EQUINE VETERINARY EDUCATION/AMERICAN EDITION

VOLUME 33 NUMBER 3

MARCH 2021

EQUINE VETERINARY EDUCATION

American Edition | March 2021

BEVA

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

IN THIS ISSUE:

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References:

[1] Nogradi N, Couetil LL, Messick J, Stochelski MA, Burgess JA. Evaluation of an Omega-3 Fatty Acid Containing Feed Supplement in the Management of Horses with Chronic Lower Airway Inflammatory Diseases. J Vet Intern Med 2015; 29:299-306.

[2] Couetil LL, Cardwell J.M, Gerber V, Lavoie J.-P, Leguillette R, Richard E.A. Inflammatory Airway Disease of Horses. ACVIM Consensus Statement J of Vet Intern Med 2016; 30:503-515 p. 508-510.

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EQUINE VETERINARY EDUCATION
AMERICAN EDITION
MARCH 2021 • VOLUME 33 • NUMBER 3

Equine Veterinary Education is a refereed educational journal designed to keep the practicing veterinarian up to date with developments in equine medicine and surgery. Submitted case reports are accompanied by invited reviews of the subject (satellite articles) and clinical quizzes. Tutorial articles, both invited and submitted, provide in-depth coverage of issues in equine practice.

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From the president: Sniffing out opportunities for positive change

By Scott Hay, DVM

Dr. Scott Hay

I recently read (for about the 10th time) a short, motivational business book by Spencer Johnson, M.D., entitled, "Who Moved My Cheese." The book addresses our struggle with changes that are presented to us and how different personalities react to those changes. Every time I struggle with the thought of change in my personal or professional life, I pick up this book and try to absorb its principles.

Events of the past 12 months, particularly the ongoing pandemic, have imposed significant challenges upon us that have affected both our personal and professional lives. These changes have hit each of us in different ways, affected some more than others, and forced us to adapt as best we can. Veterinarians have always been good at adapting, and the pandemic situation has been no exception. As we begin to see light at the end of the tunnel and gradually return to normalcy, some aspects of how we practice and live our lives will be permanently changed. However, I anticipate that we will look back on these times and see that many of the changes will have been for the better.

The AAEP is no stranger to change. When the pandemic forced postponement of last summer's in-person CE meetings, the association, with little notice, created the online Virtual CE Summer Series. Volunteers, staff and, most importantly, the membership embraced the change in approach, and its' success has led to return of the summer series in 2021—and likely beyond. Stay tuned for subject matter and dates for this year's series.

Similarly, the necessary shift of the 2020 annual convention entirely to a virtual format certainly stoked my personal fears of change as the event's program chair. Some staff may have felt those same fears; if they did, however, they never let me know. Led by Executive Director David Foley, Director of Education Karen Pautz and Scientific Publications Coordinator Carey Ross, this change in format never missed a beat. A virtual convention was a first-time starter for the AAEP and, from your reviews, it was a big success. Hopefully, we will all be able to meet again, live, in Nashville this December. Rest assured if we are able, we will be presenting a hybrid program that mixes the always popular live program with what we learned from the changes necessary to go virtual. It will be the best of both worlds. Being forced to make changes has shown us that some of those changes will transform how the AAEP presents its educational opportunities in the future.

One of the association's major initiatives during the past year has been how to change the trend of fewer graduating veterinarians choosing equine practice as a career and the attrition of those abandoning an equine focus in their early years of practice. Frankly, it may require many of us to change how we do things to attract more veterinarians to equine and to keep them content. I do not know the answers; however, an AAEP task force chaired by Dr. Carol Clark with the help of consultant Dr. Rob Trimble is gathering data to help us understand the factors involved and formulate solutions to this dilemma.

Major societal events in 2020 have caused many organizations to examine how they address diversity, equity and inclusion in their professions. The AAEP's DEI task force, led by chairperson Dr. Jean-Yin Tan, is identifying what our organization can do to ensure opportunity for all and, if there are roadblocks to opportunity, make the appropriate changes to remove those impediments. Organizational changes to foster inclusivity will only be a positive for all.

In "Who Moved My Cheese," two of the characters are the mice Sniff and Scurry. Sniff looks to sniff out things that need to be changed proactively for their well-being. Scurry likes to scurry around and get things done once Sniff identifies them. Effective long-term change requires both character traits, but its best if we can sniff out those changes that need to be made before we scurry around to make them once they are forced upon us. I can assure you that the AAEP's board of directors is always working toward the future and "sniffing" out things that need to be done for the membership.

Foundation Equine Wellness & Performance

Veterinarians have always been good at adapting, and the pandemic situation has been no exception.

AAEP board focuses on priorities for 2021

By David Foley, AAEP Executive Director

David Foley

The AAEP board convened by video conference for its winter meeting Jan. 26 with all directors present. Following is a synopsis of the meeting.

After opening remarks by AAEP President Dr. Scott Hay, the board approved the minutes of its Dec. 1 meeting.

Discussion shifted to the 2020 Virtual Convention. David Foley reported that the meeting went very well, especially considering the abrupt pivot from an in-person meeting to a virtual format that was new to staff, attendees, speakers, sponsors and exhibitors. Attendee feedback on surveys ranked the on-demand viewing option and relevant topics as the top two reasons for attending. Most survey respondents indicated they were "extremely satisfied" or "satisfied" with their virtual convention experience. Attendance at Virtual Table Topics exceeded comparable on-site attendance. Due to the strong reception, the AAEP will offer Table Topic-style virtual sessions throughout the year, up to two per month.

During an update from The Foundation for the Horse, Keith Kleine reported an increase in unrestricted giving despite the effects of the pandemic.

In her budget report, Treasurer Dr. Amy Grice indicated that the association would not need to dip into its cash reserves following the success of the virtual convention combined with the expense reductions that the association had been making for the past 10 months.

Following budget discussions, the board addressed work group recommendations. Specific actions taken included:

- Approval of a recommendation from the Infectious Disease Committee to accept the proposed Equine Protozoal Myeloencephalitis Guidelines.
- Approval of a recommendation from the Welfare & Public Policy Advisory Council to accept the revised Euthanasia Guidelines.

The board also heard updates from the Wellness Committee, which is seeking to expand the topics for its popular "group meet-ups" on Zoom so that all members will have a topic that resonates with them; and the Diversity, Equity and Inclusion Task Force, which is seeking to develop strategic recommendations throughout the year. The board reviewed and provided feedback on the task force's initial Values, Vision and Mission statements.

The meeting's focus then turned to a review and update of the strategic plan. David Foley discussed proposed organizational priorities for 2021 related to each goal:

The Profession Goal:

- Conduct qualitative and quantitative research on retention
- Reinstate the Emerging Leaders program, which was delayed last year due to COVID
- Further develop the Outrider mentorship program to address needs of younger members
- Develop a New Practitioner Symposium concept
- Work on future actions proposed by the Wellness Committee and Diversity, Equity and Inclusion Task Force

The Education Goal:

- Implement a monthly Table Topic-style virtual series
- Conduct another Virtual CE Summer Series in lieu of in-person summer meetings in 2021
- Develop a New Practitioner Symposium concept
- Incorporate a digital component to the annual convention to allow for both in-person and virtual attendance
- Expand dry lab offerings at the annual convention and explore wet lab opportunities

The Horse Goal:

- Evaluate the need for any additional position statements or guidance documents related to racing and performance horse welfare
- Reconvene the Scope of Practice subcommittee of the Welfare & Public Policy Advisory Council to delineate AAEP's role in scope of practice issues
- Audit AAEP's existing horse owner resources for currency and relevancy; and determine feasibility of a new business model for horse owner education

There was general agreement by the board that these were the right priorities for AAEP to pursue in 2021. The meeting then adjourned.

New Practice Life podcast takes expansive look at equine practice issues

What's in store for equine practice in 2021? How will the economy likely affect your horse-owning clients? Why should your practice have a sufficient maternity leave policy? Is corporate consolidation of equine practices a good thing?

