomen, ready to start suturing.

To remove, reverse the sequence. Hold the suture 2–4 cm from the attachment on the needle. Withdraw the needle holders to the peritoneum and then withdraw the cannula up the needle holder shaft and then withdraw the needle holder and suture – any size needle can be removed with this technique and the needle follows its own natural curve and no clinical damage occurring to the tissues.

Needle manipulation within the abdomen

When moving a needle around the abdominal cavity, hold the suture, not the needle to reduce the risk of visceral puncture. A needle held by the suture carries very low risk of any injury but whilst held fixed in the needle holder, extreme care must be exercised. Move slowly within the abdomen.

Suturing

A 35 mm half-curved needle works well and is a good choice to start suturing; in practice try to avoid going smaller as these are difficult to use and tend to bend but any size needle can be adopted using these techniques.

Keep suture lengths short, 20 cm length is a typical length, as longer lengths increase the complexity. Experience will allow the surgeon to determine the correct length of suture required. Single ties may only require approximately 10–15 cm lengths.

Correct needle position within the needle holders

In order to place the needle perpendicular to the needle holder, hold the very tip of the needle in the ANH and the suture material 2 cm from the needle in the PNH. Then push and pull both needle holders in the horizontal plane in opposite directions back and forth with the needle positioned vertically, using slow movements, the reflected light will move along the concave curvature of the half-curved needle. The centre of the needle will be located when the light reflection is located visually at the middle of the needle; stop movement at this point. If using a zero-degree laparoscope, a light reflection will be created on the needle and when the

light reflection is maximal on the entire needle then it confirms that the needle is perpendicular to the laparoscope. The target is to grasp the needle one third of the distance along the needle from the swaged side of the needle with the PNHs. Once grasped by the PNH, bring the needle close into view and rotate the needle holder through 360° in the same plane as the circular exterior of the laparoscope to see if the needle looks correctly aligned. It tends to look as if the needle is slightly coming towards you. This is worth practising outside the abdomen to increase confidence. It is also worth practising this manoeuvre with the needle incorrectly positioned so that you can see what this error looks like. The perpendicular principle is particularly relevant when suturing obliquely to the incision rather than transversely to it, as if true perpendicular needle location in the needle holders is not achieved, then the needle will buckle out of the needle holders. Also check that there is no obvious movement between the needle and the needle holders to ensure a secure normal grip.

Practice suturing

A banana placed in the pelvitrainer works well. Split the rind of the banana along one of its seams. Place a black pen dot either side of the seam level with each other and perpendicular to this split in the rind (**Supplementary Item 1**). These represent the ideal entry and exit points for your needle. Repeat these paired black spots all along the seam of the banana skin for your continuous suture. The needle needs to be introduced vertically into the black spot for a short distance and thereafter use wrist rotation only with no further movement of any other part of the arm. This will take you to the black dot on the other side of the split. It can help to try this outside the pelvitrainer with just a simple pair of Mayo needle holders to sense the difference in technique required between the two methods. Notice how you push the needle through the skin in open surgical suturing rather than just rotating the wrist alone as required for effective intracorporeal suturing. The ANH can be used to hold the edge of the banana rind perpendicularly to assist with the passage of the needle.

So, for this purpose the needle has been passed from right to left. Grasp the suture close to the needle after the needle has exited the second black dot using the PNH. Create a horizontal C shape, on the suture exit side with the open side of the C to the right and the needle end of the C loop closer to you and still being held by the PNH. The ANH is then placed above and laid down onto the C suture length (**Fig 1**) and with the PNH held still the ANH tip reaches under the suture close to tip of the PNH and lifts up the suture to create a single loop (curved tipped needle holders help this process) (**Fig 2**). Sliding the tip of the ANH a short distance up the shaft of the PNH after creation of the loop, helps to prevent dropping this loop. The end of the tail of the suture is grasped by the ANH (**Fig 3**), and this is pulled back to the left whilst the PNH is pulled to the right (**Fig 4**), all conducted above the incision and the first throw is made. Now the suture is grasped close to the needle with the ANH, and a C-shaped loop is made as before but with the open side of the loop to the left. This time the PNH is laid above and down onto the C-shaped loop (**Fig 5**), and the PNH is passed under the suture adjacent to the ANH to create the second loop (**Fig 6**). The tip of the PNH is kept in contact with the ANH

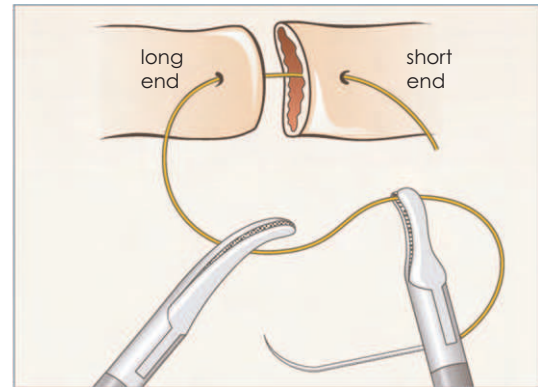


Fig 1: The suture is passed through the tissues and a 'C' is configured.

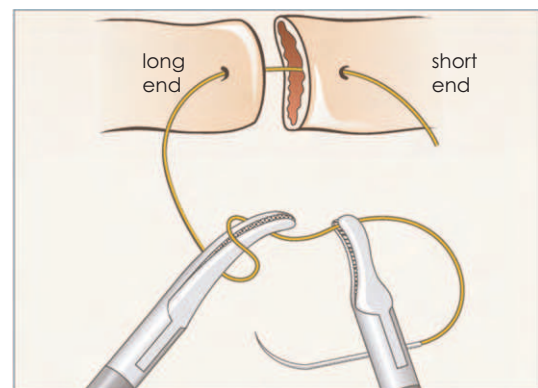


Fig 2: The first throw is made.

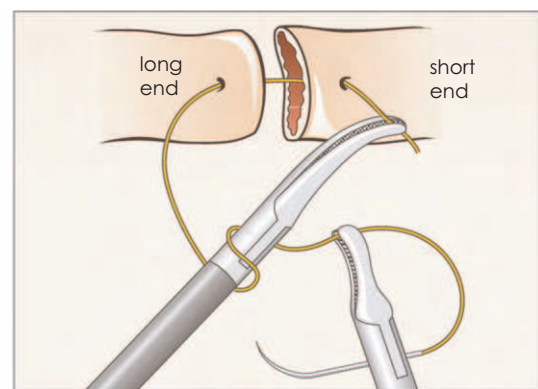


Fig 3: The short tail is grasped.

and may be slid a short distance up the shaft of the ANH to stop the loop being dropped from the PNH. The tail of the suture is grasped with the PNH and the throw is laid by pulling the PNH to the right and the ANH to the left (**Fig 7**). This creates a loose square knot (**Fig 8**).

To now tighten the knot; first convert the square knot to a slip knot. Grasp the suture between the knot and the visceral incision on the exit side with the ANH and grasp the suture between the knot and the needle with the PNH and pull against each other, perpendicular to the knot. This converts

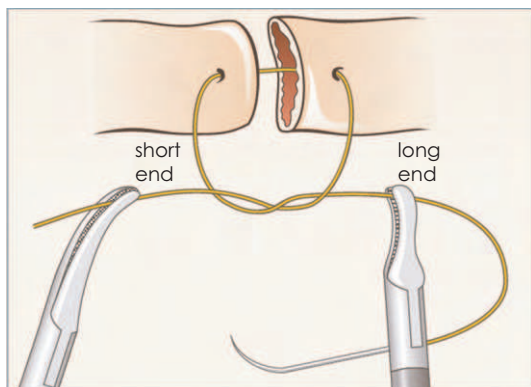


Fig 4: The needle holders are pulled in opposing directions to lay the first throw.

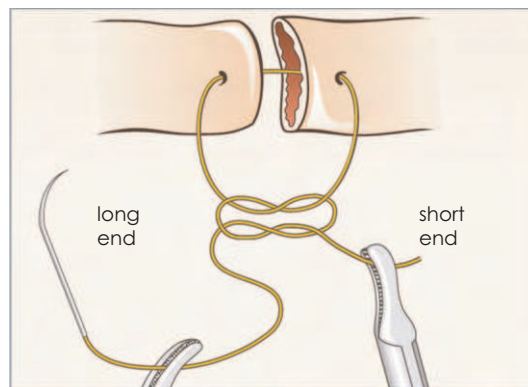


Fig 7: The needle holders are pulled in opposing directions to lay the second throw.

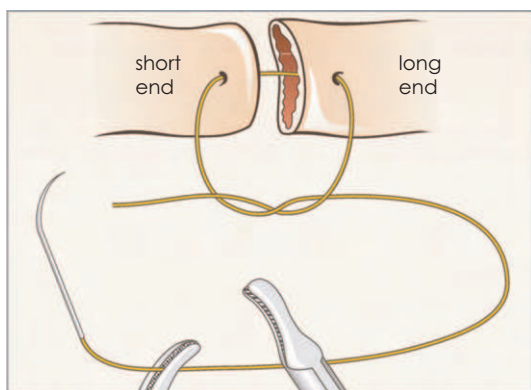


Fig 5: The 'C' is created for the second throw.

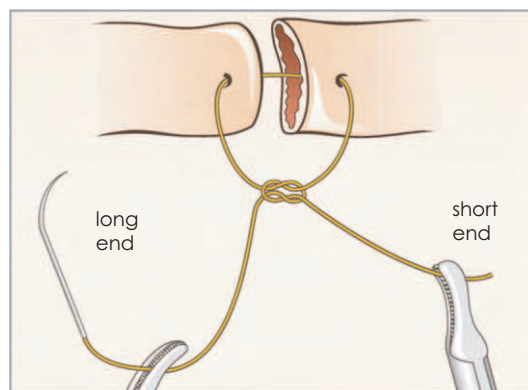


Fig 8: The square knot is closed.

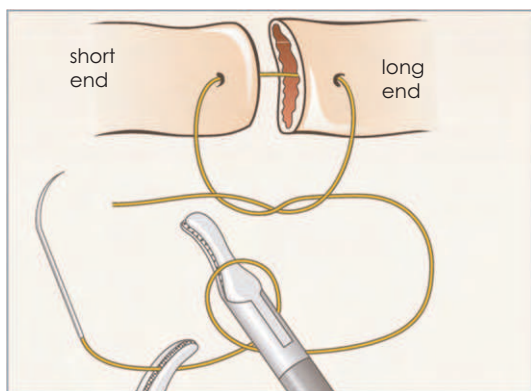


Fig 6: The second throw is made.

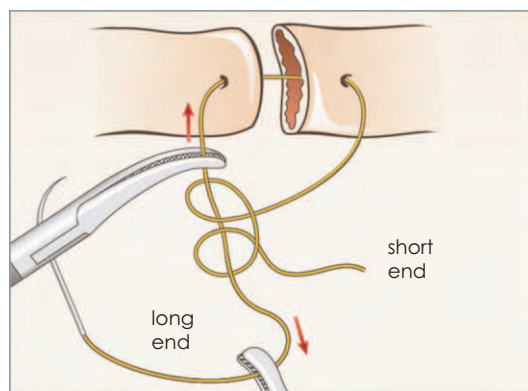


Fig 9: The square knot is converted to the slip knot.

the square knot into a slip knot (**Fig 9**). Release the ANH and place between the knot and the PNH (**Fig 10**) and use the ANH to slide the knot down and tighten (**Fig 11**). The knot may slide to one side of the incision so pull back to the centre and retighten. If you then release the PNH and grasp the short tail and pull the two needle holders horizontally in opposing directions the slip knot will convert to a locking square knot (**Fig 12**). You can then place one or two throws on top of this to complete or you could simply just place another throw or two onto the slip knot to complete. When

tightening these additional throws pull strands horizontally away from each other (**Supplementary Item 2**).

If the knot tightens above the incision leaving the residual loop too large, convert to a slip knot as above, by placing one needle holder between needle and the knot and the second needle holder on one arm of the loop of the knot and pull the two needle holders away from each other at 180° to redislocate the knot. If knot tightens rather than releases, maintain hold on the needle thread but switch the other needle holder to the other half of the loop of the knot

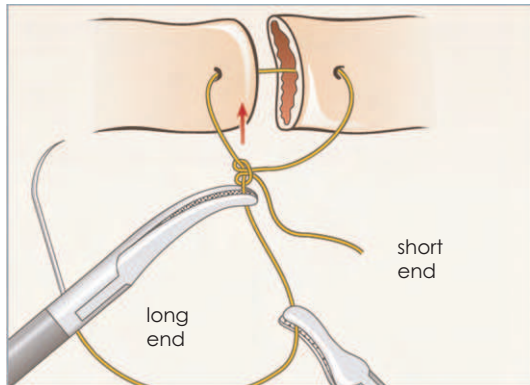


Fig 10: The slip knot is slid towards the viscus.

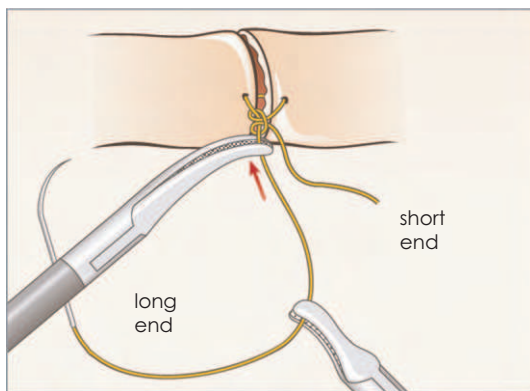


Fig 11: The slip knot is cinched down to the desired degree of security.

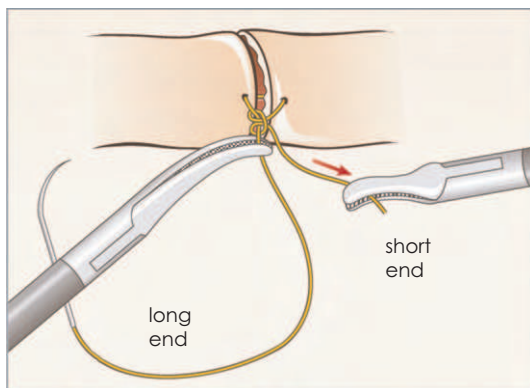


Fig 12: Conversion of the slip knot back to a square knot.

and pull again at 180°. The knot can be felt to click when it dislocates.

Double throws are uncommonly used because if the loop of the knot is deemed too loose after tightening then it may be difficult to adjust further. Occasionally, tissue tension will require the double throw.

These knot manipulations can be easier to perform if the suture material is moistened.

The quality of your technique can be tested by substituting the banana for something tougher like a car chamois leather. It also helps to practise the technique initially in 3-D with the lid of the pelvitrainer removed.

Continuous suture pattern

Securing an incision of say 10 cm in a viscus, using a two-layer closure with a simple continuous pattern would be conducted thus. The two ends of the incision are labelled A and B. Firstly, create a single simple interrupted suture (SIS) at one end (B). Then, starting at A, initiate your simple continuous suture, create the first layer of the closure and on reaching B, tie the continuous suture to one tail of the SIS created initially at B and either, cut the suture and start afresh again at A, or do not cut after the knot is made with the SIS at B and return, the simple continuous suture as the second superficial layer from B to A and tie your second layer continuous suture to the tail of your original deeper continuous suture at A. The principle is that it is better to use this technique, than finishing a continuous suture by creating a loop and using this as one arm with which to construct the final knot, as would be done traditionally, in open surgery.

The entire procedure may be done after your first entry, without exiting the abdomen, but this will require a suture length three times the length or greater of the visceral incision to complete, so in this instance one would need to start with a 30–40 cm length of suture.

If a continuous suture looks loose, the only way to salvage the situation is to remove the suture and start again.

As a routine multifilament absorbable sutures are preferable to monofilament sutures but you should not deviate from selecting the right suture for the task.

Barb sutures do carry the small risk of snagging other visceral organs, in the sense that jejunum could adhere to an exposed barb.

Authors' declaration of interests

No conflicts of interest have been declared.

Ethical animal research

No animals were involved in this commentary.

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None.

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Authorship

Both authors contributed equally to the concept and design of this commentary. N. Woodford prepared the manuscript and M. Whittaker contributed to the development and also supplied the videos. Both authors have given their final approval.

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Further reading

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Supporting information

Additional Supporting Information may be found in the online version of this article at the publisher's website:

Supplementary item 1: Real time construction of the intracorporeal knot in a simulator.

Supplementary item 2: Animation depiction of intracorporeal suture construction.

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Case Report

Long-term successful outcome of a *Streptococcus equi* subspecies *equi* brain abscess

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Keywords: horse; magnetic resonance imaging; strangles; craniotomy

Summary

A 7-year-old Quarter Horse mare presented for acute onset of ataxia and hypermetria, leaning to the right with a head tilt (poll to right), right-sided facial nerve paresis, right-sided blindness, circling to the left, and subsequent collapse. The deficits developed 4 months following an uncomplicated strangles infection that had not warranted treatment. A *Streptococcus equi* subspecies *equi* brain abscess was diagnosed using computed tomography and was successfully treated by a combination of medical management and surgical drainage. The mare returned to serviceable function within a year of initial treatment and had a successful performance career for over 10 years until carpal arthritis prompted retirement. Detailed neurological and ophthalmic examinations 14 years after initial treatment revealed no deficits other than atrophy of the left temporalis muscle. Magnetic resonance imaging revealed a T2 hyperintense, FLAIR hypointense, non-contrast medium enhancing mass in the left diencephalon and telencephalon. In addition, a 1.5 cm defect was present in the left aspect of the temporal bone attributable to the previous craniotomy. These findings were consistent with a fluid-filled cystic region in the area of prior abscessation with fibrosis and probable gliosis (Fig 1).

Over the next 4 years the mare maintained a normal neurological status but progressive carpal arthritis resulted in lameness at a walk and a decision for euthanasia. A new finding was bilaterally symmetrical, intermittent fine tremors of the external nares but no other neurological deficits were apparent (atrophy of the left temporalis muscle persisted). Ophthalmic examination revealed no evidence of visual



Fig 2: Necropsy photograph of the formalin-fixed brain 18 years following successful treatment of a cerebral *Streptococcus equi* subspecies *equi* abscess. Dorsal section, at the level of the neurohypophyseal stalk: * = left piriform lobe, with central white area of fibrosis; spaces indicating loss of neural tissue and a portion of left lateral ventricle; arrow = fibrous adhesion between left side of the corpus callosum and hippocampus, partially obliterating the lateral ventricle.

impairment and pupillary light reflexes were normal. On necropsy examination the brain appeared grossly normal externally but dorsal sections revealed areas of discoloration, softening and cavitation in the left side of the thalamus, the left piriform lobe, the left hippocampus and the left side of the corpus callosum. The core of this area was white and fibrous, and the surrounding nervous tissue was friable and mottled grey, tan and brown (Fig 2). The rest of the brain was grossly normal and no lymph node abscesses were found throughout the remainder of the body. Despite persistent cerebral and midbrain lesions detected by MRI and at necropsy, this case demonstrates that brain abscesses in horses may be successfully managed long term by combined medical and surgical treatment.

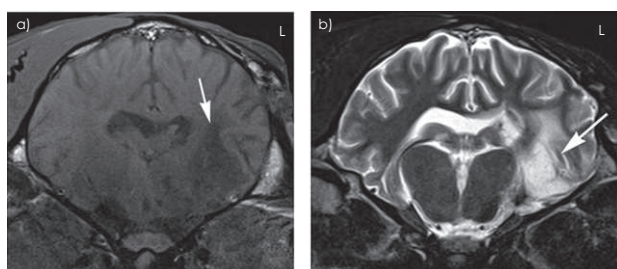


Fig 1: MRI images obtained 14 years after successful treatment of a brain abscess caused by *Streptococcus equi* subspecies *equi*: a) T1-sequence after contrast medium administration revealing the lack of contrast medium enhancement within the left cerebral lesion (arrow) or surrounding margin, indicating lack of active inflammation; b) T2-sequence showing a strong T2 signal within the lesion in the left cerebrum (arrow).

Key points

- Previous reports of intracranial infections in 20 horses have shown half to be caused by metastatic *Streptococcus equi* spp. *equi* and spp. *zooepidemicus* abscesses and half were mixed bacterial and fungal infections of the calvarium extending from trauma, paranasal sinusitis, pituitary gland abscesses or pneumonia.
- The prognosis for intracranial infection is guarded (4/20 survived), with both medical treatment and surgical drainage required for successful outcome.
- Magnetic resonance imaging is useful for determining whether or not surgical intervention may be possible.



Case Report

A two-step ovariohysterectomy with unilateral left flank laparoscopic assistance in a Quarter Horse mare**D. T. N. Kadic**  and **A. G. Bonilla****Department of Clinical Sciences, College of Veterinary Medicine, University of Montreal, St-Hyacinthe, Quebec, Canada***Corresponding author email: aa.garcia.bonilla@umontreal.ca***Keywords:** horse; minimal invasive surgery; laparoscopy; ovariohysterectomy; pyometra**Summary**

A 5-year-old, 485 kg Quarter Horse mare was presented for ovariohysterectomy to treat chronic pyometra secondary to pneumovagina and physometra, and associated with discomfort during exercise. Poor perineal conformation and regional atony of unknown origin were diagnosed a year earlier and treated with perineal body reconstruction and episiotomy with unfavourable results.

At admission, reproductive examination revealed pneumovagina secondary to an open ventral vulva and vestibulo-vaginal sphincter despite the presence of an episiotomy. Ultrasonographic examination was compatible with pyometra and physometra. *Pseudomonas* spp. was isolated from uterine fluid samples and treated with uterine lavages and local antimicrobials prior to surgery.

For the first part of the procedure, the mare was placed in standing stocks and the left paralumbar region was aseptically prepared for surgery. After standard draping and local anaesthesia of the laparoscopic portals, four 15-mm incisions were made. The laparoscopic portal (A) was created first, followed by portals B and C. The left ovary was identified and manipulated with atraumatic grasping forceps. The left mesovarium, mesosalpinx and broad ligament were anaesthetised and dissected up to the level of mid-uterine body. Once completed, a fourth portal (D) was made to access the right ovary/uterine horn by elevating the descending colon and mesentery with a fan retractor. The mesenteric attachments were anaesthetised after pulling the right ovary towards the left flank and mesenteric dissection was completed as previously described. After complete dissection (**Fig 1**), laparoscopic portals were routinely closed (surgical time: 90 min).