In the latest episode of the AAEP Practice Life podcast, entitled "AAEP Business News Hour Recap and 2021 Outlook," Dr. Mike Pownall hosts a wide-ranging discussion of pertinent practice issues with his AAEP Annual convention business session co-panelists Dr. Caitlin Daly, owner of Mid Coast Equine in Waldoboro, Me., and Dr. Amy Grice, AAEP treasurer and a veterinary business consultant in Virginia City, Mont.

During a discussion of attrition in the profession, the guests expressed hope that practices will continue to become more welcoming to young veterinarians by recognizing the need for a hard stop to the work day for those with small children; exploring a four-day work week or offering part-time work weeks; minimizing emergency call responsibilities by small practices joining together in emergency cooperatives; pricing services robustly in order to compensate associates and staff appropriately; and setting appropriate boundaries so that work life does not creep into every moment of one's personal life.

Additional topics explored during the 45-minute episode include gender bias, media and technology consumption, virtual meetings, and work-life balance. Download or listen to the episode at podcast.aaep.org or on iTunes.

The AAEP Practice Life podcast is sponsored by Boehringer Ingelheim.

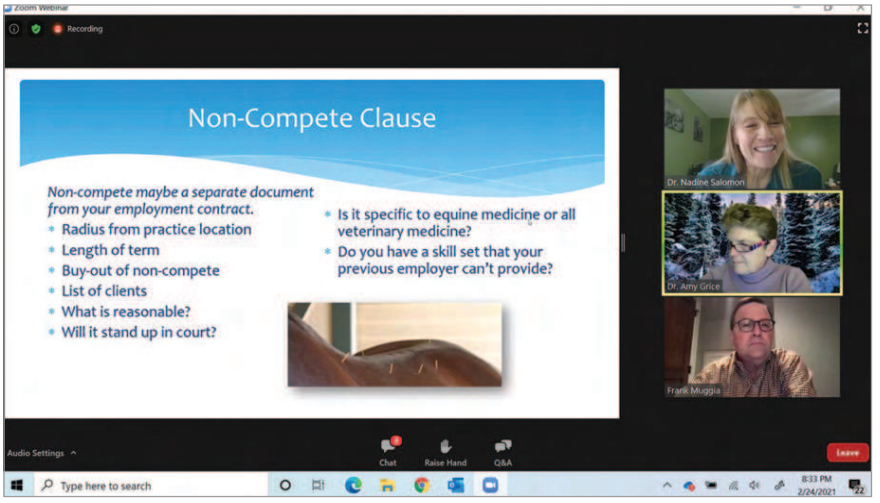
Grab a seat at AAEP's new virtual round tables for education and engagement

Engage with subject matter experts and colleagues on important clinical and non-clinical aspects of equine practice during AAEP's new, twice-monthly online educational series "Virtual Wednesday Round Tables."

On the second and fourth Wednesday of each month between March and October, DVM and student members can participate in live, moderated virtual discussions—similar to the popular Table Topics offered during the annual convention—in areas related to equine health, practice success and personal wellness. There is no cost to participate; simply sign-up in advance through AAEP Anywhere, the association's free-to-members online learning platform, at aaepanywhere.org.

If unable to attend any of the live 90-minute round tables, you can watch a recording on-demand through AAEP Anywhere. CE credit is not offered for the round tables.

"Among the key takeaways from our virtual convention in December was members' overwhelming enjoyment of the virtual format, particularly the Table Topic sessions," said AAEP's Director of Education Karen Pautz. "Our new Virtual Wednesday Round Tables are a natural extension of the Table Topics and provide members with a regular opportunity to connect with each other virtually throughout the year on a variety of topics pertinent to practice."



Each month's round tables feature one clinical and one non-clinical topic. Following is the tentative schedule of sessions through April:

March 24:
Utilizing a Technician

April 14:
Pain Management

April 28:
Student Debt Relief Strategies

A pair of Virtual Wednesday Round Tables—on the topics of employment contracts (pictured left) and vaccinations—were held prior to the mailing of this issue. You can watch these sessions on demand at aaepanywhere.org.

The Virtual Wednesday Round Tables are sponsored by Boehringer Ingelheim and CareCredit LLC.

5 things to know about AAEP this month

1. View the AAEP's new Equine Protozoal Myeloencephalitis Guidelines or save them as a PDF to your mobile device at https://tinyurl.com/ynk4gfq5.
2. Gather with colleagues twice each month for education and engagement at AAEP's new Virtual Wednesday Round Tables. Learn more at aaepanywhere.org.
3. The Virtual CE Summer Series will return this summer in place of the Focus and 360 meetings. More information will be available in late spring at aaep.org/meetings.
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. Access digital versions of *EVE*, *Proceedings*, guidelines and more using the free AAEP Publications App. Search "AAEP Publications" at your app store.

Additional technique among revisions to Euthanasia Guidelines

The AAEP board of directors at its winter meeting approved Euthanasia Guidelines revisions recommended by the Welfare & Public Policy Advisory Council. Chief among the revisions is the addition of administration of lidocaine hydrochloride 2% (intrathecal) with the horse in a surgical plane of general anesthesia as a technique deemed acceptable when performed by trained personnel.

"The guidelines not only address how to euthanize a horse, but also when to euthanize, which can assist owners in making the difficult decision to say good-bye to their beloved animal," said Alina Vale, DVM, chair of the AAEP's Welfare & Public Policy Advisory Council. "When a veterinarian and owner objectively review the guidelines together, they can determine if a horse has a good quality of life, or whether euthanasia is the most humane option. A delayed death is a welfare concern if a horse is in pain or suffering from an unmanageable condition."

The choice of euthanasia technique should take into consideration local laws and regulations, the experience and training of the veterinarian, and the final disposition of the horse. In some jurisdictions, the use of pentobarbital may be discouraged due to the potential for environmental residues.

Read the revised Euthanasia Guidelines at aaep.org/guidelines/euthanasia-guidelines or in the 2021 edition of the Leadership Resource Guide, which is accessible through aaep.org/newsroom/publications.

AAEP Publishes Equine Protozoal Myeloencephalitis Guidelines

Comprehensive guidelines to assist with identification, diagnosis and control of Equine Protozoal Myeloencephalitis (EPM), a progressively debilitating disease of the central nervous system that affects horses that reside or once spent time in North or South America, are now available on the AAEP website.

"EPM is widely considered the most important infectious neurologic disease of horses in North America," said guidelines author Amy Johnson, DVM, DACVIM. "The variable clinical signs and widespread seroprevalence pose challenges to diagnosis. These guidelines aim to summarize essential information regarding this disease process, as well as highlight the three criteria for highest diagnostic accuracy in potentially affected horses."

The EPM Guidelines, available as a PDF file, were reviewed and approved by the AAEP's Infectious Disease Committee and board of directors. View the EPM Guidelines or save them to your mobile device for future reference at https://tinyurl.com/ynk4gfq5.

Multifocal neurologic signs with asymmetric deficits or muscle atrophy should increase clinical suspicion of EPM.

In addition to EPM, AAEP guidelines for 20 other equine infectious diseases are available at aaep.org/guidelines/infectious-disease-control.

Ethics in action

As an educational resource for members, the AAEP's Professional Conduct & Ethics Committee has compiled synopses of real-life ethical situations and issues addressed by the committee in recent years. The case series began in the November 2020 issue, and a different matter is being presented each month, with names omitted to protect the privacy of those involved.

Case of the month – March

AAEP member "Dr. M" was fined $7,500 by the local racing commission for shock wave therapy outside the withhold period prior to race day. The AAEP's Professional Conduct & Ethics Committee became aware of the fine and sent a letter of inquiry to Dr. M requesting his account of what occurred. In his response to the request, Dr. M expressed no contrition and took no responsibility for his actions.

Outcome: Dr. M's AAEP membership was suspended for one year.