Following laparoscopy, the horse was induced under general anaesthesia (GA) and placed in dorsal recumbency to complete the ovariohysterectomy. An approximately 10-cm-long incision was made. The ovaries and uterus were gradually exteriorised and after placement of three Doyen clamps on the uterus/cervix, the uterine body was transected between the cranial and middle clamps. The uterine stump and celiotomy incision were closed (GA time: 113 min; surgery time: 81 min) and the horse recovered uneventfully.

Antimicrobial therapy and NSAIDs were continued for 13 and 6 days, respectively. The mare was discharged 11 days after ovariohysterectomy.

Follow-up information was obtained by telephone conversation with the owner and trainer 13 months after surgery. At that time, the mare was back on full exercise without any discomfort. No complications occurred during the post-operative period. The referring veterinarian reported no signs of vaginal or cervical infection during re-evaluations.



Fig 1: Intraoperative picture (obtained from fusing two separate images) at the end of the laparoscopic part of the procedure depicting dissection of the mesovarium, mesosalpinx and broad ligament bilaterally (*). A, uterine body; B, right uterine horn; C, left uterine horn; D, left ovary. Bottom of the picture is cranial, the top is caudal.

Keypoints

- Ovariohysterectomy is a procedure uncommonly performed in the horse and is invasive, surgically demanding and can be associated with significant complications when a ventral midline approach is performed.
- A two-step laparoscopic-assisted ovariohysterectomy through one flank reduces the surgical invasiveness and potentially minimises the surgical time and risk for complications (i.e. wound infection, septic peritonitis or abdominal organ perforation).
- The technique was useful for the reported case. However, large-sized mares or animals with a large uterus that cannot be drained before surgery or exteriorised through a relatively small ventral midline incision may not be good candidates for this unilateral technique.





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* Manfredi JM, Stapley ED, Nash D. Effects of a dietary supplement on insulin and adipokine concentrations in equine metabolic syndrome/insulin dysregulation. In J Equine Vet Sci 2020;88:102930.

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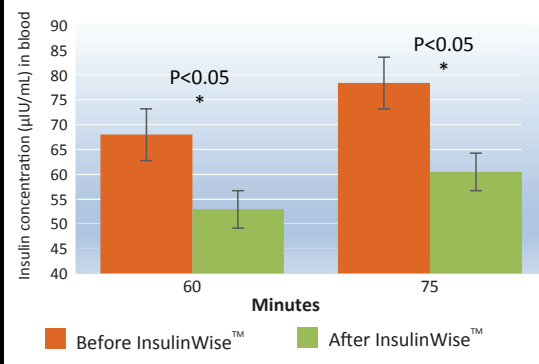


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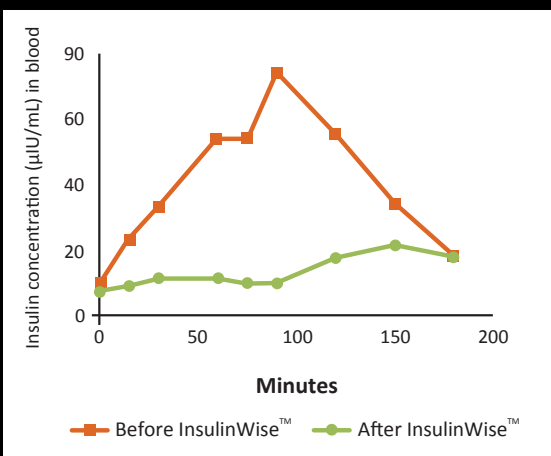
Insulin Concentrations Following OST Challenge

Supplementation with InsulinWise significantly reduced insulin blood levels, signifying increased insulin sensitivity.



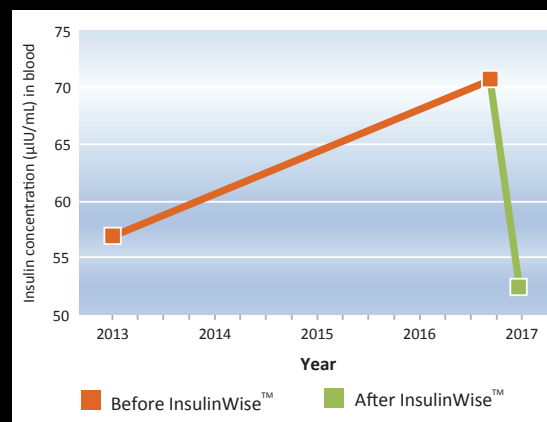
InsulinWise Supported a Decrease in Insulin Resistance

In four of the horses previously identified as insulin resistant, insulin regulation reverted to levels classified as normal after supplementation with InsulinWise.



Insulin Levels at 60 Minutes During Oral Sugar Tests from 2013 to 2017

Over time, EMS horses became more insulin resistant. Supplementation with InsulinWise significantly reduced insulin levels in the blood, signifying a decrease in insulin resistance.



Original Article

The influence of rider:horse bodyweight ratio and rider-horse-saddle fit on equine gait and behaviour: A pilot study

S. Dyson^{†*} , A. D. Ellis[‡], R. Mackechnie-Guire[§], J. Douglas[#] , A. Bondi[¶]  and P. Harris[‡] 

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Keywords: horse; lameness; body mass index; obesity; saddle; ethogram

Summary

The effect of rider weight on equine welfare and performance requires further investigation. The objective of this prospective, cross-over, randomised trial was to assess gait and behavioural responses of horses to riders of similar ability, but different bodyweights. Six nonlame horses in regular work were ridden by each of four riders: Light (L), Moderate (M), Heavy (H) and Very Heavy (VH). Saddle fit was assessed subjectively throughout the study. Each horse was ridden twice by riders L and M, and once by rider H. Rider VH rode five horses once and one twice. Each horse-rider combination undertook a standardised, 30-min 'dressage-test' which was abandoned if we observed lameness grade $\geq 3/8$ in one limb, grade $\geq 2/8$ in ≥ 2 limbs, or $\geq 10/24$ behavioural markers of pain. Horses were reassessed in hand 45–60 min after any abandonment. Mean rider bodyweights, body mass index (BMI) values and rider:horse bodyweight percentages for the L, M, H and VH riders were respectively: 60.8, 77.8, 91.0, 142.1 kg; 23.2, 28.0, 26.3, 46.9 kg/m²; 10.0–11.7%, 12.8–15.0%, 15.3–17.9%, 23.6–27.5%. All 13 H and VH rider tests (lameness, $n = 12$; behaviour, $n = 1$) and one of 12 M rider tests (lameness) were abandoned. Lameness was confirmed using inertial measurement unit data. All horses trotted sound after test abandonment and completed the study moving well when ridden. Limitations of the study were saddle fit was not ideal in all horse-rider combinations and abandonment criteria were subjective. The conclusions and clinical relevance of the study were that large riders can induce temporary lameness and behaviours consistent with musculoskeletal pain. This may relate to rider bodyweight and/or weight distribution. Riders M and H had similar BMI but markedly different test abandonment rates, therefore bodyweight is likely to be more relevant than BMI. Further work is required to determine if horse fitness, adaptation to heavier weights and better saddle fit for heavier/taller riders will increase horses' weight-carrying capacity.

Introduction

As the human population gets heavier (Reilly and Dorosty 1999; Rennie and Jebb 2005; Han *et al.* 2015; Wang *et al.* 2017), there has been growing debate about relative rider-horse sizes. This was highlighted as a research priority at the 2nd International Saddle Research Trust Workshop (Clayton *et al.* 2015). In 2015, World Horse Welfare, in conjunction with the British Equestrian Federation, hosted a meeting attended by senior representatives from the UK equine industry and it

was concluded that 'innovative ways should be developed, so that riders can assess if they are the correct weight for their horse, explore pre-riding fitness initiatives and also develop guidance to support judges and officials to ensure that the horses' welfare always remains paramount' (World Horse Welfare 2015).

Studies investigating rider weight have been performed (Sloet van Oldruitenborgh-Oosterbaan *et al.* 1995; Powell *et al.* 2008; Matsuura *et al.* 2013a,b, 2016; Gunnarsson *et al.* 2017; Stefánsdóttir *et al.* 2017), but few have satisfactorily addressed this issue in a typical riding situation. They have, for example, utilised lead weights to alter the total load carried (Matsuura *et al.* 2013a,b, 2016; Gunnarsson *et al.* 2017), which does not address potential differences in physique and balance in riders of differing weights, or treadmill exercise (Sloet van Oldruitenborgh-Oosterbaan *et al.* 1995), which does not necessarily equate with overground exercise, and does not include turns and circles. In addition, several have utilised very high total load:horse bodyweight ratios (Matsuura *et al.* 2013a,b, 2016; Gunnarsson *et al.* 2017; Stefánsdóttir *et al.* 2017), so we do not know whether changes in equine performance may occur at lower rider:horse bodyweight ratios.

Therefore, although it is widely recognised that inappropriate rider size has welfare implications for horses (Clayton *et al.* 2015), there is a lack of reliable scientific evidence on which to base guidelines. This is a multifactorial issue with many inter-related aspects, including the horse's age, its fitness and muscle development, thoracolumbar length and the presence or absence of lameness; the type, speed and duration of work; the rider's skill, fitness, balance and coordination; the ability of the rider to sit straight; the fit of the saddle to both the horse and rider; and the terrain over which the horse is ridden (Clayton *et al.* 2015).

Lameness may be present in ridden horses that is not detectable in hand or on the lunge (Licka *et al.* 2004; Greve and Dyson 2014; Dyson and Greve 2016). Moreover, we have observed that a heavy rider may transiently induce lameness in a horse that was not lame when ridden immediately previously by a lighter rider, and that lameness may be exacerbated in a lame horse ridden by a heavy rider compared with a lighter rider (S. Dyson, unpublished data). In addition, it has recently been shown that, during ridden exercise, lame horses may show behavioural differences compared with nonlame horses (Dyson *et al.* 2017, 2018a). Application of a ridden horse ethogram has demonstrated an association between the presence of $\geq 8/24$ behavioural

markers and musculoskeletal pain (Dyson *et al.* 2018a) and a reduction in the number of markers after resolution of lameness by diagnostic analgesia (Dyson and Van Dijk 2020; Dyson *et al.* 2018b).

The aim of this investigation was to assess gait and behavioural responses in typical nonelite competition riding horses undergoing a standardised exercise test, when ridden by four riders of similar ability but different bodyweights. The study design mimicked the situation that occurs in many riding establishments and equestrian disciplines in which a horse or pony may be ridden in its usual saddle by riders of varying weights and body shapes.

Materials and methods

The study was approved by the Clinical Ethical Review Committee of the Animal Health Trust (AHT 28 2016). The horse owners gave informed consent for inclusion of their horses in the study.

Study riders

There were four riders of similar ability (Williams and Tabor 2017) but differing bodyweights, assessed by British Horse Society (BHS) Instructors prior to selection (S.D.) and during the study (A.B.) using the (Fédération Equestre Internationale 2017) 0–10 scale for riders: Light (L: K.S.) – a BHS Intermediate Instructor and experienced rider, with >25 years of professional riding experience, who had competed in British Eventing to Intermediate level and to Advanced Medium in British Dressage (BD), and who was currently an equine technician at the Animal Health Trust (AHT); Moderate (M: S.G.) – an experienced rider with 5 years of professional riding experience who had competed to Medium level in BD and was currently an equine technician at the AHT; Heavy (H: T.T.) – a BHS Instructor with >25 years of professional riding experience; Very Heavy (VH: K.A.) – an experienced rider for >25 years. All riders were accustomed to riding a variety of horses and were riding daily. The riders' ages were 49, 26, 56 and 36 years respectively.

Horses

All horses were volunteered by their owners. Eight horses (six test horses [designated Horses 1–6; Warmbloods, $n = 3$; cob-type, $n = 2$; Lusitano, $n = 1$] and two reserve horses [Irish Sports Horse and Thoroughbred]) were selected from 24 evaluated based on the absence of forelimb lameness or hindlimb lameness grade $>1/8$ (Dyson 2011). All horses were evaluated by a Royal College of Veterinary Surgeons Specialist in Equine Orthopaedics (S.D.), specifically for the study, 6–8 weeks before the start of the study in hand at walk and trot and ridden by their usual rider in walk, trot (including 20 and 10 m diameter circles) and canter. There was no detectable lameness in seven horses; one horse had episodic grade $1/8$ left hindlimb lameness when ridden. Horses were selected based on a bodyweight category of 500–600 kg so that, during the study, the rider: horse bodyweight percentages would be 10–12 (L), $>12 \leq 15$ (M), $>15 < 18$ (H) and >20 (VH). The owners considered that their horses were capable of being ridden 'on the bit' for 30 min, predominantly in trot and canter, twice daily. At the time of selection, the horses' body condition scores (BCS) ranged from 5.0 to 7.0 (1.0–9.0 scale; Henneke *et al.* 1983). The owners, who were less

experienced than the test riders, provided estimates of their own height and bodyweight.

Saddle fit

The saddle fit for each horse was assessed by a Master Saddle Fitters Consultant (C.M.) and adjustments were made to improve fit when required, in order to minimise the risk of a horse entering the study with pre-existing thoracolumbar pain. On the day prior to commencement of the study, the saddle fit was rechecked (C.M.) and further adjustments were made if necessary. On all days throughout the study, saddle fit was rechecked for each horse and abnormalities of fit were recorded.

The day prior to commencement of the study

The horses were stabled at World Horse Welfare. All horses were assessed moving in hand in straight lines at trot on a hard surface by S.D. and the presence of lameness was graded and recorded (0–8; Dyson 2011). One horse was rejected because of grade $4/8$ right hindlimb lameness. All horses were ridden in the indoor arena by their usual rider ($n = 5$) or rider L (one test horse and one reserve horse) to familiarise them with the study test environment.

Measurements of the riders, horses and tack prior to the study are detailed in **Table 1** and **(Supplementary Items 1–3)** and the results are presented in **Table 2** and **Supplementary Item 4**.

The study days

Horse and rider weights

On each study day, the horses were weighed at 07:00 hours and the riders were weighed, wearing their riding equipment, at 08:00 hours.

Objective gait assessment methodology

Five MTw (2nd generation) inertial measurement units (IMUs)¹ in custom-built pouches were attached using double-sided or hook and loop tape (IMU central position was marked with white correction fluid on hair for future consistency of positioning) in the following positions: left and right tubera coxae; between the tubera sacrale ('pelvis'); dorsal aspect of the withers; bridle headpiece on the midline ('poll'). Data were synchronised to a wireless transmitter/receiver² attached via USB to a laptop computer. Data were processed at an internal sample rate of 1000 Hz (from raw data to orientation) and sent wirelessly from each sensor to the laptop computer running MTManager software¹ at an update rate of 60 Hz. Custom-written MATLAB scripts³ were used for stride segmentation (Starke *et al.* 2012a), as well as for filtering, rotation from a sensor to a horse/gravity-based reference frame and double integration to vertical displacement (Warner *et al.* 2010). For each stride, movement asymmetry values at the pelvis (pelvis Minimum Difference [PMnD], pelvis Maximum Difference [PMxD]), poll (PollMnD, PollMxD), withers (WMnD, WMxD) and tubera coxae (Hip Hike Difference [HHD]) were calculated based on previously published definitions (Pfau *et al.* 2018).

Procedures prior to each ridden test

Each horse trotted in hand in a straight line for approximately 40 m twice on the arena surface, and IMU recordings were acquired (RG, TP, ES). The gait was simultaneously assessed subjectively (S.D.).

A force mat,⁴ the saddle and saddle pads were placed on the horse. To facilitate assessment of saddle movement relative to the horse, a strip of fluorescent tape was stuck to the horse's dorsal midline immediately cranial to the tail head and two pieces of tape were placed on the caudal aspect of the cantle of the saddle, one aligned vertically in a central location, the second aligned horizontally. The rider mounted from a purpose-designed mounting block (maximum height, 103 cm; second step, 69 cm) to minimise disturbance of the force mat. The saddle fit to horse and rider was subjectively assessed (A.B.). A lateral photograph of the horse standing in front of a 100 cm line on the wall was acquired to record rider position in the saddle. The riders wore snug-fitting black tops, with a green cross on the back comprising a midline vertical line and a horizontal line at armpit level.⁵

The test programme

The predefined, 30-min test (**Supplementary Item 2**), with which the riders were familiar, was performed in a 20 × 60 m marked arena. It included walk, rising trot and canter on both reins. The test was called by RY, who also checked that, in trot, the rider sat on the correct diagonal (i.e. when the outside forelimb and inside hindlimb were bearing weight).

Objective gait assessment

Inertial measurement units data were collected with the horse moving in straight lines (2 × 60 m) and circles on both the left and right reins during the first and second trot periods (**Supplementary Item 2**) of each individual horse:rider test.

Subjective assessments

Subjective assessment of gait was performed continuously throughout the test by S.D. The presence and grade (0–8) of lameness in walk and trot were recorded for each test movement. The presence of 24 behavioural markers (Dyson *et al.* 2018a; **Supplementary Item 3**) were recorded continuously. The assessor stood between C and H and between C and M, for work performed on the left and right reins respectively. The ridden horse ethogram was also applied retrospectively to video recordings of all horse-rider combinations for predetermined parts of the test. The results are presented elsewhere (Dyson *et al.* 2018c).

All events were timed and the nature and timing of unexpected events (e.g. spooking, head up) were recorded (CC). Rider position and straightness were assessed by a BHS Instructor (A.B.). Saddle movement was defined on a binary (yes/no) scale as mild left/right oscillation, severe left/right oscillation, saddle consistently slipping to one side (mild/severe) and/or bouncing.

Physiological assessments

For each test, equine temperature, pulse and respiratory rates were recorded pre- and post-exercise, with continuous monitoring of heart rate⁶ during exercise. Base line, pre- and post-exercise saliva samples were collected for measurement of cortisol concentration (Roberts *et al.* 2018). The response to palpation (muscle tension and pain) of the thoracolumbar region was determined pre-exercise and immediately post-exercise (Quiney *et al.* 2018). Thoracic dimensions were measured at predetermined sites pre- and immediately post-exercise. Data for all these measurements are reported separately (Quiney *et al.* 2018; Roberts *et al.* 2018).

Test abandonment

For welfare reasons, there were predefined criteria for test abandonment: (i). Development of lameness grade $\geq 3/8$ in one limb or grade ≥ 2 in ≥ 2 limbs; (ii). Display of $\geq 10/24$ behavioural markers of pain (e.g. ears back, constant moving of head, tail lashing, reluctance to go forwards willingly; **Supplementary Item 3**; Dyson *et al.* 2017, 2018b). Test abandonment was signified by blowing of a whistle, at which point the horse was stopped immediately and the rider dismounted. If a test was abandoned, the horse was reassessed by S.D. trotting in hand on the arena surface 45–60 min after termination of the test.

Test order

The horse:rider test order was randomised whilst ensuring that each horse's test times were distributed between morning and afternoon sessions in a ratio of 4:2, or, for one horse, 3:3. Each horse was to be ridden once by riders L and H and twice by riders M and VH. However, the protocol was amended on the third study day when, unexpectedly, all H and VH rider trials had been abandoned before test completion. Therefore, the VH rider's test was only repeated in one horse and no H rider repeats were conducted. Instead, the L and M riders' tests were repeated for all horses. This change in protocol necessitated alteration of the test order.

For the first two study days, horses were randomly assigned to morning exercise slots. The following days' test orders were changed to an imbalanced Latin square design in order to ensure the following: (i). Each horse was ridden once/day for 4 days and twice on 1 day; (ii) If a horse was ridden twice/day, one rider was always L and there were at least 3 h between tests; (iii) Riders rode no more than three times/day and had at least 1 h between tests.

Data analysis

Within this paper, most data presentation is descriptive. The riders' body mass index (BMI) (NIH 2018) and rider:horse bodyweight percentages were calculated. In order to compare subjective observation lameness scores (1 = lame, 0 = nonlame) for each limb with IMU (poll and pelvis) data for each horse:rider test, IMU asymmetry for the pretest trot and for the trots prior to the first canter of the test on the left and right reins were scored as either 1 (asymmetry exceeds published thresholds for nonlame horses; Starke *et al.* 2012b; Pfau *et al.* 2013, based on Buchner *et al.* 1996; Greve and Dyson 2016; Greve 2016) or 0 (asymmetry does not exceed that found in nonlame horses). If the IMU data indicated asymmetry, direction of asymmetry was determined. We calculated the percentage of horse:rider tests in which agreement was achieved between the subjective and IMU lameness assessments in terms of both presence/absence of lameness and, if lame, the identity of the lame limb. Gait analysis data were analysed for normal distribution (Kolmogorov Smirnov). Only trot data up to the first canter (the point that most tests reached before abandonment) were used for analysis.

Saddle fit was unequal among riders and there was a smaller number of tests for riders H and VH, therefore multiple one-way ANOVA's were used to test for the fixed effect of rider using the trial mean data per horse. Data were therefore treated as unrelated/independent and a between-group test was chosen. To analyse for extent of asymmetry statistically,

data were transformed to positive deviations (nondirectional) from baseline, but actual symmetry with untransformed data are presented in the figures. Tests for rider VH were abandoned earliest, and IMU data were predominantly from riding on the left rein in straight lines. Therefore, mAnova was used, with a Bonferroni post hoc test, to assess for minimum and maximum differences according to riders for all horses at Poll, Withers and Pelvis for trot in straight lines on the left rein only. An additional test was carried out for straight lines and circles on both reins to test for differences among L, M and H riders. A Spearman rank correlation was also performed, to test asymmetry according to rider, for all measures in trot in a straight line, on the left rein. The significance was set at $P < 0.05$. The Statistical package of IBM SPSS 23 (2017)⁷ was used.

Results

The weather was cool (13–19°C) over the 5-day test period.

Dimensions of the horses' usual riders

The horses' usual riders had estimated bodyweights of 61–92 kg and rider:horse bodyweight percentages and BMIs of 10.9–17.4 (mean, 13.0; median, 12.5) and 21.1–37.3 kg/m² respectively (**Supplementary Item 4**).