AAEP ETHICAL PRACTICE
Every Day-Every Time

CONTINUING EDUCATION

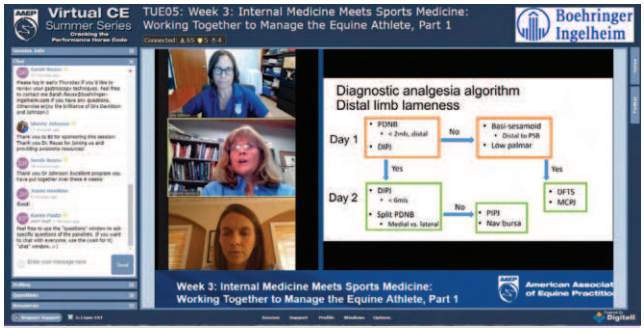
Virtual CE Summer Series to return in 2021

Covide-19 claims 360°, Focus meetings for a second year

After debuting to strong reviews last August, the AAEP's Virtual CE Summer Series will be offered again this year as a means for members to acquire pertinent case-based CE online from the convenience of their home or office.

More than 250 practitioners and students participated in the inaugural Virtual CE Summer Series, which featured a pair of live two-hour sessions each week last August with on-demand options for those unable to attend any of the live sessions. As one attendee commented during the series, "Very good information and well presented. I really like the on-demand option … This is a great way to get really useful CE!"

The program for this year's Virtual CE Summer Series is being formulated and will be available in late spring at aaep.org/meetings.



While the summer series returns to the CE calendar, the 360° and Focus meetings postponed from summer 2020 to 2021 will not be held this year due to ongoing uncertainties surrounding coronavirus, restrictions on in-person gatherings and concern for member safety.

Promising equine researchers receive career development awards

Drs. Callum Donnelly and Aileen Rowland, who in 2019 were among the inaugural recipients of resident/graduate student research grants from The Foundation for the Horse, have been awarded $20,000 career development awards from Grayson-Jockey Club Research Foundation.

Dr. Callum Donnelly

Dr. Aileen Rowland

Dr. Donnelly, with the University of California, Davis, received the Storm Cat Career Development Award for his project, "Proteomic Investigation of Equine Spinal Ataxia," which is expected to identify novel protein biomarkers that differentiate normal horses from those with spinal ataxia, with high sensitivity and specificity.

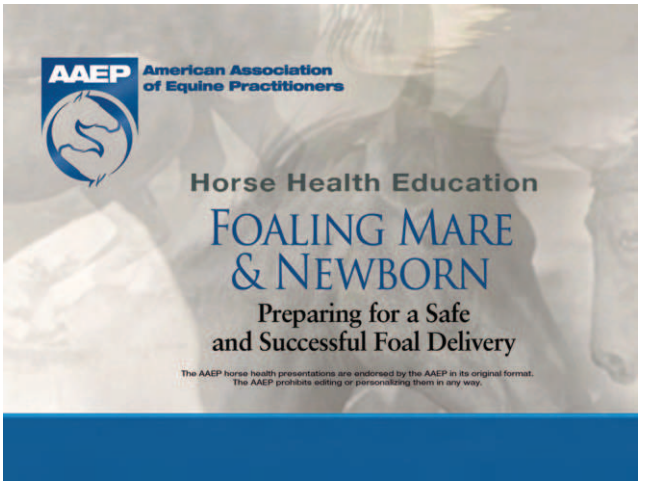
Dr. Rowland, with Texas A&M University, received the Elaine and Bertram Klein Career Development Award for her project, "Efficacy of Xenogeny-Free Mesenchymal Stem Cells for Osteoarthritis," which is expected to have considerable value to the equine sports medicine community and be directly applicable to human regenerative medicine.

Benefit: Save time on client education with AAEP PowerPoints

Owner education events can be a great venue to improve the daily care of client horses, strengthen client relations and introduce yourself to prospective clients. While the food and beverage menus are up to you, AAEP has shouldered much of the preparation by creating PowerPoint presentations on pertinent equine healthcare topics.

As a benefit of your membership, you can download any of the following 18 presentations. Each contains the most current information on the topic so that your clients receive fundamental knowledge that will help them maintain the health of their horses as well as recognize and respond to warning signs of different ailments and diseases.

Colic
Dental Care
Disaster Preparedness
Emergency Care
Equine Herpesvirus (EHV)
Foal Growth
Foaling Mare and Newborn
Hay Quality and Nutrition
Immunizations
Internal Parasites
Lameness Exams
Laminitis
Neurology
Overweight Horse
Poisonous Plants
The Expectant Mare
The Older Horse
Understanding Equine Strangles



These presentations may be downloaded from aaep.org/dashboard/clienteducation/presentations.

For additional information about the owner education PowerPoints and other benefits of your AAEP membership, contact Megan Gray, member concierge, at mgray@aaep.org.

New *EVE* podcast focuses on local anaesthetics for analgesia

In the latest episode of the *Equine Veterinary Education* podcast, Dr. Lindsey Boone discusses the review article, "Local anaesthetics for regional and intra-articular analgesia in the horse." Download or listen to the 33-minute episode at equineveterinaryeducation.podbean.com.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67th Annual AAEP Convention
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2021
ANNUAL
CONVENTION
& TRADE SHOW
Registration opens this summer at
convention.aaep.org

Members in the News

Dr. Jeff Blea to become equine medical director in California


Dr. Jeff Blea

AAEP Past President Dr. Jeff Blea has been appointed equine medical director of the California Horse Racing Board. The appointment is effective in July upon the retirement of Dr. Rick Arthur.

Dr. Blea is a southern California racetrack practitioner and partner in Von Bluecher, Blea, Hunkin Inc., in Sierra Madre, Calif. He is a member and former chair of the AAEP's Racing Committee and has served on numerous other committees over the years. Dr. Blea received his veterinary degree from Colorado State University.

Dr. Liara Gonzalez named NC State University Faculty Scholar


Dr. Liara Gonzalez

Dr. Liara Gonzalez, assistant professor of gastroenterology and equine surgery at the North Carolina State University College of Veterinary Medicine, has been named a University Faculty Scholar for outstanding academic achievements and teaching, service and scholarship contributions.

She joined NC State as a large animal surgery resident in 2007, a year after receiving her veterinary degree from Cornell University. She heads the College of Veterinary Medicine's Intestinal Regenerative Medicine lab and co-directs the large animals model core for the Center for Gastrointestinal and Biological Disease, a research center partnership between NC State and the University of North Carolina at Chapel Hill.

In addition, Dr. Gonzalez chairs the CVM's diversity committee and is a member of the AAEP's Diversity, Equity and Inclusion Task Force.

AQHA honors Dr. Charles Graham

AAEP Honor Roll and American Quarter Horse Hall of Fame member Dr. Charles Graham received the AQHA's 2020 John Andreini Special Recognition Award.


Dr. Charles Graham

Esteemed as a veterinarian, horseman and influential voice in governance and political matters that benefit the horse industry, Dr. Graham is founder of the Elgin Veterinary Clinic and Southwest Stallion Station as well as co-owner of Heritage Place Sale Co.

A veterinary graduate of Texas A&M University, Dr. Graham is an AQHA director-at-large and previously chaired the AAEP's Racing Committee in the early 1980s.

Dr. Martin Nielsen receives film award for parasite series


Dr. Martin Nielsen

Dr. Martin Nielsen, the Schlaikjer Professor of Equine Infectious Disease at the University of Kentucky's Gluck Equine Research Center, received a Winnie Award for best educational film at the 2020 EQUUS Film and Arts Fest. His 7-part series, "The Parasite Journey of the Horse," explores the parasites a horse will encounter during its life.

Dr. Nielsen received his veterinary degree from the Royal Veterinary and Agricultural University in his native Denmark. All seven videos in the series can be found on his Youtube channel at https://tinyurl.com/mneppjth.

Dr. Nielsen photo courtesy University of Kentucky College of Agriculture, Food and Environment

Three honored by The Right Horse Initiative

Drs. Shannon Reed, Patricia Tersteeg and Stacy Whitton are the veterinarian recipients of The Right Horse Initiative's Good People for Good Horses Awards, which recognize outstanding contributions to equine adoption and welfare efforts.


Dr. Shannon Reed


Dr. Patricia Tersteeg


Dr. Stacy Whitton

Dr. Reed, associate professor of equine surgery at The Ohio State University and a veterinary graduate of the University of Missouri, was recognized in the Eastern region for her work with the Retired Racehorse Project. Dr. Tersteeg, owner of Exclusively Equine Ambulatory Practice LLC in Grandview, Texas, and a graduate of Kansas State University, was recognized in the Central region for her work with the Humane Society of North Texas. Dr. Whitton, a University of Illinois graduate and associate with Iron Horse Equine Medical & Surgical Services in Elizabeth, Colo., was honored in the Western region category for her work with the Dumb Friends League Harmony Equine Center.

Additional information about their contributions to adoption efforts is available at therighthorse.org/gpfgh.

Five recently enshrined on My Mentor Honor Wall

Five pioneers in equine veterinary medicine have been added in perpetuity to The Foundation for the Horse My Mentor Honor Wall. In all, 30 individuals are now enshrined on the wall in recognition of their profound impact through mentorship during their lives and esteemed careers.

Thanks to colleagues, friends, clients and others who nominated and made gifts to The Foundation in honor of the most recent My Mentor Honor Wall inductees pictured at right:

To learn more about the most recent inductees, previous inductees, and the program, visit www.foundationforthehorse.org/support/mentor-honor-program.

Dr. Terry Blanchard

Dr. Jay C. Hansen *(deceased)*

Dr. DeWitt Owen, Jr. *(deceased)*

Dr. Norman Rantanen

Dr. Dickson Varner

INDUSTRY

Federal grants available to support rural veterinary practice

The USDA's Veterinary Services Grant Program is accepting applications through April 16 to establish or expand veterinary services in rural communities as well as support training for veterinarians, students and residents. For more information or to apply, visit https://nifa.usda.gov/program/veterinary-services-grant-program.

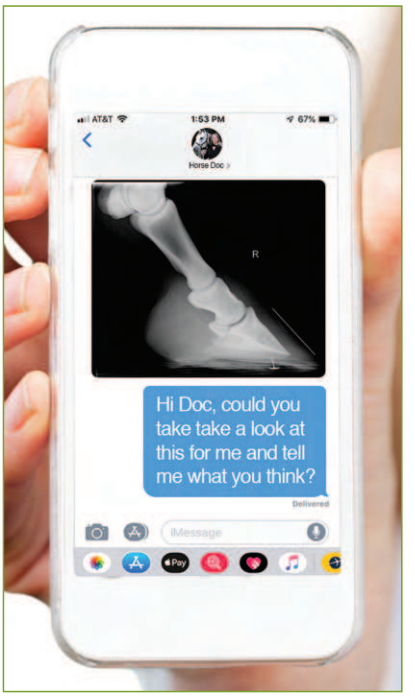
AVMA issues telehealth guidelines for veterinary practices

The AVMA has introduced a step-by-step guide to help veterinary practices implement and expand telehealth services within the concept of "connected care." This refers to the use and integration of digital technologies "to enhance and support the veterinarian-client-patient relationship and facilitate proactive and ongoing care through improved communication, diagnosis and monitoring."

The AVMA Guidelines for the Use of Telehealth in Veterinary Practice is designed to make telehealth more successful for patients, clients and practices. The reference handbook covers:

- Definitions of the key components of the telehealth landscape
- Context around federal and state regulations and legal considerations, including the VCPR
- Sample practice workflow
- Technological and workspace considerations
- How to engage the practice team and clients in ways that support effective service delivery, including marketing new services
- Pricing strategies

For more information or to download the guidelines, visit avma.org/blog/avma-guidelines-support-telehealth-use-veterinary-practices.



AAEP Educational Partner Profile: IDEXX

Being an AAEP Educational Partner is just one of the ways IDEXX Laboratories supports equine care and the practitioners who provide it.

Our extensive range of solutions includes innovative diagnostic tests, expert consulting, and advanced patient monitoring technologies. Each product or service is designed to help equine practitioners meet their clients' need for faster, more accurate diagnoses.

The IDEXX VetLab® integrated suite of in-house analyzers produces a comprehensive patient picture in just minutes. The suite includes the Catalyst One® and Catalyst Dx® chemistry analyzers, featuring the Catalyst® Equine 15 CLIP of 13 essential chemistries along with 2 ratios for screening and identifying equine health concerns. Practitioners can turn to the ProCyte Dx® and the new ProCyte One Dx® Hematology Analyzer for precise and comprehensive hematology results, including flags for banded neutrophils and equine fluid analysis. And for fast, critical answers in the field, there's the SNAP® Foal IgG Test.

For routine and advanced testing, or case consultations, equine practitioners can rely on our global network of IDEXX Reference Laboratories. IDEXX provides exclusive equine advanced testing protocols, including the Comprehensive Equine Respiratory RealPCR™ Panel, which lets veterinarians submit one specimen to test for 10 pathogens: equine rhinitis A and B viruses; equine herpesvirus types 1, 2, 4, and 5; equine adenovirus as well as *Streptococcus equi* subsp. *equi* and equine influenza virus, with the option to add a test for equine arteritis virus. They also offer the Strangles RealPCR™ Screen, an economical way to test for the three pathogens that can cause strangles or strangles-like disease; and the Equine Diarrhea RealPCR™ Panel, which uses just one specimen to test for 10 gastrointestinal pathogens for more focused treatment decisions.

IDEXX is committed to delivering solutions that protect the welfare of horses and support those who care for them. For the latest information on IDEXX diagnostics, visit idexx.com/equine.

MFM Pellet™

Special Needs Nutrition for Muscle Recovery and Repair

A recently identified muscle disorder seen in Warmbloods, myofibrillar myopathy (MFM) is characterized by exercise intolerance, unwillingness to go forward, and inability to achieve or maintain collection. Muscle biopsies taken from diagnosed horses have revealed consistent abnormalities.

Because MFM involves muscle breakdown and atrophy, rations should focus on providing high-quality protein and specific amino acids, which support muscle repair and regeneration.

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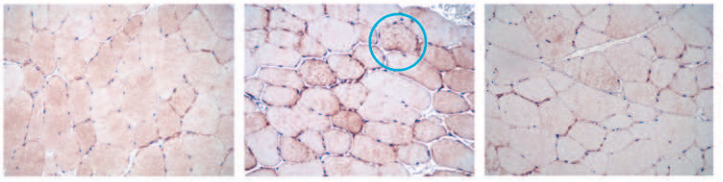
MFM Case Study



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Highlights of recent clinically relevant papers

Immune-mediated haemolytic anaemia

This retrospective case-control study by UK-based Charlotte Easton-Jones and co-workers in the USA aimed to characterise the clinical presentation, clinicopathological data, underlying conditions, treatment and outcome of immune-mediated haemolytic anaemia (IMHA) and thrombocytopenia (IMTP) in horses.

Horses were classified as primary or secondary IMHA/IMTP cases based on whether they had evidence of underlying infections, neoplasia or drug administration prior to the onset of clinical signs. Twenty-four horses and one donkey met the inclusion criteria for cases. Two horses were diagnosed with IMHA only. Both horses were positive for anti-RBC antibodies on Coombs test. Eight equids were diagnosed with IMTP only and 15 were diagnosed with IMHA and concurrent thrombocytopenia. Controls were equids presented for nonimmune-mediated disease immediately prior to and after study animals.

Neoplasia incidence was significantly higher in the study population (28%) vs controls (8%). Overall short-term survival to discharge was 60%. There was no difference in survival between horses with IMHA, IMTP or both. Equids with primary disease were 13 times more likely to survive to discharge than those with secondary disease (8/9 vs 7/16). Treatment with corticosteroids, azathioprine or blood transfusions did not significantly affect outcome, although group numbers were small. Survivors had a significantly lower blood urea nitrogen (BUN) than those that died or were subjected to euthanasia (survivors, 6.1 $\pm$ 2.5 mmol/L vs non-survivors, 9.9 $\pm$ 3.1 mmol/L). The odds of short-term mortality were also higher in horses presenting with increased BUN. Elevated BUN may act as a marker of the extent of hypoxic damage and severity of the immune-mediated disease.