Dimensions of the horses and test riders

Horses ranged in height from 150.0 to 165.0 cm (mean, 157.3 cm; median, 157.0 cm) and in bodyweight for the 6 days of investigation from 507 to 591 kg (mean, 555 kg; median, 528–546 kg). There was variation in bodyweight within normal variance (–14 kg to +1 kg) between the day of admission and the final test day. BCS was estimated as 5.5–8.0 (mode, 5.5). Horses 3 and 5 had increased to BCS of 8.0 and 7.5, respectively, since selection for the study. Forelimb dimensions and thoracolumbar region length are summarised in **Supplementary Item 1**. Muscle development of the cervical, thoracolumbosacral and pelvic regions was subjectively considered moderate in all horses (Walker *et al.* 2016).

The mean and range of bodyweight of each rider over the test period was: L, 60.8 (60.0–61.5) kg; M, 77.8 (77.0–79.0) kg; H, 91.0 (90.0–92.0) kg; and VH, 142.1 (141.5–143.0) kg. Each horse's saddle plus pads and numnah weighed 7.5–11.0 kg (mean, 9.7 kg; median, 9.0–10.0 kg) and the force mat weighed 2.0 kg. **Table 1** summarises the rider and rider-plus-tack weights as a percentage of horse bodyweight and **Table 2** shows rider height and body proportions. Rider BMI for

the L, M, H and VH riders was, respectively, 23.2, 28.0, 26.3 and 46.9 kg/m² (**Table 2**).

Saddle fit to horses and riders: subjective observations

All saddles were general-purpose type. No saddle fitted the horses ideally, despite recent fitting (within 3 months) by professional saddle fitters (Horses 1 and 4), and adjustments made by C.M.

Saddle length was appropriate for riders L and M for all horses, and for rider H for Horse 1 only (**Table 3**; **Figs 1** and **2**). Rider H sat on the cantle of the saddle for Horses 2–6. The VH rider's seat extended caudal to the cantle on all horses. Vertical alignment of the riders' shoulders, tubera coxae ('hips') and heels was assessed from lateral photographs, which were acquired with the horses stationary. Vertical alignment was present for rider L on all horses, and for rider M on Horses 2–5. In all other horse-rider combinations (rider M on Horses 1 and 6, riders H and VH on all horses), the rider's shoulders, 'hips' and heels were not in vertical alignment. This persisted for rider VH during motion; the position of rider H varied according to gait. Detailed analysis of rider position during the tests will be reported separately.

Saddle movement

Mild side-to-side oscillation of the saddle in trot was observed with the VH, H, M and L riders in 14.3, 50.0, 76.9 and 84.6% of their tests respectively. Severe oscillation was not documented. The caudal aspect of the saddle did not bounce with rider VH, but did with the other riders on Horses 1, 2, 4 and 5. When considering all riders, severe saddle slip to the right occurred in Horses 3 and 5 in trot and canter in 85.7 and 83.3% of tests respectively; mild saddle slip to the right also occurred in Horses 1 and 6 and to the left in Horse 4, particularly associated with crookedness in canter, in 71.4, 75.7 and 16.7% of these horses' tests respectively. Horse 4 had saddle slip to the right in trot with rider H.

Gait and behaviour: subjective observations

The following lamenesses were exhibited during one pretest trot up only: Horse 1, grade 1 left hindlimb; Horse 3, grade 1 right hindlimb; Horse 4, grade 1 right hindlimb; Horse 5, grade 1 right hindlimb. On two separate occasions, Horse 6 exhibited, respectively, a grade 1 right forelimb lameness and a grade 1 left hindlimb lameness. On all other occasions, the horses showed no detectable lameness on pretest trot up.

No horse showed detectable extension of the thoracolumbosacral region when mounted or when moving off at the walk. Observations of lameness grade ≤ 2 during the

TABLE 1: Rider percentage of horse bodyweight on day 1 and rider-plus-tack (including force mat) percentage of horse bodyweight for the six horses (1–6)

Horse	L		M		H		VH	
	Rider	Rider + tack	Rider	Rider + tack	Rider	Rider + tack	Rider	Rider + tack
1	11.7	13.8	15.0	16.9	17.9	20.0	27.5	29.7
2	11.4	13.5	14.6	16.7	17.4	19.5	26.8	28.9
3	10.8	13.2	13.9	16.3	16.6	19.0	25.5	27.9
4	10.0	12.2	12.8	15.0	15.3	17.5	23.6	25.8
5	11.4	13.6	14.6	16.9	17.4	19.7	26.8	29.1
6	10.2	11.8	13.1	14.7	15.6	17.3	24.1	25.7

L, light; M, moderate; H, heavy; VH, very heavy.

TABLE 2: Height, upper body length, leg length (cm), mean body weight (kg) over the 6-day study and body mass index (BMI; kg/m²) of the four riders (L, light; M, moderate; H, heavy; VH, very heavy).

Rider	Height	Upper body length: humeral tubercle to tuber coxae		Leg length: tuber coxae to lateral malleolus of tibia		Mean weight	BMI*
		Left	Right	Left	Right		
L	162.0	42.5	43.0	89.0	91.0	60.8	23.2
M	167.0	41.0	41.0	96.0	99.0	77.8	28.0
H	185.5	46.0	45.5	105.5	101.0	91.0	26.3
VH	174.0	50.0	49.0	97.0	95.0	142.1	46.9

* BMI categories: Underweight <18.5 kg/m², Normal weight = 18.5–24.9 kg/m², Overweight = 25–29.9 kg/m², Obese ≥30 kg/m².

TABLE 3: Saddle fit for the six horses (1–6) relative to rider size (L, light; M, moderate; H, heavy; VH, very heavy)

Horse	Rider	Length of saddle seat relative to rider size	Rider's shoulder, tuber coxae and heel in vertical alignment
1	L	Correct	Yes
	M	Correct	No
	H	Correct	No
	VH	Very short	No
2	L	Correct	Yes
	M	Correct	Yes
	H	Short	No
	VH	Very short	No
3	L	Correct	Yes
	M	Correct	Yes
	H	Short	No
	VH	Very short	No
4	L	Correct	Yes
	M	Correct	Yes
	H	Short	No
	VH	Very short	No
5	L	Correct	Yes
	M	Correct	Yes
	H	Short	No
	VH	Very short	No
6	L	Correct	Yes
	M	Correct	No
	H	Short	No
	VH	Very short	No

Correct, rider sitting in the centre of the saddle with clearance behind and in front. Short, rider sitting on back of cantle. Very short, rider's seat extends beyond the cantle. The alignment of the rider's shoulder, tuber coxae ('hip') and heel was assessed with the horse stationary.

test are summarised in **Table 4**. Low-grade lameness was seen in horses ridden by riders L and M, but was inconsistently present within and among tests. Going above the bit in transitions to canter, crookedness in canter and spontaneous change in gait from canter to trot were observed with all riders, not necessarily associated with overt lameness at the trot. Frequency of occurrence could not be compared among all riders because riders H and VH did not complete the tests.

All rider VH tests (n = 7) were abandoned because of lameness (**Table 4**). Five rider H tests were abandoned for lameness and one was stopped because the horse demonstrated 10/24 behavioural markers in canter. One rider M:Horse 3 test was abandoned because of lameness;

however, the second rider M:Horse 3 test was completed. Although the test was abandoned three times for Horses 3 and 6 and twice for Horses 1, 2, 4 and 5, only in Horses 2, 3 and 6 was the same lame limb identified on ≥2 occasions. When reassessed subjectively moving in hand at trot 45–60 min after test abandonment, no horse showed detectable lameness. All horses moved as well or better when ridden by riders L and M at the end of the study compared with the beginning, when evaluated both subjectively and objectively. Horses 3 and 4 successfully completed a test with rider L later on the same day as an abandonment.

Objective gait analysis

For the pretest trot up, the mean ± s.d. (range, mm) for all horses and all tests combined was 2.4 ± 2.7 (0, 8) for absolute PolMnD, 0.05 ± 2.8 (0, 9) for PolMxD, 3.11 ± 4.8 (0, 14) for PMnD, 2.2 ± 4.8 (0, 15) for PMxD and 4.3 ± 6.0 (0, 18) for HHD.

During ridden exercise, the IMU data varied considerably among horses, with no consistent patterns across all horses (**Fig 3**). However, the magnitude of asymmetry or variability in asymmetry appeared greater for the heavier riders on the left or the right rein, depending on the horse.

Comparison of subjective lameness analysis and objective gait analysis

Comparison of the subjective lameness scoring for each limb (lame or nonlame and direction of asymmetry) for each horse and rider with lameness scores derived from IMU data resulted in a 100% agreement for lameness/nonlameness seen at trot pretest and during the test in all horses for each rider. **Figure 4** shows a clear example of the IMU data for HHD in trot on a straight line, highlighting the much greater asymmetry values for the heavier riders according to horse.

Comparison of IMU data among riders

Figure 5 highlights overall differences in IMU data among riders. Statistical analysis was limited because of the early test abandonments for riders H and VH. For trotting on the right rein on the straight, horses ridden by rider H had a significantly higher level of asymmetry than for riders M and L for PMxD (F = 7, P < 0.01, mAnova, Bonferroni, excluding rider VH). Horses ridden by rider VH had a trend towards a higher HHD (hip hike difference) on the left circle (P = 0.08, F = 2.3).

When ridden on the left rein there was sufficient data to look at correlations among all riders and transformed differences measuring extent of asymmetry. This highlighted a significant positive correlation between riders' bodyweight and amount of asymmetry for PelvisMxD (P < 0.05, R² = 0.4) and HHD (P < 0.01, R² = 0.4; Spearman Rank; **Fig 6**).



Fig 1: Lateral images of the four riders, from left to right, Light (L), Moderate (M), Heavy (H) and Very Heavy (VH) stationary on Horse 2. The seat of the saddle is of correct length for riders L and M, is short for rider H, who is sitting on the back of the cantle, and is very short for rider VH, whose seat extends beyond the cantle. There is lack of vertical alignment of the shoulder, tuber coxae ('hip') and heel for riders H and VH.



Fig 2: Caudal images of the four riders, from left to right, Light (L), Moderate (M), Heavy (H) and Very Heavy (VH) on Horse 2.

Discussion

We have documented a substantial temporary adverse effect of rider on gait and behaviour, with no test being

completed by the H or VH riders. The two factors that are most likely to underlie this finding are: (i) rider weight as a proportion of horse weight; (ii) rider position in the saddle/on the horse's back (which is a function of rider size). The design

TABLE 4: Reasons for test abandonment when six horses (1–6) were ridden by four riders of different bodyweights (L, light; M, moderate; H, heavy; VH, very heavy)

Horse	Rider	Reason for abandonment	Saddle slip direction	Lameness observations with other riders
1	VH	Lame LH 4/8 1st trot left rein	Right	L rider: grade 1 LH
	H	10/24 behavioural markers in canter	Right	M rider: grade 1 RH
2	H	Lame RH 3/8 2nd trot left rein		L rider: grade 2 LF
	VH	Lame LF 3/8 and RH 4/8 1st trot right rein		L and M riders: grade 1 and 2 RH respectively
3	VH	Lame LH 4/8 1st trot left rein	Right	H rider: grade 1 LF
	M	Lame LH 3/8 1st trot left rein	Right	L rider: grade 2 LH
	H	Lame LH 4/8 1st trot left rein	Right	
4	VH	Lame LH 4/8 1st trot left rein		
	H	Lame LF 3/8 1st trot right rein	Right	
5	H	Lame RF 3/8 and LH 2/8 1st trot right rein	Right	
	VH	Lame LF 4/8 1st trot left rein		
6	VH	Lame LH 4/8 2nd trot left rein	Right	
	VH	Lame RF 3/8 and LH 3/8 1st trot left rein		
	H	Lame 3/8 LH 1st trot left rein	Right	

The data are shown in the order in which each horse was ridden by the respective riders. The mean time to abandonment was 16.6 min (range 9.0–25.2) for rider H and 8.3 min (range 6.0–19.0) for rider VH. Lameness observations for other tests and saddle slip presence are also summarised. LF, left front; RF, right front; LH, left hind; RH, right hind. Lameness was graded 0–8 (Dyson 2011). The lameness observations for riders L and M were only observed in one of the two tests for each horse.

of this pilot study does not allow us to determine which of these two factors is most influential or whether, indeed, both are important. In terms of rider weight, our results suggest that rider BMI, per se, is not a key factor: both the M and H riders were classified as overweight, based on BMI; however, rider M completed 11 out of 12 tests whereas rider H did not complete any of their six tests.

Saddle fit for the rider may affect the horse's ability to move comfortably (Greve and Dyson 2013b). For Horse 2, the owner and rider H had identical rider:horse bodyweight percentages (17.4) and similar weights (92 and 91 kg respectively), but different heights (157.0 and 185.5 cm respectively). This large difference in height has major potential implications for saddle fit for the rider and consequently for the rider's position and weight distribution (Schleese 2014; Dyson *et al.* 2015). However, when considering rider height, leg length vs. upper body length must also be considered. Although riders H and VH were the tallest of the four riders, rider M had similar leg length to rider VH (Table 2). The different body proportions of the four riders suggest that a range of saddles would have been required for each horse if optimum rider saddle fit was to be maintained. However, we deliberately elected not to use different saddles for each rider because this would have introduced another variable factor. Moreover, the use of rider-specific saddles would not mimic the situation which occurs in many riding schools, where usually each horse has one saddle, nor the situation at competitions when a pony may be ridden-in by an adult before being ridden by a child. In addition, in the current study, saddles that were sufficiently large for rider VH would have extended beyond the eighteenth thoracic vertebra in all the horses. It has been generally accepted that a tree should not extend beyond the eighteenth thoracic vertebra (Harman 2005; Schleese 2014), although there is a growing opinion which needs scientific validation, that to extend to the second lumbar vertebra may be acceptable. With custom-designed saddles, the seat of the saddle may be manufactured to extend

beyond the length of the tree, allowing a large rider to sit more centrally in the seat of the saddle.

In the current study, all trot was performed 'rising'. Using objective gait assessment, there are detectable differences in hindlimb movement symmetry in horses ridden in rising trot compared with sitting trot, in both straight lines and circles (Persson-Sjodin *et al.* 2018) and, in rising trot, in circles compared with straight lines (Robartes *et al.* 2013). We mandated the use of rising trot in our study because: (i) the horses were not used to being ridden continuously in sitting trot and the riders did not ride daily for long periods in sitting trot; (ii) the majority of riders in English saddles (except dressage riders) ride predominantly in rising trot. Moreover, the purpose of the study was to determine if there were consistent measurable differences in equine gait among the riders; mandating that all riders sat on the same diagonal reduced the potential for inconsistencies among riders.

The study design tested each horse's ability to perform a 30-min test, predominantly at trot and canter, which their owners were confident they would be able to achieve. However, the high BCS of Horses 3 and 5 (8.0 and 7.5 respectively) could have influenced their performance. Retrospectively, fitness for the work performed was considered adequate for Horses 1, 2, 4 and 6 and borderline for Horses 3 and 5. Nonetheless, Horses 3 and 5 were able to complete a test with riders L or M on the same day on which a test was abandoned and recovery data did not differ among horses (full results reported separately). The BCS of Horses 3 and 5 had increased in the 6 weeks' interval since selection for the study. Had Horses 3 and 5 been of a lower BCS, the rider:horse bodyweight ratios for these horses would have been higher. Owners, however, should be dissuaded from increasing horse bodyweight to reduce rider:horse bodyweight ratios.

In previous studies that demonstrated changes in gait in association with additional weight (Matsuura *et al.* 2013a,b, 2016; Gunnarsson *et al.* 2017), the weight difference was achieved using a single experienced rider with added lead

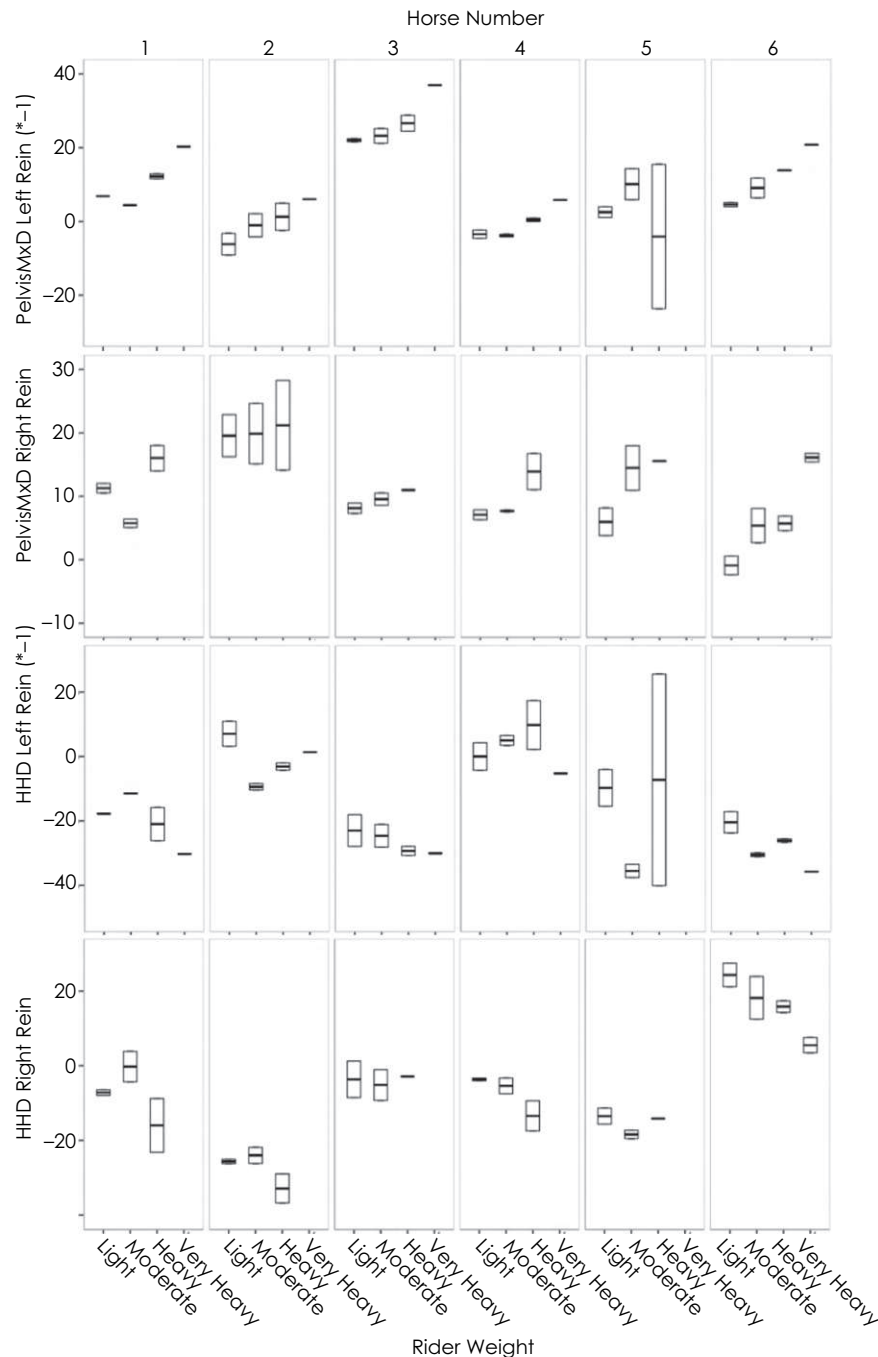


Fig 3: Inertial measurement unit data (mm) for Pelvis Maximum Difference (PMxD) and Hip Hike Difference (HHD) among six horses (1–6) and four riders of different bodyweights, light (L), moderate (M), heavy (H) and very heavy (VH), when trotted on the left rein when moving in straight lines around the periphery of the arena (*Data transformed by multiplying by -1 , so that data from the left and right reins can be compared without showing direction of asymmetry; Starke et al. 2012c). These box and whisker plots show the median (solid line) and interquartile range (box) which includes 50% of the values, and maximum and minimum values (=whiskers), excluding outliers.

weights, rather than riders of different weights. Cross spectrum analysis of accelerometer data acquired from horses' chests was used to assess gait symmetry and stability of rhythm in Japanese native horses (mean bodyweight, 340 kg) and Taishuh ponies (mean bodyweight, 232 kg) carrying total loads of 80–130 kg (24–38% of bodyweight) and 70–120 kg (30–52% of bodyweight) respectively (Matsuura et al. 2013a,b). The test

took place at walk and trot only, over a short distance (40 m). In the Japanese native horses, trot symmetry at 100 kg was less than at 80 kg and it was concluded that the maximum permissible load should be <100 kg (i.e. <29% of horse bodyweight). In the Taishuh ponies, gait rhythm slowed with heavier weights and it was concluded that the maximum permissible load should be ≤100 kg (i.e. ≤43% of horse

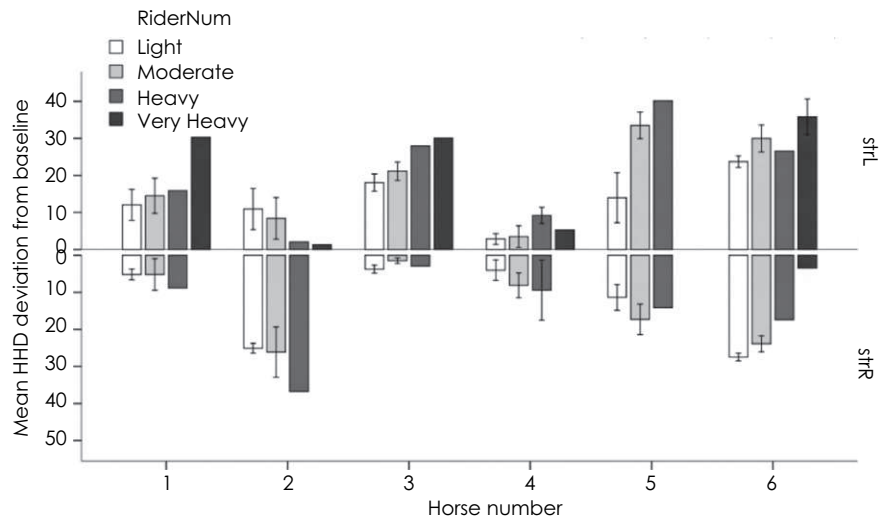


Fig 4: Inertial measurement unit data for Hip Hike Difference showing mean ($\pm$ standard error) deviation from baseline (perfect symmetry) for six horses when ridden by four riders of different bodyweight on the straight on the left rein (strL) or right rein (strR). The reins are 'mirrored' to allow better assessment of symmetry between reins within horses and riders.