Differentiation between primary and secondary aetiologies can be challenging. Primary IMHA/IMTP cases have a reasonable prognosis and warrant treatment. Secondary cases have a poor prognosis and are frequently associated with a neoplastic process. BUN may have utility as a prognostic indicator for IMHA/IMTP cases.

Septic peritonitis

This study by Juliana de Moura Alonso and co-workers in Brazil evaluated the accuracy of differences in blood and peritoneal glucose (DBPG) to differentiate between septic and non-septic peritonitis in horses.

Blood and peritoneal fluids were harvested from 35 horses that presented clinical and laboratory signs associated with peritonitis. Plasma and peritoneal glucose levels, total nucleated cell count, direct microscopic and microbiological examinations of the peritoneal fluid were evaluated.

Using DBPG levels, the animals were classified into two groups: difference $\geq$50 mg/dL (positive test) and difference <50 mg/dL (negative test). Positive microbiological examination and/or presence of bacteria in direct microscopic examination was used as a gold standard to detect septic peritonitis. The accuracy parameters analysed were: sensitivity, specificity, and positive/negative predictive values, for which the results were respectively: 0.23, 0.91, 0.60 and 0.67. Due to poor accuracy, other cut-off margins and peritoneal glucose concentrations were evaluated.

The test was considered most accurate when the DBPG was zero with sensitivity, specificity, and positive/negative predictive values of 0.85, 0.82, 0.73, 0.90, respectively. Peritoneal glucose concentrations alone were not a reliable feature to detect peritonitis. DBPG $\geq$50 mg/dL, widely used for the diagnosis of septic peritonitis, does not have a good accuracy and the DBPG = 0 has a better accuracy for detecting the disease.

Racing performance of foals with septic arthritis

In this retrospective study by Thomas O'Brien and colleagues in Australia and Hong Kong, future racing performance of 114 Thoroughbred foals ($\leq$180 days old) with septic arthritis was compared with their maternal siblings. Factors associated with survival were also investigated.

Foals had undergone arthroscopic, cannulae or through-and-through needle lavage for the treatment of septic arthritis over a 6-year period.

The stifle (35%) and tarsocrural joints (20%) were most commonly involved. Overall, 130 synovial fluid samples were submitted for culture and cytology. Bacteriological growth was detected in 80 samples (61.5%). *Streptococcus* sp. were isolated most frequently (32%), followed by *Enterobacteriaceae* sp. (28%) and *Staphylococcal* sp. (15%). Repeat lavage of the affected synovial structure was required in 39 foals (34%).

Ninety (78%) foals were discharged alive. Foals <26 days old at the time of admission were 5 times less likely to be discharged alive and foals with concurrent multisystemic disease were 6 times less likely to be discharged alive. Sixty (67%) foals discharged alive started in $\geq$1 race and there was no difference in the proportion of foals that started in a race or racing performance between foals treated for septic arthritis and their maternal siblings.

The prognosis for survival in foals with septic arthritis is good. Future racing performance does not appear to be affected. Younger foals and those with concurrent diseases are less likely to survive. Bacterial culture should be attempted on synovial fluid samples to guide treatment.

Intra-abdominal hypertension

The objectives of this prospective clinical cohort study by Patrick Foth and co-workers in the USA and UK were to determine an abdominal pressure cutoff value for intra-abdominal hypertension (IAH) in the horse and characterise IAH in horses with acute colic.

This study included 9 healthy adult horses and 56 horses with acute colic. Ventral intra-abdominal pressure (IAP) was measured in triplicate at end expiration and averaged. Each colic case was classified as medical or surgical and large intestine (LI) or small intestine (SI). Management and final outcome were also recorded. IAH was defined as $\geq$32 mm Hg (mean + 2 SDs of ventral IAP in control horses).

Intra-abdominal pressure was higher in horses with colic compared to controls. Over 18 months, 30.4% of horses with

colic had IAH (10 LI lesions, 7 SI lesions). Horses with LI medical lesions had the highest IAP of all lesions (mean 36.5 mm Hg). IAH horses with medical lesions were 15 times more likely to survive than IAH horses requiring surgery.

The authors concluded that acute colic in horses is associated with an increased ventral IAP. IAH does exist in horses with colic, notably LI medical lesions, and is associated with nonsurvival in horses that require surgery.

Silent carriers of *Streptococcus equi* ssp. *equi*

This study by John Pringle and co-workers in Sweden, Germany and the UK aimed to determine whether clinical examination, markers of inflammation, or serology differentiate silent carriers of Streptococcus equi *in recovered comingled horses*.

This prospective observational study was performed 6 months to 2 years after strangles outbreaks and included 98 Warmblood yearlings and 72 unaffected mares on a large breeding farm (outbreak A), 38 mature Icelandic horses at a riding stable (outbreak B), and 27 mixed breed horses at a boarding stable (outbreak C).

Any animal positive on culture or qPCR to *S. equi* from nasopharyngeal lavage or guttural pouch endoscopy and lavage was defined as a carrier. Complete physical examinations were performed on most horses and one group included evaluation of white blood cell counts and serum amyloid A. Sera from all horses was tested for antibodies to antigens A and C of *S. equi* using an enhanced indirect ELISA. Descriptive statistics were calculated.

Apart from weanlings at 6 months in outbreak A, there was no significant association between any clinical markers or serology with carrier state. Furthermore, 3/12 culture positive carriers were seronegative to *S. equi*.

Silent carriers of *S. equi* do not differ clinically or on markers of inflammation to their noncarrier herd-mates. Moreover, serology alone will not distinguish carriers in comingled horses.

Use of aminoglycoside antibiotics

This questionnaire-based study by Adam Redpath and co-workers in the UK aimed to document the use of aminoglycosides with a particular focus on gentamicin.

Generalist equine veterinary surgeons and specialists in internal medicine were asked to complete an online questionnaire to determine the perceived importance, frequency of use and routes of administration of the aminoglycoside antibiotics. A series of hypothetical scenarios were also evaluated regarding gentamicin. Data from 111 responses were compared to evaluate the impact of the level of specialisation on prescribing practices for different antibiotics using Chi-squared and Fisher's exact tests.

Gentamicin was commonly used empirically without culture and susceptibility testing. Generalists were more likely to use gentamicin only after susceptibility testing than specialists in a variety of clinical presentations including respiratory diseases, septic peritonitis, acute febrile diarrhoea, cellulitis and contaminated limb wounds. Intravenous administration of gentamicin was most common, although inhaled and regional administration of gentamicin and amikacin were also described. Amikacin was most commonly used by intra-articular administration. Gentamicin was more likely to be used in high-risk procedures or contaminated surgeries (86% and 74%, respectively) compared with clean surgery (32%). Gentamicin was often used perioperatively in horses undergoing exploratory celiotomy and more commonly used in horses undergoing an enterotomy (90%) than without and enterotomy (79%). Most respondents (86%) used gentamicin at a dose of 6.6 mg/kg in adults, with few changing their dosing strategies based on the presence of sepsis, although higher doses were often reported in foals (7-15 mg/kg) irrespective of the presence of sepsis.

Aminoglycosides are widely used in equine practice and use outside current EU marketing authorisations is common. Stewardship of the aminoglycoside antibiotics could be enhanced in both generalists and specialists through the more frequent use of susceptibility testing, regional administration and dose adjustment, especially in foals.