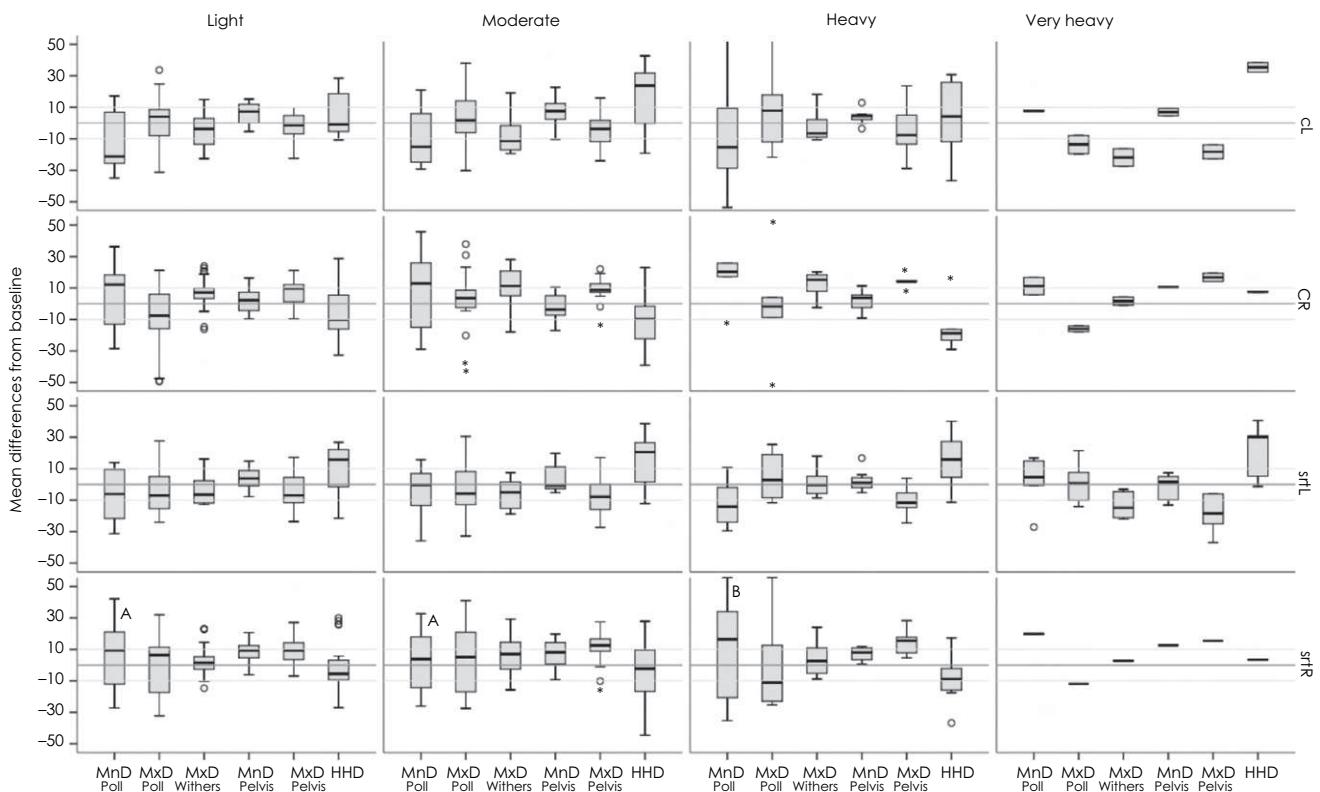


Fig 5: Mean inertial measurement unit data for Poll Minimum Difference (PollMnD), Withers Maximum Difference (WithersMxD), Pelvis Minimum Difference (PelvisMnD) and Maximum Difference (PelvisMxD) and Hip Hike Difference (HHD) for six horses ridden on the left (L) or right (R) reins on the straight (str) or in a circle (c), with four riders of different bodyweights (Light, Moderate, Heavy, Very Heavy). Superscripts not shared among riders within a row indicate significant differences for that measure between riders ($P < 0.05$, mAnova).

bodyweight). These studies, performed over very short periods, assume that gait symmetry and rhythm would not alter over longer periods of work with these weight ratios. In contrast, our data showed major gait asymmetries, especially with rider VH, despite substantially lower load:horse bodyweight ratios,

possibly reflecting the distribution of the load or the longer duration of exercise.

In a study of eight Icelandic horses carrying 20, 25, 30 and 35% of their own bodyweight (single professional rider-plus-lead) at the tölt, kinematics were measured using a high-

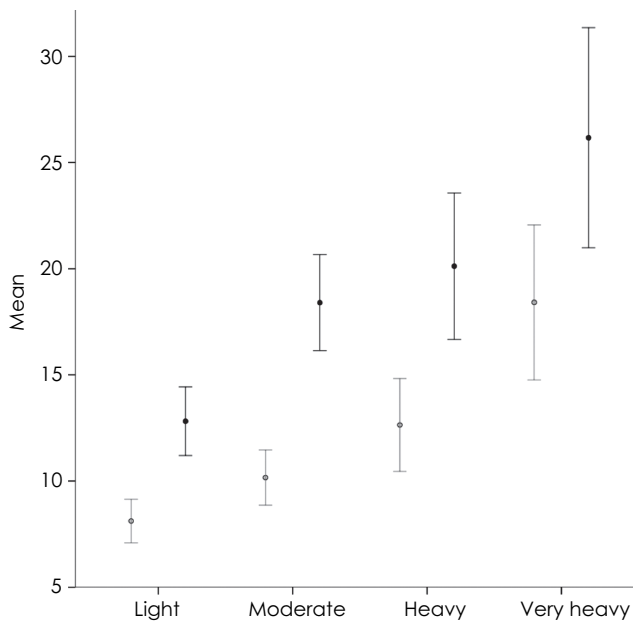


Fig 6: Mean ($\pm$ standard error) asymmetry differences (nondirectional) for six horses ridden by four riders of varying weight (Light, Moderate, Heavy and Very Heavy) when ridden on the left rein (straight line and circle data). Data are shown for hip hike difference (HHD, open circles and grey bars) and for pelvis maximum difference (PMxD, black circles and black bars) and show the correlation with the rider bodyweights (HHD, $P < 0.01$, $R^2 = 0.4$; PMxD, $P < 0.05$, $R^2 = 0.4$).

speed camera in an incremental exercise test (5×642 m; Gunnarsson *et al.* 2017). Although, in contrast to the current study, there were no measurable changes in rhythm or symmetry, increasing weight was associated with decreased stride length and increased stride frequency and duty factor in all limbs, factors not assessed in our study.

In the current study, we observed lameness in most of the horses when being ridden, which had not been apparent in hand, as has previously been documented (Dyson and Greve 2016). However, when present, lameness was usually low-grade ($\leq$ grade 2/8) and transient with the lighter riders (L, M) and was deemed acceptable for continued work. We also observed some variations in lameness induction among the different riders with respect to limb and grade; however, the heavier riders (H, VH) consistently induced more severe lameness than the lighter riders (L, M). This may be influenced by the fit of the saddle to the rider and by resultant differences in weight distribution.

There is limited information about the influence of different riders riding the same horse in succession. The effect of a novice rider versus an experienced dressage rider of similar bodyweight (65 kg) was compared in sitting trot on lame horses; there was an increase in hindlimb lameness with the dressage rider (Licka *et al.* 2004), perhaps because the more skilled rider asked for increased engagement of the hindlimbs. Forelimb or hindlimb lameness that was apparent in hand altered with a rider in an unpredictable way, sometimes becoming unapparent (Licka *et al.* 2004). In the current study, low-grade lameness that was apparent in hand was not necessarily detectable when ridden. Moreover, the more severe lameness induced by the H and VH riders was

temporary: lameness which developed during the test had resolved when assessed in hand within 45–60 min of test abandonment and all horses finished the study moving as well or better when ridden than they had begun, assessed both subjectively and objectively. Rider ability was standardised according to published definitions (Williams and Tabor 2017). We do not believe that a horse's behaviour as assessed using the ridden horse ethogram will alter with an unfamiliar, skilled rider; the test riders were more highly skilled than the horses' normal riders. The ridden horse ethogram was retrospectively applied to video recordings of predetermined sections of every test; the total scores were significantly higher for rider VH vs. all other riders, and for rider H vs. rider M (Dyson *et al.* 2018c).

In the current study, both subjectively and objectively determined gait asymmetry were influenced by the biomechanical effects of a change in load. As discussed above, further investigation is required to determine whether magnitude of load, load distribution (data to be reported in a separate publication), or both were the primary drivers of increased gait asymmetry. The adverse effects of the change in loading were particularly apparent with rider VH. A variety of studies have assessed the biomechanical effects of loading that may potentially influence lameness development. The effect of a 75 kg load (de Cocq *et al.* 2004) or a rider (Schamhardt *et al.* 1991; Clayton *et al.* 1999) on the gait of nonlame horses was investigated kinematically on a treadmill (de Cocq *et al.* 2004) and overground (Schamhardt *et al.* 1991; Clayton *et al.* 1999). Extension of the thoracolumbar region increased at walk, trot and canter with a rider compared with nonridden, although thoracolumbar range of movement did not change and there were no major changes in limb kinematics (de Cocq *et al.* 2004). However, there was greater extension of the metacarpophalangeal joints in trot in ridden compared with nonridden horses (Clayton *et al.* 1999). The presence of a rider increased ground reaction forces (GRFs) more in forelimbs than in hindlimbs, although a rider resulted in alteration of the centre of mass towards the hindlimbs compared with a static load of the same weight (Schamhardt *et al.* 1991). This highlights the importance of conducting weight-carrying investigations with riders rather than dead weights.

We chose riders of different weights, rather than adding static load, because this is a more realistic representation of what happens when riders of varying size ride horses. Force is the product of mass and acceleration and heavier riders will therefore be associated with larger forces. In addition, with a larger rider, the forces are unlikely to be ideally distributed because the saddle may not fit the rider. This mimics what happens in some branches of equestrianism (e.g. riding schools, trekking centres, adults riding children's ponies). The position of a rider is affected by many factors, including the saddle seat length, the position of the stirrup bars, the size and shape of the saddle flaps and the position and size of knee rolls and thigh blocks (Harman 2005; Schleese 2014). Rider position and thus force distribution will also be influenced by the rider's core strength, limb muscle strength and coordination and balance (Peham *et al.* 2001, 2004; Lagarde *et al.* 2005; Bogisch *et al.* 2014), features that were not assessed in the current study.

Rider position when horses are stationary may change when the horse is in motion (Meyners 2004); detailed analysis of rider position during the tests is reported separately. If riders

cannot sit in a balanced position with their shoulder, 'hip' and heel consistently in vertical alignment (as in this study for riders H and VH [Fig 1]) and in the correct place relative to the horse's centre of gravity, this has implications for both rider balance and force distribution. Moreover, if large riders ride relatively small horses, it may not be possible to find a saddle that has sufficient seat length for the rider, a tree that does not extend beyond the eighteenth thoracic vertebra (Harman 2005; Schleese 2014) and that allows the rider to be positioned correctly and as close as possible to the horse's centre of gravity. The seat of the VH rider extended beyond the cantle of the saddle in all horses and none of the horses could have accommodated a saddle of longer length. Custom-made saddles can be manufactured with a standard tree length but longer panels and seat, to accommodate larger riders. Using such a saddle with a larger horse, it should have been possible to achieve adequate saddle fit for the VH rider.

There is a positive relationship between speed and the forces between the rider, saddle and horse (Peham *et al.* 2010). With increased speed at trot, peak forces increase in association with increased vertical oscillation of the equine thoracolumbar region, higher GRFs and decreased range of motion of the thoracolumbar region. Increased load results in increased extension of the thoracolumbar region in walk, trot and canter (de Cocq *et al.* 2004). In the current study, no horse reached the criteria for abandonment in walk, but rider H was stopped in the first trot phase in four tests, the second trot phase in one test and in the first canter on Horse 1. The tests for the VH rider were abandoned six times in the first trot phase and once in the second trot phase. If a horse is only worked at walk it may be reasonable that it carries a heavier weight than if worked at faster gaits.

The abandonment criteria were predefined to protect the horses' welfare and of necessity were subjective to provide rapid decisions. It had not been anticipated that such a high proportion of the tests for riders H and VH would be terminated. The assessor could not be blinded and there is a clear potential for bias. However, each lameness was clear to see for all observers (equine veterinarians), and all subjective lameness-based test abandonment decisions were verified by retrospective analysis of IMU data. In terms of the subjectivity of the real-time assessment of behaviour, the ability of a trained assessor to accurately identify behaviour in real time is supported by comparison of real-time findings and retrospective analysis of video recordings (Dyson *et al.* 2020).

A high proportion of ill-fitting saddles in the general horse population has been reported previously (Greve and Dyson 2014, 2015). In the current study, despite attempts to improve the fit of owners' tack prior to the study, saddle fit to the horse was not perfect, but was considered adequate for the purposes of the investigation. Although previous work shows that ill-fitting saddles have the potential to adversely affect force distribution and magnitude (de Cocq *et al.* 2006; Meschan *et al.* 2007; Kotschwar *et al.* 2010; von Peinen *et al.* 2010) and equine performance (Greve *et al.* 2015), the horses performed satisfactorily with riders L and M. There were recurrent problems with saddle slip to the right in Horses 3 and 5, both of which had a recent increase in BCS. Horse 3's tests were abandoned for left hindlimb lameness on three occasions and this horse showed consistently measurable asymmetry in push-off of the hindlimbs. The presence of

subclinical lameness, combined with a round back shape at the level of the thirteenth and eighteenth thoracic vertebrae associated with a high BCS, were likely contributing factors (Greve and Dyson 2013a; Greve and Dyson 2014). In future studies, we recommend the use of a panel of professional saddle fitters to facilitate ideal saddle fit.

The Horse 1:rider H test was abandoned because the horse displayed 10 behavioural markers of pain. We have previously demonstrated that the display of ≥ 8 of 24 behavioural markers is likely to reflect the presence of musculoskeletal pain (Dyson and Van Dijk 2020; Dyson *et al.* 2018a,b). For the purpose of test abandonment in the current study, we used a cut-off of ≥ 10 of 24 behavioural markers. The application of the ethogram in real time may result in underscoring, because some features (e.g. eye closure) may be more difficult to determine than during assessment of video recordings. Detailed analysis of the behaviour of all horses throughout the study will be reported separately, as will data on salivary cortisol concentrations, pulse and respiratory rates, blink rate, forces under the saddle, thoracic dimensions and response to thoracolumbar palpation.

There are anecdotal suggestions that horses with greater circumference of the metacarpal region (i.e. more 'bone') are capable of carrying more weight than horses with less 'bone'. In a study of eight unfit horses ridden by one of three experienced riders plus lead (total weight, 15, 20, 25 and 30% of horse bodyweight), metacarpal region circumference was negatively associated with muscle soreness and tightness after a 45-min exercise test (Powell *et al.* 2008). However, this study was of low power and therefore the conclusions are questionable. In the current study, Horse 5 had a metacarpal circumference of 29 cm which was larger than all the others (19–23 cm); however, all horses failed to complete the test with riders H and VH. No conclusions can be drawn without a study of sufficient power specifically designed to investigate the influence of metacarpal region circumference on load-carrying capacity.

The results of our study are not necessarily applicable to lower level activity (e.g. hacking at the walk) compared with the 30-min test predominantly in trot and canter, nor to more fit animals, nor those that have been slowly adapted to weight-carrying. It has been suggested that fit, appropriately conditioned Arab endurance horses are able to carry 20–30% of their body weight for 100 miles (Garlinghouse and Burill 1999). Similarly, the results of the current study cannot necessarily be transferred to more intense work (e.g. working at faster speeds, on undulating terrain or jumping), or work of longer duration.

In conclusion, we have clearly demonstrated deleterious effects of inappropriate rider size on equine gait and behaviour. The results suggest that any adverse influence of less than ideally fitting tack for horse or rider may be accentuated by riders who are heavier and/or taller. The results of this study do not mean that heavy or tall riders should not ride, but suggest that, if they do, they should ride a horse of appropriate size and fitness, with a saddle that is correctly fitted for both horse and rider. Further work is, however, required to determine if horse fitness, greater metacarpal region circumference, breed, adaptation to heavier weights and more ideal saddle fit will increase the weight that individual horses can carry.

Authors' declaration of interests

No conflicts of interest have been declared.

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Authorship

The idea for the study was conceived by S. Dyson and P. Harris. The study was designed by S. Dyson, P. Harris, A. Ellis, J. Douglas and A. Bondi, and was performed by all authors. Statistical analysis was performed by A. Ellis. The subjective data were interpreted by S. Dyson and P. Harris. S. Dyson, P. Harris and J. Douglas wrote the paper, which was approved by all authors.

Manufacturers' addresses

¹Xsens, Enschede, The Netherlands.

²Awinda, Xsens, Enschede, The Netherlands.

³The Mathworks Inc., Natick, Massachusetts, USA.

⁴Pliance®, Novel GmbH, Munich, Germany.

⁵Visualise Technical Sportswear, Moreton Morrell, Warwick, UK.

⁶Polar ProTrainer 5, Polar, Kempele, Finland.

⁷IBM Corporation, Armonk, New York, USA.

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Supporting information

Additional Supporting Information may be found in the online version of this article at the publisher's website:

Supplementary Item 1: Additional measurements and recordings made on the day prior to the study

Supplementary Item 2: The test performed by each horse-rider combination

Supplementary Item 3: The ridden horse behaviour ethogram (from Dyson *et al.* 2018a) that was applied to all horses.

Supplementary Item 4: The horses' usual riders' height (cm), bodyweight (estimated by rider; kg) and body mass index (BMI) (kg/m²), horse bodyweight (kg) and usual rider:horse bodyweight ratio for the six test horses (1-6).

Original Article

Heineke–Mikulicz pyloroplasty for the treatment of pyloric stenosis secondary to gastro-duodenal ulcer disease in three foals

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Keywords: horse; pyloroplasty; gastric; outflow; obstruction

Summary

The objective of the study was to describe a modified Heineke–Mikulicz pyloroplasty for the treatment of pyloric stenosis in foals due to gastric ulceration and assess the short- and long-term outcome of foals receiving the pyloroplasty. Medical records of foals undergoing a modified Heineke–Mikulicz pyloroplasty due to gastric outflow obstruction secondary to a pyloric stenosis were included in this retrospective case series. The pyloroplasty consisted of an oral to aboral full thickness longitudinal incision on the ventral aspect of the pylorus and proximal duodenum, which was sutured closed with 0 polydioxanone in a transverse orientation, thereby, enlarging the pyloric lumen diameter. Long-term outcome was obtained from medical and race records. The pyloroplasty was successfully performed in three foals with a surgical time of 95–121 min, with immediate return to nursing and hospital stay of 4–14 days. Complications included a small intestinal volvulus and intra-abdominal adhesions in a foal that did not survive. Another foal had an incisional infection. Two of the three foals went on to race. It was concluded that the pyloroplasty procedure is an acceptable option for the treatment of pyloric stenosis and secondary gastric outflow obstruction due to gastric ulceration. The limited amount of bowel manipulation with no change in intestinal flow, along with the successful outcomes achieved, make this another surgical option available for the correction of pyloric stenosis in foals.

Introduction

Gastroduodenal ulcer disease (GDUD) in foals have four distinct presentations; silent (subclinical), active (clinical), perforated or strictures from healing ulcers (Becht and Byars 1986). The reported prevalence of glandular or duodenal ulcers in foals at post-mortem is 12% (Elfenbein and Sanchez 2012). The healing process can cause pyloric or duodenal stenosis, which in turn can lead to gastric outflow obstructions. Conditions associated with gastric outflow obstructions include severe gastric ulceration, oesophagitis, aspiration pneumonia, gastro-oesophageal reflux and cholangitis (Andrews and Nadeau 1999). Pyloric strictures seen in foals are rare and are typically seen in 3- to 5-month-old foals, and infrequently in yearlings (Becht and Byars 1986). Diagnosis of gastric outflow obstructions with pyloric or duodenal stenosis involves performing investigative procedures including gastroscopy examination (Murray 1989; Murray *et al.* 1990), an upper gastrointestinal barium study (Campbell *et al.* 1984) and evaluating the stomach and duodenum with ultrasonography (Bain 2012).

If a foal fails to respond to medical management, treatment options for gastric outflow obstructions consist of

different surgical bypass procedures as well as a pyloroplasty, with the aim to restore gastric emptying. Depending on where the stricture causing the gastric outflow obstruction is located, a gastroduodenostomy, a gastrojejunostomy, with or without a jejunojejunostomy, and a duodenojejunostomy have been performed. The most recent reports of the bypass procedures in foals have shown improved outcomes with 50–67% surviving to racing age compared with previous studies (Campbell-Thompson *et al.* 1986; Orsini and Donawick 1986; Barr 2006; Coleman *et al.* 2009; Zedler *et al.* 2009). In 1980, it was reported that a Heineke–Mikulicz pyloroplasty, in which the stricture was enlarged by suturing a longitudinal incision transversely with 0 polyglycolic acid, successfully corrected pyloric stenosis in a 2-month-old foal (Barth *et al.* 1980). Despite this good outcome, no other cases treated with this procedure have been reported in the literature to the best of our knowledge.

When performing a Heineke–Mikulicz pyloroplasty, normal gastro-intestinal flow is maintained, unlike the bypass procedures previously mentioned. It is the author's clinical impression that the procedure is also less technically demanding than bypass procedures, making it a more favourable management option. The purpose of the following case series is to describe a Heineke–Mikulicz pyloroplasty procedure and the short- and long-term outcomes of the foals treated using this surgical technique.

Materials and methods

Medical records between 2001 and 2017 from Peterson and Smith Equine Hospital were reviewed, and foals treated with a Heineke–Mikulicz pyloroplasty due to gastric outflow obstruction secondary to pyloric stenosis were included. From the medical records, signalment, history, physical examination findings, diagnostic tests and their results, medical treatment, surgical findings, procedure and complications were recorded. Also, surgical time, length of hospital stay and post-operative treatments were recorded.

Diagnostic tests included bloodwork, transabdominal ultrasonography, gastroscopy and gastrointestinal barium studies (5 mL/kg of a 30% wt./vol. barium suspension via a nasogastric tube [Campbell *et al.* 1984]). Standing right lateral radiographs (typical settings 80 kVp, 0.20 mAs) and recumbent lateral radiographs were taken at designated time intervals over 2 h post-barium administration. Gastric outflow obstruction secondary to pyloric stenosis was suspected if minimal to no contrast was observed in the duodenum after 30–120 min (Campbell *et al.* 1984). Gastroscopy was used to examine the severity of gastric ulcers, presence of oesophagitis

and pyloric contractions. Ultrasound was used to assess stomach and duodenal motility, distention and thickening.

Preoperatively the patients were refluxed and administered flunixin meglumine (1.1 mg/kg bwt i.v. once) or firocoxib (0.3 mg/kg bwt i.v. once and continued at 0.1 mg/kg bwt i.v. every 24 h for 2 days), gentamicin (6.6 mg/mg bwt i.v. every 24 h for 5 days) and potassium penicillin (22,000 IU/kg bwt i.v. every 6 h for 5 days). The foals were sedated and anaesthetised with xylazine (0.8 mg/kg bwt i.v.), ketamine (2 mg/kg bwt i.v.) and midazolam (0.08 mg/kg bwt i.v.), then continued on inhalational anaesthesia (isoflurane). Anaesthetised foals were positioned in dorsal recumbency, aseptically prepared for a ventral midline celiotomy, starting 2 cm caudal to the xiphoid process and extending 20 cm caudally.

The abdomen was briefly explored and the stomach, pylorus and duodenum were palpated to determine patency and to examine for evidence of fibrosis and stenosis. Once pyloric stenosis was confirmed as the only cause of the delayed gastric emptying, a pyloroplasty was performed. Any remaining gas and fluid were suctioned out of the stomach via a 16 gauge needle. The pylorus was isolated from the abdomen with saline soaked sponges and suction maintained adjacent to the pylorus to minimise peritoneal contamination. Two 2-0 polydioxanone (PDS) stay sutures were placed through the serosal and muscularis layers on the ventral half of the pyloric sphincter, 2 cm apart. A full thickness 4 cm longitudinal incision was made through the ventral pylorus and proximal duodenum, extending orad to aborad between the stay sutures (Fig 1). The gastric veins and short gastric arteries were avoided and the incision was centred over the pyloric sphincter. Traction was maintained on the stay sutures to prevent spillage and the longitudinal incision was converted to a transverse opening by retracting the stay sutures apart. Four to eight single-layer, full thickness simple interrupted 0 PDS sutures were placed between the oral and aboral side of the now transverse orientated incision, starting at the centre (the initial commissures of the incision). Patency of the newly formed opening was determined with digital palpation through the sphincter. The closure was examined for leakage by manually lightly pressurising the lumen and the abdomen was lavaged with saline and heparinised saline (20,000 IU/L). An omentectomy was performed with transfixing ligatures of 0 polydioxanone. The abdomen was closed in three layers, linea alba, subcutaneous tissue and skin, all with a simple continuous pattern, using 2 polyglactin 910, 2-0 poliglecaprone 25 and 0 poliglecaprone 25 respectively.

Post-operatively the foals were monitored for nursing and faecal output. Their physical parameters were recorded every 4 h. Medical management comprised perioperative antimicrobial, gastric ulcer medication, ad libitum nursing and gradual reintroduction of hay.

Outcome

Short-term survival was defined as survival to discharge from the hospital and long-term outcome was defined as achieved intended use. Medical records and race records were used to assess long-term outcome.

Results

Three foals met the inclusion criteria; two Thoroughbred foals and one Warmblood foal. In all foals, medical therapy was unsuccessful and surgical intervention elected, at which point

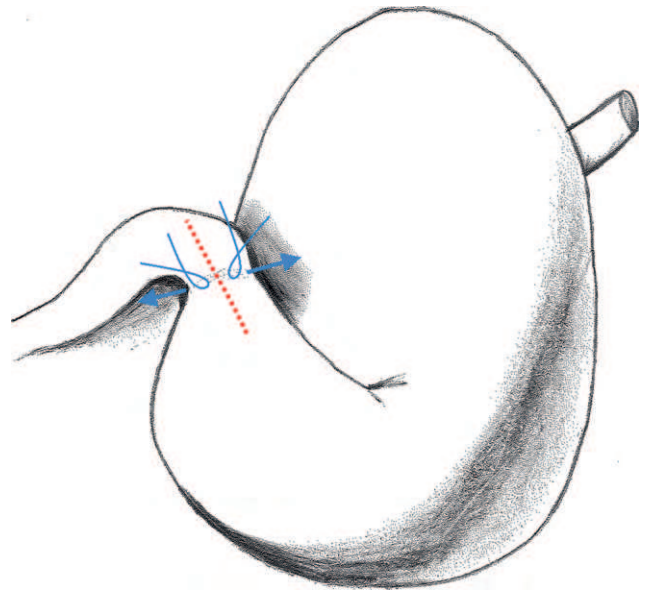


Fig 1: Illustration of the ventral view of the equine stomach and duodenum. The position of the stay sutures is indicated (loops) on the ventral pyloric sphincter and the location of the pyloroplasty incision is drawn on the ventral aspect of the pylorus and proximal duodenum, centred over the pyloric sphincter (dotted line). The arrows indicate the direction in which traction is applied to the stay sutures to convert the longitudinal incision to a transverse orientation.

their ages ranged from 102 to 168 days. These three foals are the only foals that underwent surgery in this time period to correct a gastric outflow obstruction. All three foals survived to discharge with two surviving long term and returning to intended use.

Foal 1

A 145-day old 206 kg Thoroughbred filly presented with a 1-month history of mild recurrent colic signs and diarrhoea. At presentation the filly was acutely colicky with spontaneous brown reflux, diarrhoea, bruxism, tachycardia and hypersalivation. All other physical examination findings were within normal limits. Clinical pathology revealed mild leucocytosis ($14.3 \times 10^9/L$; range $5-12.0 \times 10^9/L$) and mildly elevated bilirubin ($54.7 \mu\text{mol/L}$; range $0-34.2 \mu\text{mol/L}$). The foal resented the nasogastric tube being passed and spontaneously refluxed 4 L of brown/red material. Gastroscopy revealed grade 3 nonglandular ulcers, glandular ulcers in the cardia, oesophagitis and a subjectively narrowed pylorus. During the gastrointestinal tract barium radiographic study, no movement of barium into the duodenum was seen after 2 h (Fig 2). Ultrasonography of the duodenum demonstrated normal thickness and motility. The investigative findings of no movement of barium, gastric ulcers and a narrowed pylorus in a foal presenting with acute colic and abnormal clinical signs on a background of subacute colic indicated pyloric stenosis as the likely cause of delayed gastric emptying. Medication for gastric ulcers during hospitalisation included; minocycline hydrochloride 100mg capsules¹, (4 mg/kg bwt orally every 12 h), misoprostol 200 mcg tablets², (3 $\mu\text{g/kg}$ bwt orally every 8 h), sucralfate 1g tablets² (20 mg/kg bwt orally every 8 h), ranitidine 150mg tablets³ (1.1 mg/kg bwt i.v. every 8 h), aluminium and

magnesium antacid (30 mL orally every 6 h) and a probiotic (Full bucket equine probiotic granules⁴) containing *Saccharomyces boulardii* 1079, *Lactobacillus rhamnosus* and L-Glutamine (40-billion CFUs orally every 12 h).

An exploratory celiotomy was performed 3 days after admission once the foal had been stabilised with i.v. isotonic fluid therapy (40 mL/kg/day) and gastric decompression. In surgery the pylorus was firm on palpation with a narrowed diameter, unable to externally digitally palpate through the pylorus. A pyloroplasty was performed as described above. Surgical time was 111 min and the filly recovered well.

For the first 24 h post-operatively, the filly was on a liquid diet composed of nursing and water. A nasogastric tube was then passed to ensure no reflux and free choice forage was added to the diet. The foal was discharged 4 days post-operatively, stall rested for 2 weeks and prescribed sucralfate, ranitidine and antacid for 30 days along with minocycline for 2 weeks, doses as previously described. Gastric and oesophageal ulcers were resolved at the 4-week gastroscopy. Review at 10 months post-operatively demonstrated that the foal was training and in good body condition, however, infrequent mild colic episodes were noted. Recheck gastroscopy at that time demonstrated no evidence of gastric ulcers and normal pyloric structure and contractions. The filly raced as a 2-year-old.

Foal 2

A 102-day-old 150 kg Warmblood filly in good body condition presented with acute colic signs which were unresponsive to medical management. As a neonate the foal was treated for severe dehydration, and had a positive sepsis score (Brewer *et al.* 1988) and diarrhoea. Over the following 3 months, the foal demonstrated signs of colic on six separate occasions. Clinical signs seen at each presentation for colic were rolling, gas distention, tachycardia, fever, bruxism and hypersalivation. Nasogastric intubation at each admission would obtain 4–8 L of sour, reddish-brown, sand-containing reflux. At the first examination for colic signs (3 weeks of age), gastroscopy demonstrated diffuse glandular and nonglandular gastric ulcers (Fig 3), oesophagitis, an enlarged stomach and constricted

pylorus. An upper gastrointestinal barium study showed minimal emptying of the barium from the stomach at 2 h enabling a diagnosis of delayed gastric emptying. Two repeat barium studies, at 8 and 14 weeks of age continued to demonstrate the same findings but no defined stricture. Serial ultrasound examinations of the duodenum were within normal limits. Medical management included ranitidine, gastrogard (Omeprazole⁵), sucralfate, minocycline, equate maximum strength antacid oral suspension (Alumina, Magnesia and Simethicone⁶), bethanechol 10 mg/mL suspension⁷ (0.03 mg/kg bwt i.v. or orally every 8 h) and a probiotic, doses as previously described. With delayed gastric outflow still present and colic episodes still reoccurring, it was evident that the delayed gastric emptying had not clinically improved over the preceding 11 weeks, and therefore, surgical intervention was undertaken.

Palpation of the pylorus during the exploratory celiotomy revealed hemi-circumferential hardening consistent with fibrosis, however, the remaining small intestine appeared normal. A pyloroplasty was performed and the surgical time was 95 min. Ad libitum nursing was initiated for the initial 36 h after surgery before introducing free choice hay. Post-operatively for the first 24 h the filly was lethargic with pain elicited on palpation of the incision. During this time the foal nursed well and was passing manure. The foal was discharged 4 days post-operatively and was continued on gastroprotectant medications (ranitidine, sucralfate, omeprazole, probiotic and bethanechol).

Twenty-four days post-operatively the foal presented with acute signs of colic. Distended small intestine was seen on ultrasound and the peritoneal fluid was serosanguinous and turbid (total nucleated cell count $0.3 \times 10^9/L$, total protein 20 g/L, lactate 6.8 mmol/L). Repeat exploratory surgery revealed a small intestinal volvulus involving the distal jejunum and ileum, and a mature fibrous adhesion between the caecum, duodenum and dorsal colon, not associated with the pylorus (aborad and lateral to the pyloroplasty surgical site). Due to the poor prognosis for an uncomplicated survival, the foal was subjected to euthanasia.

Foal 3

A 168-day old 180 kg Thoroughbred filly presented with colic, after being seen previously on two occasions over a 12-week period, for gastroscopic examination and treatment of gastric ulcers. Medical management during the previous visits included bethanechol, omeprazole, ranitidine, sucralfate, doxycycline hyclate 100 mg tablets⁸ (10 mg/kg bwt orally every 12 h) and metronidazole 500 mg tablets⁹ (15 mg/kg bwt orally every 12 h). On admission the filly was depressed, with hypermotile borborygmi and bruxism. During gastroscopy severe glandular and nonglandular ulcers were identified concentrated around the pylorus with secondary oesophagitis. A barium study confirmed no gastric outflow of barium after 2 h. Thoracic radiographs demonstrated no abnormalities. Initial therapy at admission, prior to surgery, consisted of isotonic i.v. fluids, bethanechol, omeprazole, ranitidine, sucralfate and metronidazole. A firm, narrow pylorus was palpated on exploratory celiotomy, therefore, a pyloroplasty was performed. Surgery time for the pyloroplasty procedure was 120 min and the filly recovered uneventfully. The filly was allowed to nurse post-operatively and hay was incorporated into the diet 24 h after surgery. An incisional infection developed which was opened and allowed to drain 9 days post-operatively. The foal was treated systemically empirically with doxycycline enabling

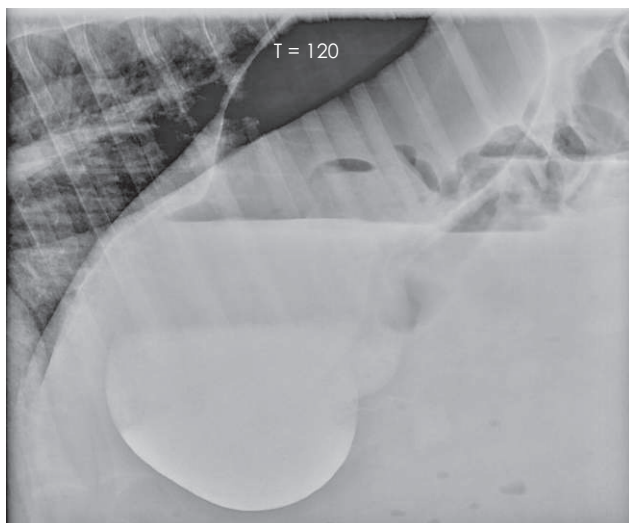


Fig 2: Right lateral abdominal radiograph 2 h after barium administration, showing no movement of the barium from the stomach and an enlarged stomach in Foal 1.

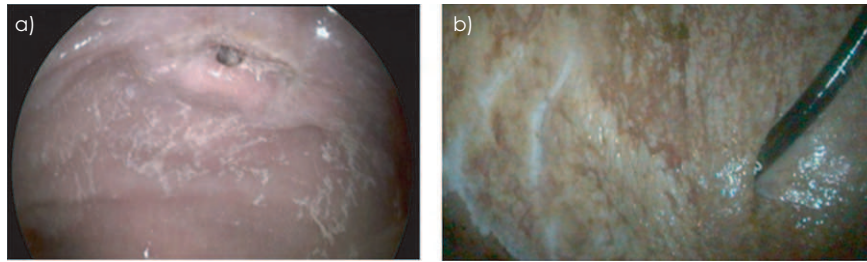


Fig 3: Abnormal partially constricted amotile pylorus a) and diffuse nonglandular ulcers in the dorsal squamous fundus b) of Foal 2. The gastroscope could not be advanced due to a small-sized pylorus.

discontinuation of i.v. perioperative antimicrobial therapy. Fourteen days after surgery the foal was discharged on omeprazole, sucralfate for 4 weeks and doxycycline and bethanechol for 2 weeks. Following discharge, recheck gastroscopy at 4 months showed the gastric ulcers had healed and the pyloric opening and contractions were normal. The filly's racing career consisted of five starts. She was then used for breeding.

Discussion

This case series describes the use of a pyloroplasty to surgically manage pyloric stenosis in foals. Pyloric stenosis is a relatively uncommon condition with few cases being described in the literature. In a previous report, eight of the 40 foals requiring a gastroduodenostomy/gastrojejunostomy procedure in the 18-year period solely had pyloric stenosis (Zedler *et al.* 2009). The foals in this current study had a history of recurrent of colic, with two foals having been initially treated medically for gastric ulcers and dysmotility. Failure to respond to medical therapy prompted surgical intervention. The surviving foals went on to race and at follow-up gastroscopy had complete resolution of the gastric ulcers. In previous reports, the gastroduodenostomy procedure success rates for pyloric stenosis vary from 50 to 100% long-term survival with most recent studies reporting 100% long-term success in eight foals with pyloric stenosis (Zedler *et al.* 2009). One foal in our study was subjected to euthanasia due to a small intestinal volvulus and intra-abdominal adhesions. This lowered our long term success but the findings during the second exploratory celiotomy were deemed unrelated to the pyloroplasty procedure. The adhesions were not present at the enterotomy site and it was deemed unlikely a small intestinal volvulus is related to enlarging the pylorus.

Complications encountered included intra-abdominal adhesions, small intestinal volvulus and an incisional infection. Adhesions can form after intestinal manipulation and if the abdomen is exposed to contaminants. Foals are more likely to form intra-abdominal adhesions after abdominal surgery compared with yearlings (Sanschi *et al.* 2010) or adults (Phillips and Walmsley 1993; Mair and Smith 2005) and adhesions are one of the most common post-operative complications post exploratory laparotomy (Phillips and Walmsley 1993). An omentectomy was performed as well as intra-peritoneal lavage with heparin, but other adhesion limiting modalities such as utilising sodium carboxymethyl cellulose intraperitoneally and/or sodium hyaluronate and fucoidans (Munsterman *et al.* 2016) were not used. In foal 2, with the adhesion not occurring at the surgical site, resorbable membranes may not have been beneficial in this

case to limit adhesion formation. The adhesion was not formed of the omentum so this still may have been a positive step taken in these foals especially with its proximity to the surgical anastomosis.

The use of antimicrobials for the treatment of gastroduodenal ulcers is standard practice in human medicine as the aetiology is frequently *Helicobacter pylori* (Malfertheiner *et al.* 2007). There is some evidence to suggest that *Helicobacter* species exist in the gastrointestinal tract of foals but the complete significance is not fully known (Collier and Stoneham 1997). In foals that are unresponsive to initial medical management or have severe ulcerative gastroduodenitis, antimicrobials in addition to the routine acid suppression drugs may be an appropriate treatment choice, given what we already know about human species, for successful treatment of GDUD, despite not yet being supported in the current guidelines (Sykes *et al.* 2015).

The size of the foal and depth of the abdomen dictates surgical access to the pylorus on the dorsal midline, and thus determines the ease of the procedure. The pylorus is relatively accessible in foals and weanlings compared with adults, making this a viable option for the treatment of pyloric stenosis that typically occurs in foals. One author (D.E.S.) however, has performed this procedure successfully in a Thoroughbred yearling. In comparison to Barth where he incised through the hepatoduodenal ligament to mobilise the pylorus (Barth *et al.* 1980), this was not deemed necessary in these foals or the aforementioned yearling, as exposure of the pylorus was adequate and minimal contamination occurred. However, this could be considered in specific cases where exposure is poor. The suture (size and material) differed from the previous case report to limit bacterial wicking and No. 0 compared with No. 1 (Barth *et al.* 1980) seemed adequate to hold the thick inelastic tissue involved in the enterotomy.

Typically, the size of the final pyloric opening is about 1.5 cm (as determined by digital palpation through the pylorus). Mild abdominal contamination may occur during the initial incision into the pylorus, however, this is adequately controlled by prior gastric decompression, isolating the pylorus with sterile sponges, traction on the stay sutures, utilising active suction during the pyloroplasty and suturing in an efficient manner. Intraoperative abdominal lavage before abdominal closure should be performed to remove and dilute fibrin, inflammatory mediators, and potential contaminants (Hague *et al.* 1998).

Post-operatively the foals were allowed to nurse unrestricted and were started on solid feed from 24 to 36 h post-operatively. This is a rapid return to enteral nutrition and no post-operative reflux or ileus was observed in this case series. This is likely due to minimal change in the flow of

gastro-intestinal contents and little intestinal manipulation. There is also no risk of blind loop complications or problems related to bypassing the duodenum such as decrease in weight gain (Coleman *et al.* 2009).

In our experience this procedure is less technically demanding and requires a shorter surgical time than a bypass procedure as it only requires a short enterotomy and a single layer closure, unlike the gastroduodenostomy. Current literature would suggest that the pyloroplasty would be unsuccessful had these foals had a perforated ulcer due to described complications associated with septic peritonitis (Campbell-Thompson *et al.* 1986).

The aim of the study was to describe an acceptable approach to treat gastric outflow obstruction without complete intestinal bypass surgery. The main limitation of this study is the small number of cases. The outcome and limited complications of the pyloroplasty procedure were encouraging, but a larger clinical study is warranted. The Heineke-Mikulicz pyloroplasty used in this case series to correct a stenosis is a suitable alternative to various previously reported bypass procedures for treatment of pyloric stenosis. The pyloroplasty requires less intestinal manipulation, does not alter the route of intestinal contents and is less technically challenging. The effect of the pyloroplasty in the incidence of gastric ulcer or colic predisposition cannot be determined and requires further investigation, but both surviving foals had resolved gastric ulcers at follow-up and went on to race.

Authors' declaration of interests

The authors report no financial or other conflicts related to this report.

Ethical animal research

Not applicable.

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Authorship

A. Kent contributed to study design, study execution, data analysis and interpretation, and preparation of the manuscript. D. Slone contributed to study design and study execution. C. Clark contributed to study execution and data analysis and interpretation. T. Lynch contributed to study design and preparation of the manuscript.

Manufacturers' addresses

¹Aurobindo Pharma Ltd., Hyderabad, India.

²Greenstone LLC, Peapack, New Jersey, USA.

³Amneal Pharmaceuticals Pvt. Ltd., Ahmedabad, India.

⁴Animal Stewards International LLC., Dennis, Texas, USA.

⁵Meril Inc., Duluth, Georgia, USA.

⁶Wal-Mart Stores Inc., Bentonville, Arizona, USA.

⁷Wedgewood Pharmacy, Swedesboro, New Jersey, USA.

⁸Chartwell Pharmaceuticals LLC., Congers, New York, USA.

⁹Frontida Biopharm Inc., Philadelphia, Pennsylvania, USA.