S. WRIGHT
EVE Editorial Office

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Case Report

Successful closed reduction and conservative management with traumatic elbow luxation and medial collateral ligament rupture in an equid

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Keywords: horse; cubital joint; luxation; reduction; elbow

Summary

A 9-year-old donkey jenny (212 kg) presented with an acute, non-weightbearing left forelimb lameness of 24–36 h duration. On presentation, the limb was held in flexion and abduction, with the toe not reaching the ground. The limb was rotated laterally and was unable to be manually straightened. There was significant palpable swelling along the medial aspect of the elbow joint. Radiographs revealed a medial luxation of the cubital joint with lateral displacement of the radius and ulna in relation to the humerus (**Fig 1**). An avulsion fracture of the distal aspect of the medial humeral epicondyle was present. Fragmentation could be appreciated along the craniolateral margin of the lateral humeral epicondyle, which indicated damage to the entheses of origin of the extensor carpi radialis and common digital extensor (**Fig 1**). Fracture of the tip of the anconeal process was also present (**Fig 1**). Significant displacement, avulsion fracture and instability indicated complete rupture of the medial collateral ligament. Closed reduction was accomplished under injectable anaesthesia without complication. After reduction, the lateral collateral ligament had palpable stability. A full limb bandage, a caudal splint from the ground to the point of the olecranon and a lateral splint from the ground to proximal to the scapula were placed on the left front limb. Hobbles were placed on the forelimbs proximal to the carpi. The patient was hand recovered without complication and was weightbearing and comfortable on the limb immediately upon recovery from anaesthesia. The jenny was tied and kept standing for 60 days. Full limb bandages, splints (extending proximal to the scapula), hobbles, NSAIDs and cold laser therapy were utilised, decreased and discontinued. At 74 days, a rehab programme was initiated, including passive range of motion exercises and an increasing hand walking protocol. At 8 months post-injury, the patient was not lame and was back to her previous level of exercise. Follow-up at one year post-injury found no decrease in range of motion appreciable on palpation and no lameness at a walk or trot. Elbow joint luxation in equids has been rarely described and has primarily occurred in equids less than 10 months old. Although equid elbow luxation has generally been described as having a guarded prognosis, there has now been success in 4/5 (80%) reported cases when treatment has been attempted. Closed reduction without surgical intervention in adult animals with elbow luxation can be successful, likely dependent on the level of associated injury.

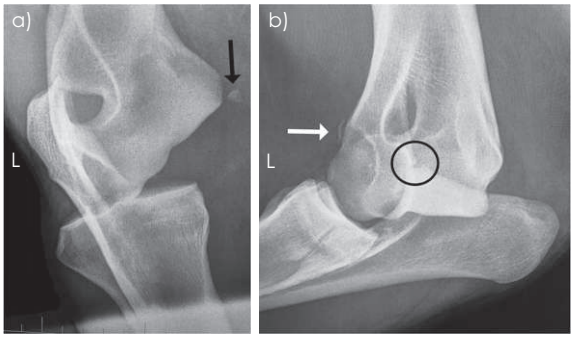

Fig 1: Craniocaudal a) and mediolateral b) radiographs acquired on presentation demonstrated medial luxation of the left elbow joint with avulsion fracture (black arrows) and rupture of the medial collateral ligament. Fracture of the tip of the anconeal process is present (black circle). Fragmentation along the craniolateral margin of the lateral humeral epicondyle indicated damage to the entheses of origin of the extensor carpi radialis and common digital extensor (white arrow).

Key points

- Full limb splints may be beneficial in cases of elbow luxation, and hobbles should be considered in cases with medial collateral ligament injury.
- Although equid elbow luxation is described as having a guarded prognosis, there has now been success in 80% (4/5) of reported cases when treatment has been attempted.
- Closed reduction without surgical intervention in adult equids with elbow luxation can be successful, likely dependent on the level of associated injury.

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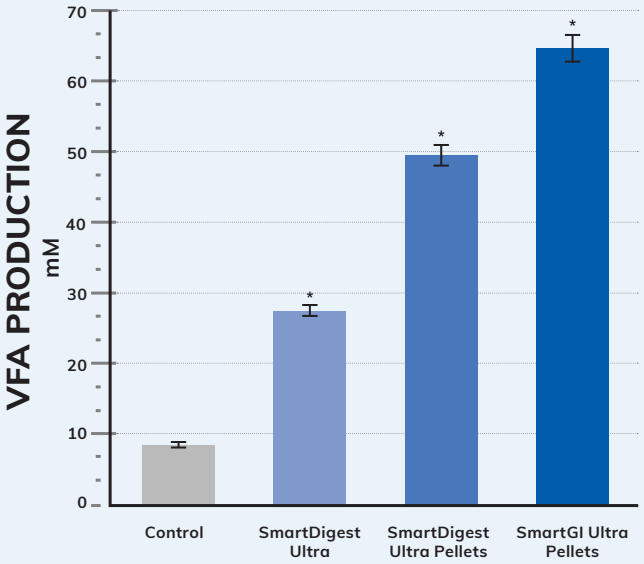

*P<0.05
Source: Diamond V Research & Innovation Center, Cedar Rapids, Iowa

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Case Report

Long bone failure after intraosseous regional perfusion

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Keywords: horse; sepsis; antimicrobials; intraosseous regional perfusion; fracture

Summary

A horse that had sustained a penetrating injury to the proximal and medial aspect of the left fore third metacarpal bone (McIII) was presented to the Charles Sturt University Veterinary Clinical Centre (CSUVCC). The horse had initially been treated with bandaging and systemic antimicrobials by the referring veterinarian but had failed to respond. Radiographs of the limb revealed bone lysis and a palisading new bone reaction on the medial splint bone that were thought to be characteristic of infection (**Fig 1**). As the associated soft tissue swelling extended above and below the carpus and therefore precluded intravenous regional perfusion (IVRP), a decision was made to use intraosseous regional perfusion (IORLP) to deliver antimicrobials to the limb. The horse was sedated with detomidine and butorphanol and an area of skin and subcutaneous tissue on the lateral diaphysis of McIII was desensitised using an infiltration of 5 mL of lidocaine hydrochloride. A 4.5-mm bone portal was made in the lateral diaphysis of the left fore McIII using the technique described by Scheuch *et al*. (2002). After a rubber tourniquet was applied to the limb above the carpus, one-third of the calculated systemic dose of gentamicin sulphate was diluted with 30 mL of normal saline and injected slowly into the medullary cavity via a cannulated screw and a short i.v. extension tube. The tourniquet was removed after 30 min, and the leg was supported with a padded bandage. The horse was maintained on systemic antimicrobials for 7 days, and using the same portal, the IORLP procedure was repeated 3 times at 48-h intervals.

Approximately 13 weeks after the IORLP, the horse was re-presented to the CSUVCC for further assessment of lameness and a swelling centred over the LF McIII in the vicinity of the original IORLP access portal. Radiographs revealed a longitudinal fracture of McIII (**Fig 2**) which appeared to have propagated from the drill hole, and the swelling was identified as a bony callus. Fortunately, the horse had survived this fracture event and had undergone a healing process that stabilised the bone. At the time of writing, the horse is sound and the healing process has continued.

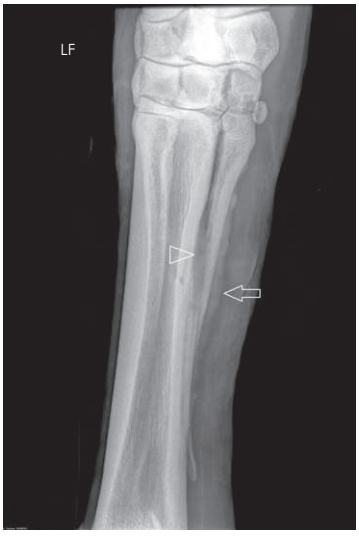

Fig 1: DMPLO radiograph showing bone lysis (arrow head) and the palisading bone reaction on McII (block arrow).

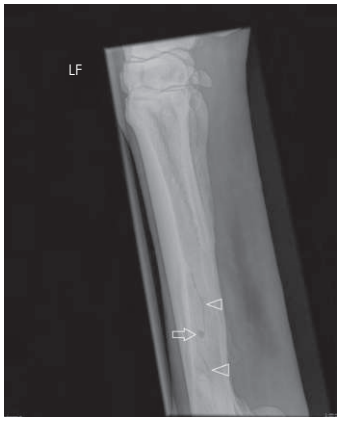

Fig 2: LM radiograph showing the bone portal (block arrow) and the associated fracture lines (arrow heads).