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Review Article

Eosinophils of the horse: Part I: Development, distribution, structure and biochemical mediators

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Keywords: horse; eosinophil; immunology; leucocyte

Summary

Eosinophils are becoming the target of increasing research interest as recent studies suggest that their role in immune homeostasis and the immune response to disease is far more complex than previously understood. Historically, the horse eosinophil has been used to study basic eosinophil biology because of the considerable volume of blood required to obtain enough viable cells for reliable, repeatable experiments. This resulted in a large but disseminated body of literature pertaining to the structure and function of the horse eosinophil. More recently, equine clinicians have produced case reports and clinical studies in an effort to define the role of the eosinophil in diseases of the horse. A thorough review of the equine eosinophil incorporating both bench research and clinical reports does not exist. The objective of this two-part review is to fill this need by integrating the basic science and clinical research into a comprehensive body of work on what is known specifically about the horse eosinophil, and its role in equine health and disease. Part I summarises the development and tissue distribution of eosinophils in the normal horse, and presents what is known about the cell structure, migration and biochemical mediators of the horse eosinophil. Part II reviews the role of the eosinophil in diseases of the horse, and concludes with a summary of knowledge gaps and open research questions to benefit both those who wish to use the equine eosinophil as a model for basic science research, and those whose primary interest lies with diseases of horse.

Introduction

Long relegated to the domain of 'worms and wheezes and weird diseases', the eosinophil now is undergoing more intense scrutiny as recent research suggests that it plays a far more complex role in immunological homeostasis and in disease than previously thought (Bochner *et al.* 2012). Eosinophils have been identified as participants in physiological and pathological processes in reproduction, gastrointestinal function and transplantation, as well as in the response to viral, fungal and bacterial infections (Blanchard and Rothenberg 2009; Ravin and Loy 2016). Immune activity of the eosinophil goes far beyond its classical role as a simple anthelmintic end-effector cell, as it is now known to engage in functions as diverse as antigen presentation, mast cell activation and thymocyte deletion (Rothenberg and Hogan 2006).

The 'granule blood-cells' discovered by Wharton Jones in 1846 (Vaughn 1953) and first described as 'eosinophils' by Paul Ehrlich in 1879 (Kay 2015) proved challenging to study

early on because of the difficulties in obtaining adequate numbers of viable cells to perform experiments. The horse eosinophil became an attractive model because of the horse's considerable size and blood volume, and methods for isolating horse eosinophils were developed and improved upon in ensuing years. Researchers were soon able to obtain large numbers of pure horse eosinophils of sufficient quality to be used in morphological and metabolic studies (Archer 1960; Archer and Hirsch 1963a; Anan and Ozaki 1964; Heyneman *et al.* 1975; Jorg *et al.* 1978). As a result, extensive but widely dispersed data have been amassed on the structure and molecular biology of the equine eosinophil. A significant body of clinical literature including case reports and clinical research arose more recently as veterinary clinicians work to understand the role of the eosinophil in specific diseases of the horse.

Here, we synthesise for the first time in one work the existing basic science research, clinical research and case reports pertaining to the equine eosinophil. Part I reviews the development and distribution of eosinophils in clinically healthy horses, and builds a construct of the equine eosinophil using data generated primarily in laboratory studies and also gleaned from clinical reports. Part II reviews common clinical diseases of the horse in which the eosinophil plays a conventional role, including parasitic, respiratory and other allergic diseases. Less common conditions and those in which a major dysregulation of eosinophil biology is likely are presented next, and finally, rare reports of interest are summarised. We conclude with an integrated summary of knowledge gaps and open research questions that may facilitate the work of both those who wish to use the equine eosinophil as a model for basic science research, and those whose primary interest lies with diseases of horse.

Overview of eosinophil biology

The essential characteristics that define the eosinophil as a distinct cell type are generally similar across species (McEwen 1992; Lee *et al.* 2012). Eosinophils are leucocytes derived primarily from granulocyte precursors in the bone marrow, and rarely from CD34⁺ precursor cells within tissues (Cameron *et al.* 2000). Differentiation of eosinophils is influenced most strongly by interleukin 5 (IL-5). Mature eosinophils spend little time in the bloodstream after leaving the bone marrow, instead homing to their target tissues, most notably the gastrointestinal and reproductive tracts, and the thymus. This migration occurs via cell adhesion molecules (CAMs) in response to chemoattractants, most notably eotaxin (CCL11) acting upon its receptor CCR3, and

regulation on activated, normal T-cell expression (RANTES/CCL5). Many factors including Th2 cytokines other than IL-5, chemokines, and lipid mediators can also influence the development, adherence, migration and activation of eosinophils.

Structurally, eosinophils are characterised by lobular nuclei and the presence of large cytoplasmic granules that stain brightly with aniline dyes. The granules contain effector molecules including major basic protein (MBP), eosinophil peroxidase (EPO), eosinophil cationic protein (ECP) and eosinophil-derived neurotoxin (EDN) (Acharya and Ackerman 2014). The classical function of the eosinophil as an end-effector cell involves release of these toxic granule contents and destruction of a target pathogen, commonly a helminth parasite. Eosinophils also play a prominent, although often not well understood, role in many diseases of the gastrointestinal and respiratory systems, the skin, and other body systems. Dysregulation of the eosinophil response to stimuli is likely a factor in some syndromes in which eosinophils are the predominant cell type (Blanchard and Rothenberg 2009).

While these broad similarities in structure and function are consistent across species, differences do exist at the molecular level, for example in the presence of a specific effector molecule, or in the strength of response to a particular mediator (Sun *et al.* 1991; Lee *et al.* 2012). These nuances may be critical in elucidating a dysfunctional pathway, formulating a new therapeutic protocol, or developing an experimental model. The following sections therefore focus specifically on what is known of the horse.

Lineage and development of the horse eosinophil

Detailed studies of eosinophil development within the bone marrow of the horse have not been identified in the literature, but the emergence of eosinophils in fetal lymphoid organs has been well documented. Eosinophils have been identified in fetal foal thymuses from early thymic development at about 12 weeks gestation through term. The cells are most commonly seen in the interlobular septa and in association with Hassall's corpuscles in the medulla. Both mature cells and myelocytes of the eosinophilic lineage are present, supporting a role for the thymus in early eosinopoiesis (Mackenzie 1975). Following birth, evidence of thymic eosinopoiesis is seen in horses up to about 30 months of age, with eosinophils produced in higher numbers than any other cell except the lymphocyte. Eosinophil apoptosis is observed beginning around 5–7 years of age, and only rarely are eosinophils found in thymuses of horses aged 13 and older (Contreiras *et al.* 2004).

Mature eosinophils are also found in the paracortical areas of fetal mesenteric lymph nodes, but only rarely in the lamina propria of the fetal gastrointestinal tract (Mackenzie 1975).

Fluid and tissue distribution of the eosinophil in healthy horses

In spite of their presence in fetal lymphoid tissues, eosinophils are not detected in the peripheral blood of the fetus or the newborn foal. Eosinophils make their first appearance in the peripheral blood of the foal at about 1 week of age, and

numbers increase significantly over the first 3 months to 1 year of life (Harvey *et al.* 1984; Becht and Semrad 1985; Cebulj-Kadunc *et al.* 2003; Uluisik *et al.* 2013).

Eosinophils are absent or present only in low numbers in the peripheral blood of the healthy adult horse. Numerous studies have investigated variations in eosinophil counts across age, breed, gender, time of day, season and athletic effort in healthy adults. In Thoroughbreds aged 2–4 years old, absolute eosinophil counts tended to be lower in the 4-year-olds than in the 2- and 3-year-olds (Allen *et al.* 1984), whereas in Lippizan horses 7-year-old stallions had significantly higher eosinophil counts than younger or older adult stallions (Cebulj-Kadunc *et al.* 2003). Reference intervals developed for Icelandic horses showed that only for eosinophils did the upper range of the absolute count exceed that used for other breeds (0.5 G/L, 7.6% as compared with 0.4 G/L, 4%) (Leidinger *et al.* 2015).

Diurnal variations in eosinophil counts have been observed in Arabian horses. Unlike other leucocytes, eosinophil peaks occurred during daylight hours, with a higher peak in stallions (2.6%) as compared with mares (1.2%). Absolute eosinophil counts were not provided, but total leucocyte counts were approximately $9.5 \times 10^9/L$ and $10.0 \times 10^9/L$ respectively (Kottman-Jutter 1975; Gill and Rastawicka 1986). Seasonal variations in eosinophil counts also have been observed in Arabians, with decreased numbers in January, February and March (Gill *et al.* 1985).

Studies in athletic horses have shown decreased eosinophil counts in endurance horses in weeks 6, 8 and 12 of a training programme with rides of 10–130 km (Rose and Hodgson 1982), while Thoroughbreds racing 12–16 furlongs had higher eosinophil counts than those racing only 5 or 6 furlongs (Allen 1986). Peripheral blood eosinophil counts also increased significantly in pack donkeys subjected to intensive packing expeditions. This held true in both control donkeys and in those treated with ascorbic acid as an anti-oxidant treatment (Olaifa *et al.* 2015).

Some studies of peripheral blood eosinophils also noted that the distribution of eosinophil counts across the populations examined was unusual compared with other types of leucocytes. In the Icelandic horse population, an unusually high number of outliers were identified by statistical means (Leidinger *et al.* 2015), and eosinophils were the only leucocyte not normally distributed in a population of Thoroughbreds (Allen *et al.* 1984). The underlying causes of the differing peripheral eosinophil counts in all of these studies were uncertain, and most often attributed to variations in the exposure of individual animals to helminth parasites or other antigens, or in anthelmintic administration protocols.

Eosinophils are most often absent from the body fluids of healthy horses. Normal peritoneal fluid of foals and adults typically lacks eosinophils, but they may occasionally be found in low numbers in some individuals. Differential counts of 1–5% were found in one of 17 foals and six of 20 adults (Brownlow *et al.* 1981; Grindem *et al.* 1990). Eosinophils are only rarely found in normal equine synovial fluid, and when present make up less than one percent of the total nucleated cell count (Steel 2008). Cerebrospinal fluid from healthy horses does not contain eosinophils (Beech 1983).

Eosinophils are prominent in certain tissues of the healthy adult horse, most notably throughout the gastrointestinal tract, including the small intestine and colon (Benarafa *et al.*

2000). Within the jejunum, eosinophils are more abundant in the deeper intercryptal regions of the villi than in the villous lamina propria (Packer *et al.* 2005). Eosinophils are also found in the spleen of clinically normal horses, but are rare to absent in the lungs, liver, kidney and skin of normal horses (Benarafa *et al.* 2000).

In healthy mares, eosinophils are found in parts of the reproductive tract at certain times in the oestrous cycle, and during normal pregnancy. During dioestrus, eosinophils are consistently present within the lamina propria of the cervix, rarely in the tunica muscularis, and are absent near the mucosal epithelium. In tissue layers where cells are found, cell counts increase from the uterine end of the cervix to the vaginal end (Wehrend *et al.* 2005). In about one-third of mares presenting for routine breeding evaluation, eosinophils were present in uterine cytology or biopsy. Most but not all of these mares had abnormal perineal conformation, pneumovagina or urovagina. Eosinophils were present in mares in all stages of oestrus, but not in one ovariectomised mare or one mare that had not yet begun cycling. The reasons for the eosinophils was unclear (Slusher *et al.* 1984).

Eosinophils are not found in association with preovulatory follicles, but increase significantly between 33 and 39 h following administration of human chorionic gonadotropin (Kerban *et al.* 1999). Eosinophils are present consistently in low numbers within the corpus luteum throughout the oestrous cycle and into early pregnancy. Significantly higher numbers of eosinophils are found in the corpora lutea of mares that receive exogenous prostaglandin than in those experiencing natural luteolysis (Lawler *et al.* 1999). Peripheral blood eosinophils were significantly lower in a population of Carthusian broodmares during Days 111–120 of pregnancy relative to mares in earlier or later stages (Satue *et al.* 2010). It is also at about this time that the endometrial cups are reaching the end of their lifespan, and eosinophils are abundant in the cellular infiltrate around the dying cup cells (Grunig *et al.* 1995). Eosinophils surrounding the mature endometrial cup express TGF- β 2 mRNA (Lea *et al.* 1995). In normal post-partum Thoroughbred mares, the percentage of eosinophils present on uterine cytology increased markedly on Days 5 and 6 after foaling (Saltiel *et al.* 1987).

In a study including stallion testis collected in the month of March, eosinophils were only rarely found in the interstitial regions, with mast cells being abundant (Anton *et al.* 1998).

Anatomy of the horse eosinophil

The general structure of the horse eosinophil has been described by techniques ranging from light microscopy to electron microscopy. The most striking cytological feature of the horse eosinophil is the presence of large, brightly staining granules. Early electron microscopy studies revealed an eccentrically located nucleus, and large, round granules that clearly distinguished these cells from others. The granules varied greatly in size, with most appearing homogeneously filled with dense material. Some did appear to have internal structures, and some had vacuoles (Sonoda 1972). Later electron microscopy studies showed greater structural detail within the granules (Stockert *et al.* 1993). The cytoplasm contains microbodies, and golgi complexes are observed that range from poorly to moderately well developed. Smooth endoplasmic reticulum is seen readily, but rough endoplasmic reticulum is rare (Sonoda 1972).

Granule structure

Exceptionally large size distinguishes horse eosinophil granules from those of other species (Archer and Hirsch 1963b). The granules vary in size, with diameters ranging from 0.30 to 2.35 μ m, with an average of 1.04 μ m (Sonoda 1972). A single horse eosinophil contains an estimated 40 granules, as compared with 250 granules per cell in the rat (Archer and Hirsch 1963a). Granules in horse eosinophils contain about 45% of the protein in the cell (Archer and Hirsch 1963a).

The most detailed electron microscopy study of horse granules showed three distinct layers, including an outer membrane, a less dense matrix and a more dense, noncrystalline core (Stockert *et al.* 1993). This contrasts with other species including human subjects, dogs, rats and mice, in which the core is crystalline (McEwen 1992). Granules were found to be heterogeneous in structure, with three main variations evident. Most often the matrix was finely granular with cores having vacuolar inclusions of matrix. Less common variations included similar granules with no vacuoles, and granules with less structured matrices and vacuolated cores. The core was sometimes eccentric (Stockert *et al.* 1993). Functional significance of the heterogeneity of granules was not determined.

Contents of horse eosinophil granules

Eosinophil granules in all species contain proteins that are released in response to stimuli to perform effector functions. The earliest studies of horse granules used biochemical assays to investigate the presence of substances already identified in neutrophils and lysozymes (Heyneman *et al.* 1975; Healy 1982). Horse granules were shown to contain substantial peroxidase (Archer and Hirsch 1963a; Jain 1967), in addition to ribonuclease (Archer and Hirsch 1963a), cathepsin (Archer and Hirsch 1963a), alkaline phosphatase (Archer and Hirsch 1963a; Jain 1968), arylsulfatase (Archer and Hirsch 1963a; Healy 1982), acid phosphatase (Archer and Hirsch 1963a; Healy 1982), β -glucuronidase (Archer and Hirsch 1963a; Healy 1982) and α - and β -mannosidases (Healy 1982). Lysozyme and phagocytin were not identified (Archer and Hirsch 1963a). The significance of the high peroxidase activity was uncertain at the time these studies were performed (Archer and Hirsch 1963a; Heyneman *et al.* 1975).

The horse eosinophils had higher alkaline phosphatase (Jain 1968; Heyneman 1975; Heyneman *et al.* 1975), α - and β -mannosidase and arylsulfatase (Healy 1982) activity than horse neutrophils. The alkaline phosphatase activity was present in large eosinophilic granules as well as in fine cytoplasmic granules and appeared to be localised primarily to the granule membrane. It was not determined if one enzyme or multiple isoenzymes were present (Jain 1968). Acid phosphatase appeared to be limited to large eosinophilic granules, and could be inhibited by fluoride (Heyneman *et al.* 1976).

Horse eosinophil peroxidase was purified in 1982, and its properties, functions and location subsequently investigated. It was characterised as a basic protein that exhibited antibacterial properties in combination with hydrogen peroxide and iodide, bromide or chloride (Jorg *et al.* 1982b). In vitro studies showed that the hydrogen peroxide and halide component had a greater antibacterial effect than the other basic proteins (Klebanoff *et al.* 1989). Horse eosinophil peroxidase contains a protoheme prosthetic group

that likely provides its ability to catalyse chloride ion peroxidation, whereas some other peroxidases such as lactoperoxidase are unable to do this (Sibbett *et al.* 1985). It was identified within the granules of intact cells, and lining the vacuoles of cells degranulated *in vitro* (Henderson *et al.* 1983). In addition to antimicrobial properties, horse eosinophil peroxidase has been shown to potentiate lysis of tumour cells of murine origin in the presence of hydrogen peroxide or macrophages (Nathan and Klebanoff 1982).

A decade later, four new basic proteins were identified in horse granules, and these were suspected but not proven to be analogues of the human eosinophil cationic protein, major basic protein, and eosinophil-derived neurotoxin. These proteins were also shown to have an antimicrobial effect (Piller and Portmann 1993).

Chemical properties of horse eosinophil granules have sometimes been confirmed or inferred by the dyes that stain them. The cells are used preferentially for the testing of new dyes because of their characteristic large granules and known acidophilia, again resulting in ancillary data on horse eosinophil granules. Horse eosinophil granules stain, and in some cases fluoresce, under specific conditions with the plant-derived dyes saffron (Trigoso and Stockert 1995), and morin (Stockert *et al.* 1985), 2-methoxy-2,4-diphenyl-3(2H)-furanone (Stockert and Trigoso 1993; Stockert *et al.* 2008;), 1,8-naphthalic anhydrides (Stockert *et al.* 1994), sirius red (Wehrend *et al.* 2004), 1-hydroxy-3,6,8-pyrenetrisulfonate (Trigoso *et al.* 1995) and fluorescein isothiocyanate (FITC) (Floyd *et al.* 1983). Inorganic salts, such as sodium chloride, may suppress the activity of some dyes upon the granules (Isabel Trigoso *et al.* 1992), while treatment with ethylenediamine tetraacetic acid (EDTA) can enhance uptake by unmasking basic groups (Gomez-Perretta *et al.* 1986).

Degranulation of the horse eosinophil

The appropriately timed release of granule contents to destroy foreign substances or pathogens is a primary function of the eosinophil. The foreign targets may first be phagocytosed, or may remain external to the cell. Extensive knowledge of these processes in horse eosinophils has been gained through *in vitro* studies. Horse eosinophils have been observed to phagocytose a variety of substances *in vitro*, including human red blood cells, zymosan and antigen-antibody precipitates. In some of these cases, specific antibody was required. Phagocytosis was accompanied by granule rupture, presumed to be into the phagocytic vesicle rather than the cytoplasm (Archer and Hirsch 1963b).

Several mechanisms may be employed by horse eosinophils to ensure that granule contents are delivered appropriately to external targets, presumably so that host tissue undergoes minimal damage. Degranulation first may occur by compound exocytosis, in which multiple smaller granules fuse inside the cell to form a large granule, which then fuses with the cell membrane. A variation of this is cumulative fusion, in which a single granule fuses with the cell membrane, and then subsequent granules fuse with the first granule to form a degranulation sac, allowing degranulation through a single pore (Scepek and Lindau 1993; Lindau *et al.* 1994; Hafez *et al.* 2003). Attachment of the granules occurs by membrane tethering, and not by the joining of cytoskeletal components (Valero *et al.* 2008).

Degranulation of horse eosinophils *in vitro* can be initiated and modulated by many substances. Granule to granule fusion and granule to membrane fusion have been incited and mediated using GTP analogues and Ca^{2+} (Hartmann *et al.* 2003). Fusion pore expansion, but not formation, can be accelerated by phorbol 12-myristate 13-acetate (PMA), and by increased levels of Ca^{2+} and protein kinase C (Hartmann and Lindau 1995; Scepek *et al.* 1998). Electron microscopy showed degranulation in response to ionophore A23187 and phospholipase A_2 in the presence of Ca^{2+} . Adjacent granules appeared to fuse within the cell and open to the outside via a pore. The mechanism proposed was that an influx of Ca^{2+} induced by the ionophore initiated degranulation, possibly by endogenous phospholipase A_2 (Henderson *et al.* 1983). *In vitro* studies suggest that mature granules undergoing exocytosis are formed by the fusion of seven to fifteen smaller granules of about 450–500 nm (Hartmann *et al.* 1995).

Surface receptors on the horse eosinophil

C-C motif chemokine receptor 3 (CCR3) is the primary receptor expressed on the surface of eosinophils. It binds eotaxin (CCL11), a modulator of eosinophil migration. Molecular studies using RT-PCR and *in situ* hybridisation on horse tissues identified CCR3 mRNA in the colon and localised it to resident eosinophils. CCR3 identified in spleen was localised to lymphocytes rather than eosinophils. CCR3 mRNA was not identified in any skin samples, and in very few samples of heart, kidney, liver and lung (Weston *et al.* 2006b).

Mediators of horse eosinophil migration, adherence and activation

Knowledge of the mechanisms that regulate eosinophil migration is critical to understand the pathophysiology of eosinophil-related diseases in the horse (Hubert 2006). Early studies of horse eosinophil migration involved the simple observation of cellular movement across coated slides. The characteristics of the migrating cells included a leading pseudopod with a ruffled border, the absence of cytoplasmic streaming, and a rounded tail trailing behind. It was noted that the granules retained their relative position within the cell as it moved (Archer and Hirsch 1963b).

Early molecular studies identified the presence of a 'cell-derived chemotactic factor' produced by eosinophils (Zigmond and Hirsch 1973). More recently, *in vitro* studies have investigated the presence and action of specific molecules known to control eosinophil migration in other species. Eotaxin (CCL11) is the primary chemotactic factor for eosinophils. In a study of tissue from clinically healthy horses, eotaxin mRNA was identified by molecular means in the small intestine and colon, but not in lung, liver, skin, kidney and spleen. There was a correspondingly high number of eosinophils in the small intestine and colon and low number in the lung, liver, skin and kidney, suggesting that the tissue eosinophil distribution in healthy horses is primarily regulated by eotaxin. However, a disproportionately large number of eosinophils were found in the spleen considering the absence of eotaxin mRNA (Benarafa *et al.* 2000). Recombinant horse eotaxin used in *in vitro* studies induced migration, superoxide anion production and skeletal reorganisation of horse eosinophils (Benarafa *et al.* 2002; Weston *et al.* 2006a).