Key points

- Intraosseous regional limb perfusion is a recognised method of delivering high concentrations of antimicrobials to infected tissues.
- Long bone fracture in the horse as a complication of this technique has not been reported previously.
- More work is needed to determine the safest site for making an IORLP access portal in McIII and other equine bones.

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Case Report

Radiographic, computed tomographic and CT myelographic findings of an extensive cervical osteochondroma resulting in spinal cord compression at the atlanto-occipital junction

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Keywords: horse; vertebral osteochondroma; myelography; spinal cord; compression

Summary

A 13-year-old, crossbred mare was referred to Rainbow Equine Hospital for investigations of a progressive left-sided head tilt and neck stiffness noted for 3 months. The horse had a grey hair coat, and melanomas in the cranial cervical region were suspected. On clinical examination, the head and neck were persistently held in an extended position. Neurological examination revealed a reduced range of movement of the cervical spine both dorsoventrally and laterally to left and right. Cranial nerves with the exception of the head tilt were normal. Mild hypermetria was evident walking the horse on an incline, and no overt further proprioceptive reflex deficits were noted. Radiographic examination of the head revealed a large multilobulated mass extending caudodorsally from the dorsal aspect of the left guttural pouch. Computed tomographic (CT) examination was performed under general anaesthesia, revealing the lesion to surround the left atlanto-occipital (AO) joint laterally, dorsally and ventrally, and extending into the AO joint space on the left, with marked periarticular bone formation and remodelling of the left occipital condyle. There was a large rounded bone attenuating mass located within the vertebral canal extending along the length of the first cervical vertebra (C1) displacing the spinal cord to the right. Following intrathecal contrast administration (CT myelography), spinal cord displacement and compression at the level of C1, with alterations in the spinal cord shape and position, were identified (**Fig 1**). CT-guided surgical biopsies were obtained, with histological analysis revealing this to be consistent with an osteochondroma. The mare was conservatively managed, successfully inseminated 3 months after presentation and delivered a live, normal foal at term without complication and remains in good condition. Originally termed exostoses, vertebral osteochondroma, are uncommon benign tumours that in humans increase slowly in size in childhood and adolescence by endochondral ossification. Clinical signs relate to the lesion location with respect to adjacent structures, and although they are usually external to the vertebral column, when growing towards the spinal cord, they can cause variable neurological deficits depending on the degree of compression of the spinal cord or spinal nerve roots. In this instance, the close proximity to the spinal cord and the atlanto-occipital junction made CT an essential means to diagnose and come to an accurate diagnosis by means of CT-guided biopsies.

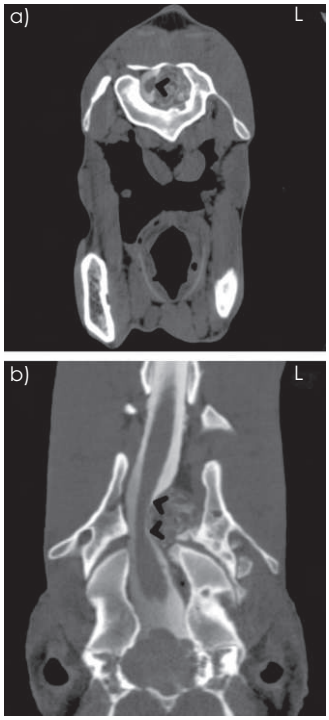

Fig 1: Transverse (a) and dorsal plane (b) CT myelographic images at the level of C1, note spinal cord displacement to the right and compression (black arrowheads) by the bony mass. There is periarticular bone formation at the atlanto-occipital joint.

Key points

- Vertebral osteochondromas are benign, slow-growing mass lesions which rarely occur in horses and result in spinal cord compression.
- Computed tomographic (CT) examination and CT myelography performed under general anaesthesia are excellent diagnostic imaging techniques for lesion characterisation and can guide potential interventions.
- Vertebral osteochondromas are frequently surgically managed in humans; however, as surgical management was considered impossible, conservative management was attempted and has been successful for >18 months in this mare.

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Case Report

Para-articular osteochondroma with intersynovial fistula between the common digital extensor sheath and carpometacarpal joint

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Keywords: horse; para-articular osteochondroma; common digital extensor sheath; tenoscopy; intersynovial fistula

Summary

A 7-year-old Holsteiner gelding was presented with a left common digital extensor sheath effusion of one-year's duration. Radiographic examination revealed two extra-articular mineralised bodies adjacent to the dorsolateral carpometacarpal joint. Ultrasonography confirmed an intrathecal location of one mineralised body in the common digital extensor sheath, palmar fraying of the common digital extensor tendon and tenosynovitis. Ultrasound could not confirm whether the second mineralised body was intrathecal or located external to the common digital extensor sheath. Common digital extensor tenoscopy facilitated removal of both mineralised bodies and revealed a fistula communicating with the carpometacarpal joint (**Figs 1** and **2**).

The mineralised bodies were histologically identified as para-articular osteochondromas. Initial speculation that the bodies were synovial osteochondromas and derived from synovium was incorrect as a synovial lining with Type B synoviocytes was not present in the histological specimens. The mineralised bodies did not show features of developmental osteochondromata, which are recognised as a solitary cartilage-capped exostosis arising at the borders of active growth plates, most commonly found in long bones.

A nodule histologically identified as a para-articular chondroma/osteochondroma is an acquired extra-articular reactive lesion that arises in dense fibrous tissue adjacent to a joint. Para-articular osteochondroma is an ossified chondroma that forms by metaplasia of fibrocytes, with 'para' defining that the fibrocytes are either located in the joint capsule or extracapsular. Similar to the histopathological findings in man, para-articular osteochondroma in the horse is histologically characterised by central trabecular bone and an incomplete cap of hyaline cartilage undergoing active endochondral ossification.

This case demonstrates the importance of histopathological analysis of osteocartilaginous bodies located in proximity to synovial structures. The large intersynovial fistula in this case report is speculated to be due to a traumatic injury to the carpometacarpal joint capsule and surrounding connective tissues. Extra-articular fibrocytes are theorised to have formed into para-articular osteochondromata that took a dependent, intrathecal position in the common digital extensor sheath. Para-articular osteochondroma should be differentiated from synovial osteochondroma and developmental osteochondroma.

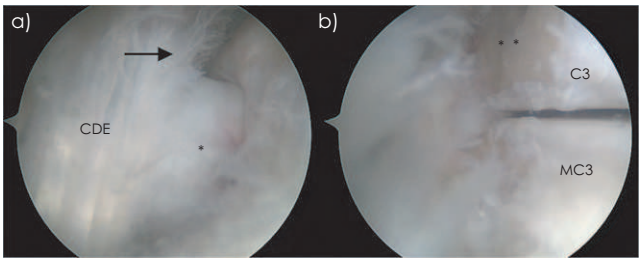

Fig 1: Tenoscopic images obtained within the common digital extensor tendon sheath. Dorsal is to the left and proximal is to the top of the image. a) An osteocartilaginous body (*) is positioned between the common digital extensor tendon and the carpometacarpal joint. Note fraying of the palmar border of the common digital extensor tendon (black arrow). CDE, common digital extensor tendon. b) The carpometacarpal joint is visualised during tenoscopy of the common digital extensor tendon sheath, indicating a fistula between the two synovial structures. A concavity on the dorsolateral third carpal bone (**) represents the anatomical dorsal attachment of the CDE and was debrided with a curette. C3, third carpal bone; MC3, third metacarpal bone.