Interleukin 5 (IL-5) modulates eosinophils in various ways in addition to their initial differentiation, including activation, migration and increased survival time. Recombinant horse IL-5 was shown to stimulate horse eosinophils *in vitro* as evidenced by adherence and superoxide production, suggesting a role in recruitment and activation of eosinophils in disease states of the horse (Cunningham *et al.* 2003). Horse eosinophils are sensitive to human recombinant IL-5 and also C5a, though the response to IL-5 of eosinophils from healthy horses as measured by adherence to equine digital vein endothelial cells was significantly less than that observed in eosinophils obtained from allergic horses (Foster *et al.* 1997; Bailey and Cunningham 2001a).

Several other classes of molecules are known to be involved in eosinophil adherence, chemotaxis, and activation, most notably leukotrienes, histamine and platelet activating factor. Considerable *in vitro* research has been conducted on these mediators to determine their production by, or effect upon, horse eosinophils under varying conditions. Bench protocols commonly use phorbol 12-myristate 13-acetate (PMA) to activate protein kinase C (Foster and Cunningham 1997; Greenaway *et al.* 2003), which is involved in the adherence and activation of eosinophils. *In vitro* studies in the horse have shown that horse eosinophils produce protein kinase C isotypes α , β , δ , ϵ , ι and ζ . In contrast to the horse neutrophil in which the protein kinase C is located in the cytosol, in the horse eosinophil it is localised to the nuclear membrane and possibly the cytoskeleton (Greenaway *et al.* 2003). Calcium ionophores, such as A23187 and ionomycin, are also used (Muller *et al.* 1989; Asmis and Jorg 1990; Lindberg *et al.* 1998).

Leukotrienes are metabolites of arachidonic acid produced via the lipoxygenase pathway. In horse eosinophils, production of leukotrienes LTB₄, 5-(S),12-(R)-6-*trans*-LTB₄, 5-(S),12-(S)-6-*trans*-LTB₄, LTC₄, 5-(S),12-(R)-6-*trans*-LTB₄ and LTD₄ has been documented *in vitro* (Jorg *et al.* 1982a; Ziltener *et al.* 1983; Asmis and Jorg 1990). The pattern of leukotrienes produced may be influenced by the respiratory burst and by the availability of glucose (Ziltener *et al.* 1983). The production of leukotrienes by horse eosinophils can occur without the addition of exogenous arachidonic acid, whereas this was required in horse neutrophils (Lindberg *et al.* 1998). Leukotriene production by horse eosinophils can be inhibited by 5-lipoxygenase inhibitors, including BAY Y 1015 and BAY X 1005 (Cunningham *et al.* 1997) and MK-866 (Lindberg *et al.* 1998). Retinoids including tretinoin, isotretinoin, retinol, retinal, acitretin and retinyl palmitate also inhibit LTC₄ production in A23187 treated horse eosinophils. One retinoid, etretinate, increases LTC₄ production, and one, R_o 15-0778 shows no effect (Lehman and Henderson 1990).

The biological activity of LTB₄, LTC₄ and LTD₄ produced by horse eosinophils, as measured by their *in vitro* ability to cause contraction of isolated guinea pig ileum or to initiate chemotaxis of neutrophils, is markedly decreased in the presence of eosinophil peroxidase, hydrogen peroxide and a halide. This suggests that eosinophils fine tune their effects at sites of activation (Henderson *et al.* 1982). Arachidonic acid in the presence of horse eosinophil peroxidase, hydrogen peroxide and iodide is known to be iodinated, although any changes that this might confer upon its biological activity have not been investigated (Turk *et al.* 1983).

Arachidonic acid metabolites including monohydroxyeicosatetraenoic acid (mono-HETE) and LTB₄ act as chemotactic

factors for horse eosinophils. Horse eosinophils are more reactive to HETE and less reactive to LTB₄ than other species studied (Potter *et al.* 1985). Under the conditions of another study, LTB₄ but not LTC₄ resulted in significant chemotaxis of horse eosinophils, with LTB₄ being a stronger chemotactic factor than histamine (McEwen *et al.* 1990).

Horse eosinophils were initially studied with respect to their antihistamine properties. Suspensions of horse eosinophils demonstrated antihistamine activity in a guinea pig bronchospasm model (Archer *et al.* 1962) and *in vitro* (Broome and Archer 1962). Intradermal injections of horse eosinophil extract were also observed to block oedema formation in horses receiving intradermal injections of antigen (Archer 1960, 1965) though in this more complex model the target molecule may not have been histamine. Interestingly, these studies also demonstrated that eosinophils, but not eosinophil extract, had an anti-heparin effect as assessed via the thrombin-plasma clotting test (Archer 1960).

Histamine initiates adherence and chemotaxis of horse eosinophils, but not neutrophils, to coated plates and treated equine digital vein endothelial cell monolayers (McEwen *et al.* 1990; Foster and Cunningham 1998; Bailey and Cunningham 2001b), and can initiate actin polymerisation and superoxide production (Weston *et al.* 2008). The effects of histamine on horse eosinophils can be reduced by inhibiting phosphatidylinositol-3 kinase. Inhibition of phospholipase C decreased histamine-induced actin polymerisation and superoxide production, but resulted in increased migration. Inhibition of protein kinase C and extracellular regulated kinases 1 and 2 also increased histamine-induced eosinophil migration (Weston *et al.* 2008). Intramedullary injections of histamine produced higher bone marrow aspirate eosinophil counts, with high doses also producing peripheral eosinopenia (Archer 1956). Intravenous histamine resulted in reduced eosinophil counts (Alexander and Ash 1955).

Platelet activating factor (PAF) also is produced by horse eosinophils in response to ionophore stimulation. One study showed that PAF production correlated with LTC₄ production, suggesting a common precursor and pathway (Asmis and Jorg 1990). PAF is chemotactic for horse eosinophils, though not as strongly as to LTB₄ (Foster *et al.* 1992b). Intradermal injection of PAF in horses increases vascular permeability, but did not change the tissue eosinophil counts over the 24-h period monitored (Foster *et al.* 1992a).

Conclusions

In the history of scientific research, the horse is an uncommon model organism, but because of the rarity of the eosinophil in healthy mammals the horse cell has long been preferred for experimental use. This has resulted in an expansive but widely dispersed body of knowledge on the structure and function of the horse eosinophil. The literature reviewed herein spans six decades, and taken comprehensively provides some key insights to consider going forward. First, the distribution of eosinophils appears to behave differently than other blood cells. This is often attributed without evidence to uncontrolled variations in helminth exposure. This assumption reflects an outdated view of eosinophils as anthelmintic end effectors, and may deter efforts to identify other causes. Studies that control for this factor are important. Second, eosinophil-related pathways are complex, and the eosinophil is likely a

modulator of immunological responses in addition to an end-effector. This is evidenced for example by the eosinophil's production of and response to certain leukotrienes. Systems biology approaches to eosinophil studies may go a long way to elucidating more complex pathways. As considerable data on the horse already exists, continued use of the horse eosinophil is ideal. Third, the mechanisms by which horse eosinophils degranulate have been elegantly described *in vitro*. It is likely that dysregulation of this process plays an important role in eosinophilic diseases. Validation of these mechanisms *in vivo* is an important next step. In Part II of this review, we summarise the existing knowledge of eosinophil-related disorders in the horse, integrate with the findings described here in Part I, and conclude by identifying key knowledge gaps and critical path research questions.

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Ethical animal research

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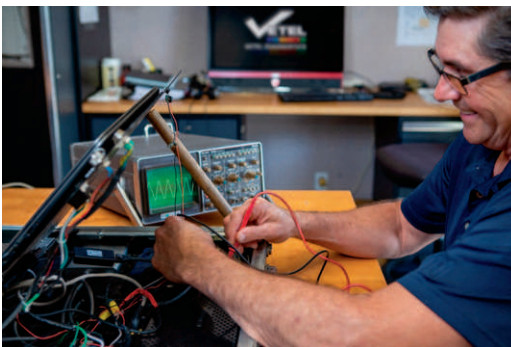
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¹ Pehkonen J, Karma L, Raekallio M. Behavioral Signs Associated with Equine Periapical Infection in Cheek Teeth. *Journal of Equine Veterinary Science*. 2019;77:144-150.

Review Article

Farriery for the foal: A review part 1: Basic trimming

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Keywords: horse; foals; farriery; hoof trimming; tendon laxity; rotational deformity; flexural deformity; angular limb deformity

Summary

The extensive nature of this topic warrants this review paper to be divided into two parts: 'Routine basic trimming in foals' and 'Therapeutic farriery in foals'. Hoof care in the first few months of life is serious business and should never be taken lightly. Good farriery is vital for the development of the hoof capsule and the conformation of the limb. Management of the feet and limbs during the juvenile period will often dictate the success of the foal as a sales yearling or mature sound athlete. Overall hoof care of a foal is often a joint venture between the veterinarian and the farrier. Part 1 of this paper will outline the concept of a footcare programme, examination of the foal's feet and limbs along with what constitutes good basic farriery to properly apply the trim. It will also emphasise the importance of maintaining a good veterinarian-farrier relationship - the farrier being responsible for basic trimming with veterinary oversight when necessary, and if orthopaedic disorders develop, the farrier will have significant input with therapeutic farriery.

Introduction

The importance of appropriate hoof care in the foal during the first few months of life cannot be denied yet the information published on this subject in the veterinary literature is sparse. There is a relative lack of controlled scientific studies in the area of foal foot care to actually assess the impact of interventions such that developing data in this area is frustratingly slow. Among the many factors that dictate the success of the foal as a sales yearling or a mature adult are accurate timely foot care decisions along with the appropriate management of the foal's feet and limbs. This is the period when hoof care plays a significant role to produce the basis for a strong foundation (hoof) for the animal's future athletic career while influencing the growth and angulation of the limb above the hoof to some degree. Realising that there are potential complications associated with excessive interventional measures involving the foal's foot, it is important to understand basic farriery principles, as well as the indications, contraindications and the appropriate treatment methodology required (Greet and Curtis 2003; O'Grady 2008, 2017; Hunt and Baker 2017). Every effort should be made to avoid causing damage to the foot or the other developing skeletal structures due to a lack of understanding of the wide array of farriery methods presently being used. One should never allow the foot to become a 'victim' of misguided, inappropriate or overzealous treatment often used to create a cosmetic effect. This paper will present a review of current credible information on hoof care in foals that can be applied in a practical manner while dispelling some of the anecdotal methodology that presently exists.

Considering this deficiency of information in the literature, segments of this text will be based on the author's extensive clinical practice, comprehensive clinical records and comparisons of case outcomes.

Initial examination

Many breeding farms have developed foot care programmes that use the skills of a veterinarian with an interest in farriery and a skilled farrier working together as a team. The team will focus on basic routine farriery applied to the foal and to those limb deformities that can be addressed through therapeutic farriery or farriery combined with surgery. The veterinarian uses his medical and anatomical knowledge while the farrier uses his technical and mechanical skills. From the onset, the emphasis should always be placed on good basic farriery and biomechanical principles rather than anecdotal or traditional farriery methods of questionable merit. This joint venture allows an earlier and more accurate diagnosis and initiation of a treatment plan, leading to faster improvement or resolution and a better prognosis for foot problems. Unless an orthopaedic disorder is identified at birth or shortly thereafter, all foals should be examined by the veterinarian, farrier and the manager/owner at the time of the first trim which is generally performed at a month of age. Problem or suspect foals are identified at this time and are then examined on a monthly or bi-monthly basis and followed through weaning. Many subtle problems or indications of potential problems can be detected early, leading to the immediate initiation of treatment. If this programme corrects the limb alignment or increases the athletic potential of one foal on the farm, the programme becomes cost effective.

Evaluating the foal

A complete physical examination and an initial evaluation of limb conformation should be performed on every foal shortly after birth which will also serve as a baseline for subsequent examinations. Good record keeping is vitally important. Records are designed to suit the individual needs of a given farm/owner. The records should reflect a thorough history from birth, physical examinations, any veterinary issues, treatments or medications administered, the physical appearance of a foal's feet and limbs, farrier comments and any subtle changes that occur during development on at least a monthly basis. Digital images (pictures, videos and radiographs) can be taken and added to the foal's record. The images can be used to create a baseline, and are helpful in determining the response to treatment. Subsequent serial images can determine whether there is progress or regression in the foal's feet/limbs. Pictures and videos can

easily be acquired with a camera, smartphone or tablet and transferred directly to the individual foal's file or record on the computer.

Foals should always be taken out of the stall and observed standing on a firm surface each time they are evaluated and before being trimmed. Also, it is essential to observe the foal walking on a firm surface before the feet are trimmed. Standing in front of the foal, the limbs are observed at a slightly oblique angle that is in line with the face of the carpus so the clinician can better judge any deviations of the limb centred on the joints. Mild carpal valgus with slight outward rotation of the forelimbs is considered normal (Adams and Santschi 2000; Santschi *et al.* 2006; Hunt and Baker 2017). An imaginary dot system is a useful method to evaluate the conformation of the feet and limbs of a foal. Starting at the ground surface of the foot, an imaginary dot is placed at the middle of the toe of the foot, the coronary band, above and below the fetlock, proximal third metacarpal bone (McIII), carpus and distal radius. When these dots are connected with an imaginary line, it is easy to see if and/or where an angular limb deformity exists. In the ideal situation, when viewed from the front, the dots should form a straight line. However, one must be careful not to rule out the presence of a rotational deformity. In this case, the carpus is rotated outward (laterally) leading to a toe out or splay-footed conformation, yet when the dots are connected, the axial alignment of the limb forms a straight line. The coronary band is observed to see if it is level or parallel with an imaginary line drawn at the ground surface of the foot and it should be noted whether the bones of the digit enter the middle of the hoof capsule or whether the hoof is offset to one side. Foals with an offset carpus should be noted as they have a tendency to develop carpal or fetlock varus as they mature (Santschi *et al.* 2006). When viewed from the side, the imaginary dots are again placed on the limb as described above. When the dots are connected with an imaginary line, the dots should form a straight line from the distal radius to the proximal fetlock and from the fetlock through the digit to the ground. Examining the feet and limbs from the side should note whether the carpus is flexed or hyperextended in the standing foal. The hoof-pastern axis is evaluated to determine if the bones of the digit are aligned and not broken forward (flexural deformity) or broken backward (flexor flaccidity). The foot is evaluated for size, conformation and any deviation in the direction of the foot/limb towards or away from the midline. Any swellings along the limb especially involving the physes are noted, palpated and recorded. Each deformity is noted, described and scored on a scale of 1–4. Grade 1 being mild whereas grade 4 is severe and warrants close observation or potential treatment. Finally, the foot is evaluated off the ground, observing the position of the hoof capsule relative to the bones of the digit, symmetry of the foot and the integrity of the horny structures of the hoof capsule. When viewing the solar surface of the foot with the foot off the ground, it is important to place the dorsal surface of McIII just above the fetlock in the palm of the examiner's hand that is closest to the foal and allow the limb to hang loose; this will place the limb in relaxation. The examiner's visual line of sight is then placed over the foot and the solar surface of the foot is viewed in relation to the ground. The author pays strict attention to the length of both heel bulbs as measured from the ground surface of the hoof wall at the heel to the hair

line. A marked disparity in heel height is an indication of disproportionate weight distribution being placed on one side of the foot as the foot lands (O'Grady 2017). The initial or subsequent evaluation would appear to be difficult and time consuming; however, it can be performed thoroughly and quickly once the evaluation protocol becomes routine. This type of evaluation enables the clinician to evaluate the feet and limbs of each foal in a thorough consistent systematic manner.

Watching the foal in motion can be challenging as they seldom walk in a straight line. This can be remedied by walking the mare next to a solid structure and letting the foal walk on the opposite side of the mare or follow the mare. The foal is observed as it walks towards and away from the examiner. The foal is evaluated for any lameness that may be present, the pattern of the limb flight, how the foot breaks over at the toe and how the foot contacts the ground. The author likes to see the foal land flat on its foot rather than an asymmetrical or toe first landing. It should also be noted whether the foal has a base narrow, normal or base wide stance during locomotion. A flight pattern towards the mid line or base narrow distal to the fetlock is generally indicative of fetlock varus or toe-in conformation of the foot (Hunt and Baker 2017). With this conformation, the foal's foot will contact the ground with the lateral aspect of the heel and breakover at the lateral wall of the toe. Foals that have straight axial alignment of the limb, but an offset carpus (defined as McIII being offset to the lateral side and not following a straight line from the radius) will often exacerbate this finding as it will place more weight bearing on the medial physis of distal McIII (Hunt and Baker 2017). Valgus deviations and rotational deviations are common and the limb will have a flight pattern that accompanies the deviation. Foals with carpal valgus conformation walk with an inward sweeping pattern with a tendency to land and lift off the medial wall of the foot. Outward rotational deformities tend to move or displace the carpus laterally and, on landing, the foal will contact the ground with the lateral wall and then load the medial side of the hoof generally displacing the heel bulb.

Trimming the foal

Birth to one month

At birth, the foal's hoof is enveloped in a gelatinous perioplic membrane (eponychium) which reduces the risk of trauma to the mare's reproductive tract during gestation and parturition (**Fig 1**). Shortly after birth, with the first steps of life, the perioplic membrane on the solar surface of the foot wears, dehydrates and retracts proximally on the hoof wall and ultimately creates a sulcus of varying depths just distal to the coronet the coronary band (**Fig 2a** and **b**). This depression, termed the sub-coronary groove, is considered normal and grows distally towards the ground. In lay terms it is often referred to as a 'milk' foot as it appears at birth and generally has grown out over the next 4–6 months by weaning. It has the potential to cause a defect or separation in the sole wall junction (white line) when it approaches the ground surface of the foot if the toe length is allowed to grow excessively long. The remnants of the sub-coronary groove create leverage at the toe if not trimmed appropriately and this force is responsible for a bending in the dorsal hoof wall or separation at the sole wall junction in the toe. The foal's foot at this time is generally tapered, being

wider at the coronet and becoming narrower distally at the ground surface (**Fig 3**). A foal's foot does not only grow in a distal direction, but it also expands as it develops. As the foal's feet are tapered, expansion occurs proximally and as the ground surface of the distal hoof is relatively small, the weight-bearing area is positioned in the dorsal section of the foot. Exercise and appropriate trimming will enlarge the area on the ground surface of the foot and move it in a palmar/plantar direction. The pointed or tapered appearance will gradually disappear in the first few months of life with appropriate trimming. In foals with acceptable limb conformation there is little need for trimming during the first month of life.

One month

Foals should be presented to the farrier at one month of age for trimming. Prior to the first trimming, basic limb and foot manipulations by trained farm personnel should have the foal accustomed to the positioning used by the farrier. Trimming should be a pleasant experience for the foal and will act as a form of imprinting if started in a gentle manner from the beginning. The farrier should be patient, perform the farriery gently and efficiently and not fight the foal. An experienced handler that is gentle but firm is essential. The use of a nose twitch or chemical restraint should be discouraged. If restraint is necessary, the author will use a piece of bailing twine that is threaded through the rings of the halter and placed under

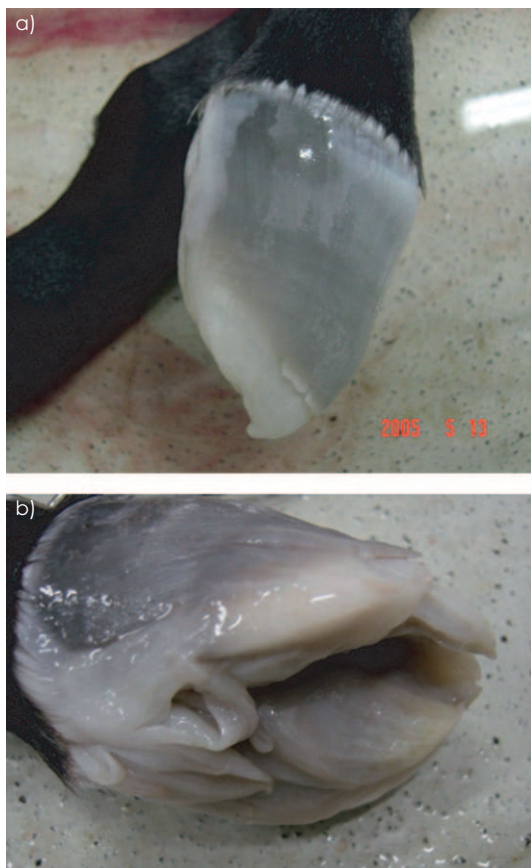


Fig 1: Peroplic membrane. Note the attachment just below the hairline that forms the sub coronary groove.



Fig 2: a) Sub coronary sulcus in a 10-day-old foal. b) Note the increased toe length in a 2-month-old foal as the sub coronary groove grows distally causing leverage. c) Flare removed and leverage reduced.

the upper lip of the foal. Mild pressure or gentle tugs (never harsh) are applied to the string if necessary while the trimming is taking place. Generally, it is only necessary to use this method during the initial trimming session. The foal is always trimmed in a stall placed alongside the mare that is positioned against the wall and backed into a corner. The outer side of the foal is trimmed; then the positioning of the mare is reversed, and the other side of the foal is trimmed.



Fig 3: The width is wider at the coronet than at the ground surface of the foot in this 6-week-old foal. Also note the pointed toe.

All that is generally necessary at 1 month of age is to square the toe of the hoof with a rasp to remove the tapered or pointed contour of the dorsal distal hoof wall perimeter and encourage the foal to break over in the centre of the foot. At this age, due to the pointed toe, the foal may break over to either the outside or inside of the toe (**Fig 3**). If the frog has receded below the level of the hoof wall, the heels should be rasped lightly using the smooth side of the rasp until the hoof wall and the frog are on the same plane. Any sharp edges are removed from the perimeter of the hoof capsule using the rasp at an angle. As will be discussed below, the use of a hoof knife or hoof nippers is discouraged when trimming foals at any age.

Two months onward

During these first few months of life, attention should be directed towards the structural integrity of the hoof capsule (foot mass/density) rather than to cosmetics. The important concerns are to promote the growth of a thick, durable hoof wall, to ensure maximum sole thickness in order to protect the vulnerable sole wall junction, the soft tissue structure and developing distal phalanx and finally to develop the structures in the palmar/plantar section of the foot. Promoting the structural mass of the foot in a foal (defined as a strong hoof wall, adequate sole depth and a solid heel base) is vital for hoof capsule development and future soundness. It is the author's opinion that a *hoof pick*, *wire brush* and a *rasp* are the only tools necessary to trim foals that are kept on a month to 5 weeks trimming schedule. Furthermore, if the foal has adequate exercise combined with a consistent trimming schedule, there is generally minimal hoof growth which makes the use of a hoof knife and hoof nippers unnecessary. The goal is to not have the foal walk exclusively on the hoof wall but rather load all the structures on the solar surface of

the foot; having the foot 'load-sharing' causes stimulation, adaptation and promotes growth. Foals that are trimmed frequently and have a lot of horn removed tend to develop weak fragile hoof capsules (O'Grady 2017).

The recommended technique of trimming foals used by the author may differ from traditional farriery (O'Grady 2008, 2017). Dirt and debris are removed from the sole and sulci of the frog using a hoof pick. The solar surface of the foot is then cleaned vigorously using a wire brush to remove any loose exfoliating horn. Any loose or exfoliating tags of horn are removed from the frog with a hoof knife if necessary. Otherwise, the ground surface of the foot and the frog are left untouched which affords the foal ample protection on the ground surface of the foot. Exfoliating horn from the sole will be continuously shed through the abrasive friction with the ground as the foal exercises. The sole of a foal is relatively thin (which can be demonstrated by showing deformation when using thumb pressure or small hoof testers is applied to the sole) and needs to develop as much thickness as possible in order to protect the immature developing structures within the capsule. Removing excess sole with a hoof knife appears to be the primary cause of sole bruising in foals and may potentially lead to flexural deformities because of the pain response (Hunt 2011; O'Grady 2012). The health of the foot throughout the animal's life is based on developing good solid heel structures. The heel base includes the hoof wall at the heel, the bars, angle of the sole, a thick digital cushion and a wide healthy frog. The bars should not be removed as they are needed for strength and to stabilise the palmar section of the hoof capsule.

After cleaning the foot, the heels of the hoof capsule are rasped gently from side to side until the rasp just contacts the frog. The hoof wall at the heels will now be on the same horizontal plane with the frog and the heels of the hoof capsule will generally extend to the widest part of the frog. When the heels are trimmed in this manner, the frog will function as an expansion joint to keep the heels wide apart and share some of the weight bearing function. The excess hoof wall at the toe and quarters is then reduced as necessary using a rasp placed at a 90° angle just dorsal to the sole wall junction (white line) at the inner part of the stratum medium of the hoof wall (**Fig 4a**). When the desired amount of hoof wall is removed, the outer sharp edge around the perimeter of the foot that is formed by the angulation of the rasp is removed by running smooth side of the rasp around the perimeter of the hoof in a horizontal direction thus creating a rounded edge (**Fig 4b**). This round edge will help to prevent cracks and chips in the hoof wall. As the foal grows and develops, the foot assumes the same growth pattern as the adult horse which follows the angulation of the horn tubules in the hoof capsule; i.e. the heels and toe grow forward relative to the centre of rotation. Therefore, the same guidelines for trimming can be applied to the juvenile horse; using the widest part of the foot, trimming the heels to the base of the frog and creating approximate proportions on either side of a line visualised across the widest part off the foot (O'Grady 2008, 2009, 2017). There is a tendency not to trim the heels appropriately in a foal and the author believes this practice detracts from the proper development of the palmar section of the foot (**Fig 5a** and **b**). The farrier should abandon the concept of lowering the heels in the foal and perhaps consider the notion of increasing the ground surface. The method of using

the rasp on an angle leaves the hoof wall and the adjacent sole on the same plane allowing both structures to share the bulk of the weight when the animal moves. It also appears to stimulate the horn to grow thicker and stronger (O'Grady 2008, 2017).

Foals given sufficient exercise do not grow an excessive amount of hoof wall in the first few months of life and our ability to influence the foot/limb by excessive trimming on one side of the foot in the horizontal plane is limited and should be discouraged. If it becomes necessary to lower one side of the foot past the point of being level due to a developing hoof capsule distortion or in an attempt to affect landing, it should not be lowered any more than few millimetres at one time. Trimming the foot at 2-week intervals may be useful when trying to change the medial lateral orientation of the foot or when trying to increase the ground surface on one side of the foot.

The traditional theory of lowering the lateral side of the foot on a foal that stands toed-out or lowering the medial side of the foot on a toed-in foal is unrealistic. In fact, it may be detrimental as the cause of the foal having a toe-in or toe-out stance generally reflects the conformation of the limb and is rarely limited to the foot (Hunt and Baker 2017). A deviation is generally found in the axial alignment of the limb

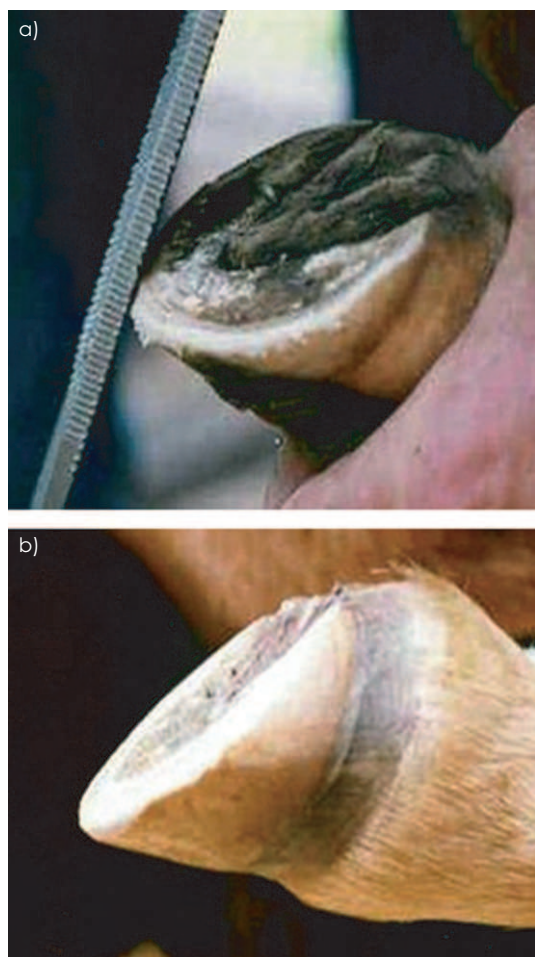


Fig 4: a) Rasp being used on a 90-degree angle to trim hoof wall. b) Rasp used in a horizontal direction to create a rounded perimeter.

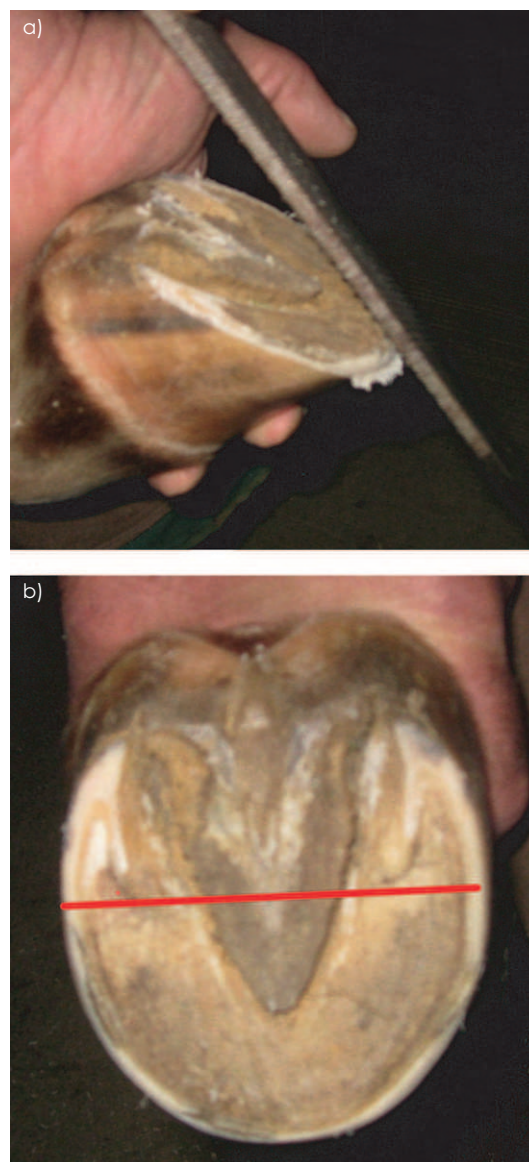


Fig 5: a) Heels trimmed to base of frog and rasp being used at a 90° angle. b) A line drawn across the widest part of the foot divides it into approximate proportions.

above the foot such as a rotational deformity of the limb distal to the carpus or the fetlock; therefore, when one side of the foot is trimmed excessively, the cosmetic appearance may be improved temporarily but over time this practice will lead to distortion of the hoof capsule (compressed growth rings and the hoof wall rolling axially on the lowered side) resulting from an unequal load on the foot. This practice will also place excessive and unequal forces on the physes and joint on the side that is being trimmed excessively. The effects of over trimming can be observed radiographically a few days after the trim (Hunt and Baker 2017; O'Grady 2017).

Rotational deformities are very common in foals and should not be considered abnormal. For example, a narrow chest coupled with short neck and relatively long forelimbs will cause many foals to adopt a base-wide stance in front in order to graze comfortably which will often be accompanied

by outward rotation of the entire limb. When viewed from the frontal plane, the entire limb will be rotated outwards, but the axial alignment of the limb will be relatively straight (Fig 6). This stance can be considered normal in foals as it confers a higher degree of stability and is gradually modified as the transverse diameters of the upper body increase with growth. As the foal moves, it is quite noticeable that the lateral side of the hoof wall strikes the ground initially because of the flight pattern caused by the rotated position of the limb. These foals should be trimmed flat or level and not have their feet lowered on the outside wall which is the traditional practice. A base-wide stance in a 3- to 4-month-old foal will often result in asymmetric hoof capsules noted in the frontal plane. The medial side of the hoof capsule will be slightly lower than the lateral aspect due to the landing pattern of the foot. If this stance is not recognised as physiological for the age and an attempt is made to 'correct' it by lowering the lateral wall, there may be a risk of creating an angular limb deformity where none existed previously. In cases where the medial heel bulb has been displaced proximally because of the asymmetrical landing pattern, although it may seem counterintuitive, the medial hoof wall is trimmed slightly more than the lateral side to create additional ground surface under the medial wall. If the medial hoof wall begins to roll under axially, the author has seen improvement by placing a small composite extension on the outer hoof wall that is used to create additional ground surface and address this hoof capsule distortion. Therapeutic trimming does not offer favourable results in the mal-positioned limb, as this deformity is corrected through growth. As the musculature of the chest increases, the chest widens and the elbows are pushed outward, which rotates the limbs inward.

Flexor tendon flaccidity

Excessive (flexor tendon) laxity in the newborn foal most commonly affects the fetlocks of the hindlimbs whereas the forelimbs generally involve the fetlocks and carpi; many foals will improve spontaneously with good husbandry (as described below) and no other treatment and will have a good prognosis. This condition is often seen in premature, dysmature or septic foals (Coleman and Whitfield-Cargile 2017). When seen in the forelimbs, there is a 'bowed' appearance to the limb when viewed from the side from a laxity of the flexor apparatus of the entire limb. The carpus and fetlock are hyperextended with the palmar surface of the pastern and fetlock on or close to the ground. There may be subluxation of the distal interphalangeal joint (DIPJ) associated with deep digital flexor tendon laxity allowing the toe of the foot to elevate off the ground. In hindlimb laxity, the DIPJ is almost always involved along with laxity noted in the pastern and fetlock (Fig 7). Initial treatment is aimed at protecting the soft tissues of the heels without over supporting the fetlock which will further promote the laxity. This can be accomplished by applying a self-adhesive pad (Equate[®] Moleskin Padding) cut in the shape of the heel bulbs. The condition tends to be self-limiting within a few days after birth as the foal gains strength and is allowed moderate exercise. However, the tendon laxity often persists and it is not uncommon to see a foal that still has digital hyperextension at 3–4 weeks of age. Treatment is sequential depending on the severity of the tendon laxity and the initial response of the foal to treatment. Therapy begins with controlled exercise



Fig 6: Rotational deformity. Note the narrow chest, carpi rotated laterally, base wide stance and medial hoof wall beginning to roll axially.



Fig 7: Flexor laxity of hind limbs in a 1-week-old foal.

allowing the foal access to a small area with firm footing for 1 h, 1–2 times daily. If there is no response by the third day post-partum, the author will place the foot on a small piece of ¼ inch plywood and trace the foot leaving 2–3 cm of

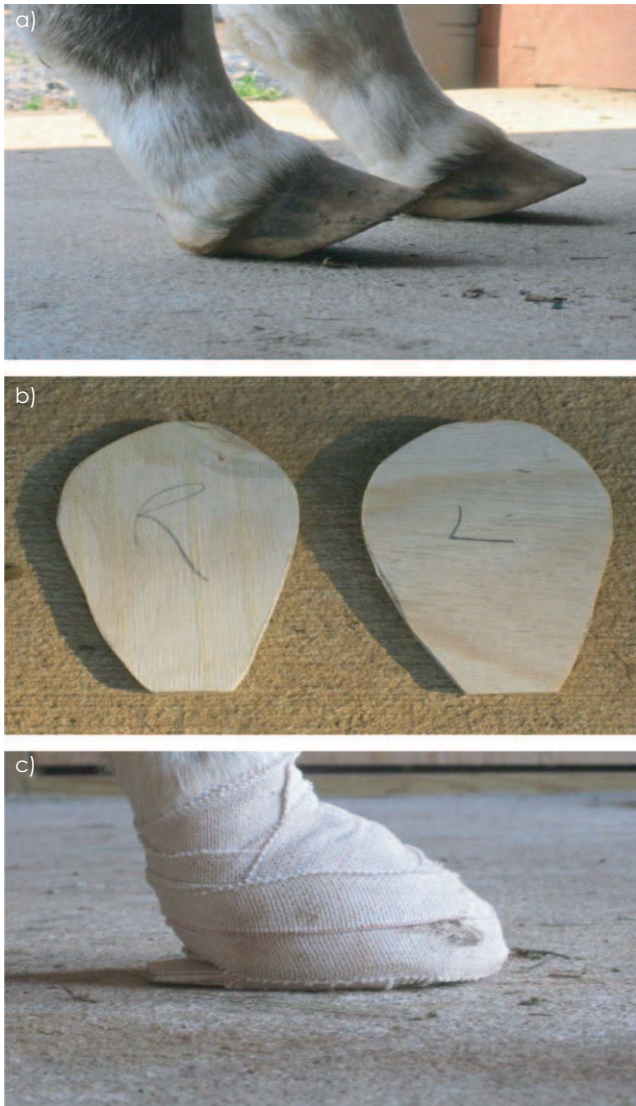


Fig 8: a) Flexural laxity in a 3-day-old foal. b) Foot is traced on plywood used to create heel extensions. c) Extension is taped on foot.

extension beyond the heels. The plywood is attached to the foot using a soft kling gauze to envelop the foot and then securing the extension to the foot using 2-inch elastic tape applied in a figure of 8 technique (**Fig 8a,b** and **c**). The exercise schedule is continued and the bandages securing the extensions are reset as necessary. The laxity will generally resolve in 7–10 days and exercise can gradually be increased. When presented with an older foal, even though the toe is off the ground, the toe length of the hoof capsule should be reduced vertically or from the outer hoof wall so no leverage is applied to the toe when the ground surface of the hoof capsule is weight bearing following the application of an extension. The heels can be rasped gently from the middle of the foot palmar/plantarly to create additional ground surface in that section of the foot; some form of a palmar/plantar extension should then be applied which extends approximately 3–4 cm beyond the bulbs of the heels to relieve the biomechanical instability of the digit (**Fig 9**). A



Fig 9: Commercial heel extension taped on the foot.

cuff-type extension shoe is commercially available or a thin aluminium plate can be fabricated as an extension shoe with the aluminium bent at the toe to align with the dorsal hoof wall to hold it in place. The author feels that either type of extension shoe should be attached with the hoof enveloped in gauze and attached with elastic tape applied in a figure of 8 pattern rather than a composite if the foal is less than 3 weeks of age. This manner of attachment avoids excessive heat being applied to the fragile hoof capsule when the composite cures and the detrimental consequences that may follow. Taping the extension in place also prevents contracture of the hoof capsule which occurs at the heels when an acrylic composite is used. Heel extensions should extend beyond the heel bulbs or further; if not of sufficient length, the extension will serve as a fulcrum and worsen the subluxation of the distal interphalangeal joint and metatarsophalangeal joint. Regardless of the method of application, the extensions should be changed at 7–10-day intervals or sooner if indicated by the extension shifting. Bandaging the limb is contraindicated as the counterpressure will further weaken the flexor tendons and promote laxity.

Care should be taken to maintain the condition of the feet while the tendon laxity is being addressed and long-term maintenance of the feet may be necessary. During treatment, the heels become distorted and the hoof wall growth is oriented dorsally which requires gradual re-shaping once the tendon laxity is resolved. The heels of the hoof capsule should be trimmed to the level of normal tubular alignment if possible and the heels of the hoof capsule should be on the same plane as the frog. If the foal had been allowed to walk on the bulbs of the heels for an extended period of time, there may be a demarcation or groove between the coronet and the heels of the hoof capsule (**Fig 10a**). The author has been successful improving horn tubular growth and alignment by filling the groove with an acrylic composite (**Fig 10b**). The toe length should be trimmed or reduced as necessary. This process may require 3–4 months to accomplish but over time a normal foot should and can be the result.

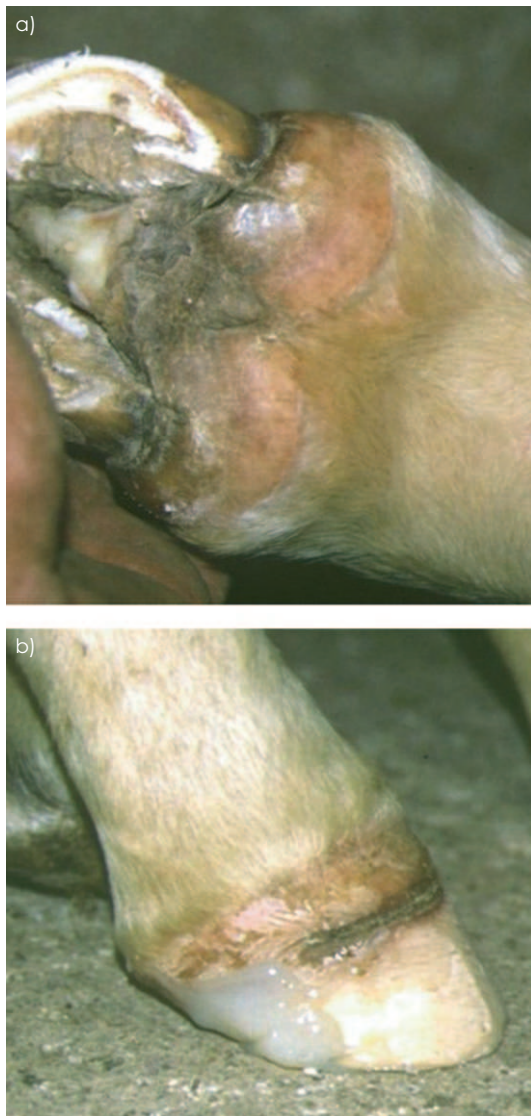


Fig 10: a) Note the groove created between the coronet and the hoof wall at the heels due to excessive loading of the bulbs. b) shows the groove filled with acrylic which will redirect the force from the ground to the coronet (Courtesy Hans Castelijns). [Colour figure can be viewed at wileyonlinelibrary.com]

Conclusion

Routine hoof care in the first few months of life should never be taken lightly. The importance of good farriery in the foal plays a vital role in both the development of the hoof and

the conformation of the limb. Management of hoof capsules and limbs during this juvenile period will often impact the success of the foal as a sales yearling or mature sound athlete. Foal trimming should always be based on good basic farriery principles and the appropriate biomechanics. Hoof care in the foal should always be a joint venture between the veterinarian and the farrier. The importance of maintaining a good veterinarian-farrier relationship should be emphasised; the farrier is responsible for basic trimming with veterinary oversight and if orthopaedic disorders develop, the farrier will have significant input with therapeutic farriery. A sound foot care programme is time-consuming whereas assembly-line trimming is quick and easy, but the former is much more beneficial with a better outcome. Flexural and angular limb deformities in foals will be covered in part 2 of this review.

Author's declaration of interests

No conflicts of interest have been declared.

Ethical animal research

Not applicable.

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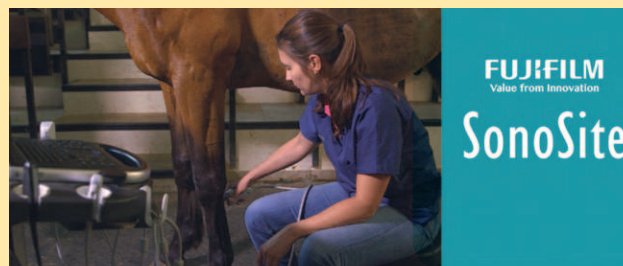
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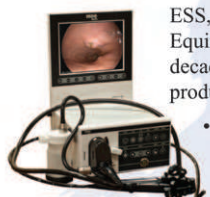
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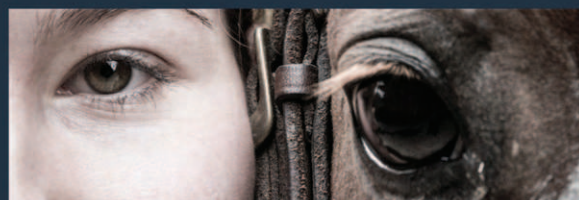

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