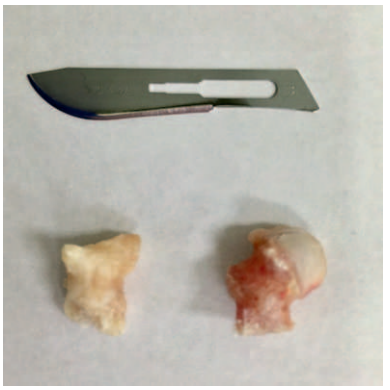

Fig 2: Gross specimens of the two surgically removed chondro-osseous bodies from the common digital extensor sheath, compared to the size of a number 10 blade.

Key points

- Para-articular osteochondroma is an ossified chondroma that initially arises by chondroid metaplasia of fibrocytes either in the joint capsule or fibrous tissue around a joint.
- Histology of this chondro-osseous body shows central trabecular bone and an incomplete cap of hyaline cartilage undergoing active endochondral ossification.
- Histological analysis of an osteocartilaginous body is important to differentiate a para-articular osteochondroma from a synovial osteochondroma or developmental osteochondroma.

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Case Report

Mineralisation of the longitudinal odontoid ligament in three horses identified on computed tomographic examination

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Keywords: horse; mineralisation; longitudinal odontoid ligament; computed tomography

The purpose of this case report is to describe the identification and appearance of mineralisation within the longitudinal odontoid ligament in three horses.

Three horses underwent computed tomography (CT) examination as part of investigation for either head-shaking or perceived neck or poll pain. A CT examination of the head and cranial cervical spine was performed, and marked mineralisation of the longitudinal odontoid ligament of the dens (**Fig 1a**) was identified in these three clinical cases. The other concurrent CT findings for these three horses were mild and considered unlikely to be clinically significant. The three clinical cases described were compared to age–match controls, and the CT appearance of the longitudinal odontoid ligaments of these three horses identified a well-demarcated, clearly marginated, symmetrical shaped, bilobed structure (**Fig 1b**).

There are currently no reports of mineralisation of the longitudinal odontoid ligament in horses. Extrapolating from the literature regarding the ligaments of the occipitoatlantoaxial region in other species and mineralisation of ligaments other than those of the occipitoatlantoaxial region in the horse, we speculate that the possible aetiopathogenesis of mineralisation of the longitudinal odontoid ligament of the horse may include accumulative repetitive strain, acute trauma, age-related change, inflammation, genetic predisposition or, less likely, metastatic mineralisation. Although the significance of this finding to the presenting clinical problems in the cases described remains speculative, an association between mineralisation of the longitudinal odontoid ligament and compatible clinical signs merits further investigation.

Key points

- The normal CT appearance of the longitudinal odontoid ligaments is of a well-demarcated, clearly marginated, symmetrical shaped, bilobed structure.
- The cause for mineralisation of the longitudinal odontoid ligament is unknown.
- The significance of this finding remains speculative, and an association between mineralisation of the longitudinal odontoid ligament and compatible clinical signs of head-shaking or neck/poll pain merits further investigation.

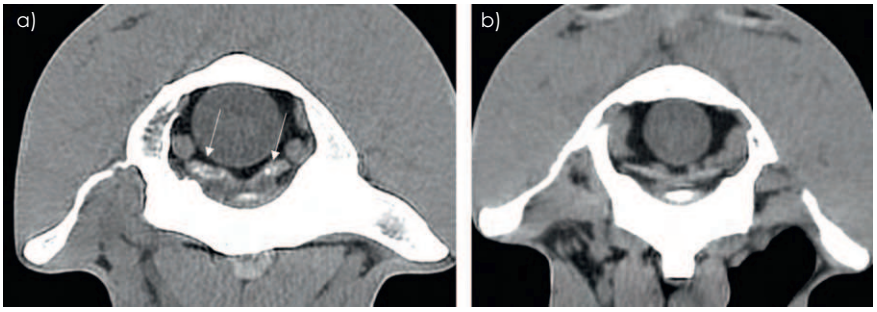

***Fig 1:** Transverse multiplanar reconstruction (MPR) image (left is on the right-hand side of the image, top is dorsal) at the level of the dens of C2 reconstructed using a soft tissue algorithm and displayed using a soft tissue window WW 350 WL 40. a) Case. There are multiple, focal, slightly poorly defined regions, of approx. 2 mm × 2 mm, of mineral attenuation within each lobe of the longitudinal odontoid ligament. White arrows indicate the mineral attenuation within each lobe of the longitudinal odontoid ligament. b) Age-matched horse. The longitudinal odontoid ligament is symmetrical and bilobed in shape, with clearly defined margins and a uniform heterogenous attenuation evident.*

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Case Report

Conservative management of iatrogenic bladder rupture and uroperitoneum in a gelding with urolithiasis

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Keywords: horse; cystoscopy; dysuria; stranguria; urogenital

Summary

This report details a case of iatrogenic bladder rupture in a gelding that was successfully treated with conservative management (**Figs 1** and **2**). Rupture of the caudoventral bladder wall occurred at the time of attempted cystoscopy, whilst the bladder was being insufflated with air using a manual pump for further investigation of stranguria and suspected urolithiasis. A temporary perineal urethrostomy was performed to remove the urolith. Peritoneal drainage was performed via a drain in the most dependent point of the ventral abdomen, and the abdomen was lavaged via the drain for 7 days. Urine was allowed to drain passively from the bladder via a Foley catheter for 7 days. Intravenous crystalloids, antimicrobials, nonsteroidal anti-inflammatories and misoprostol were also administered. Six weeks after discharge from the hospital, the horse was reported to be clinically well and urinating normally via the penis. The perineal urethrostomy healed without complication. The horse made a complete recovery and returned to competition work.

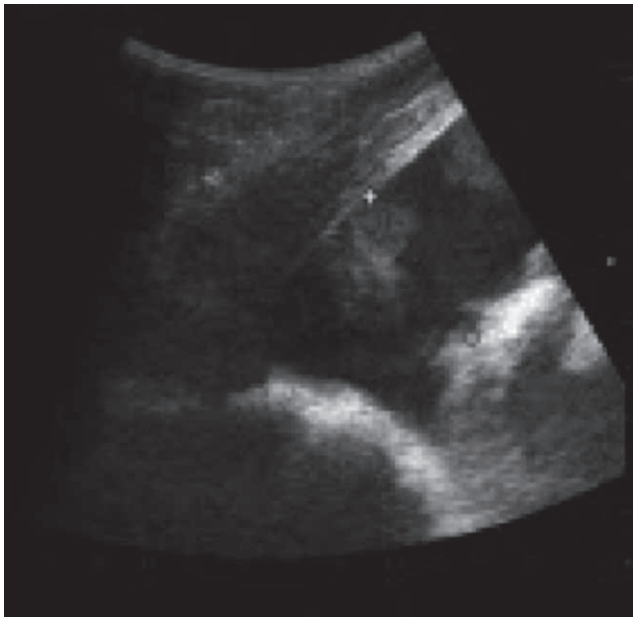

Fig 1: Ultrasonograph of the ventral abdomen of a 14-year-old Irish gelding showing an accumulation of anechoic fluid in the ventral abdomen following iatrogenic bladder rupture.

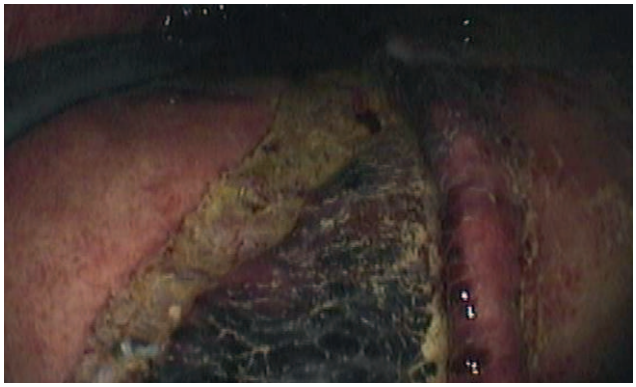

Fig 2: Cystoscopy image of the bladder of a 14-year-old Irish gelding shortly after bladder rupture is assumed to have occurred. Oriented with dorsal to the top. The ridge of tissue with petechial haemorrhages to the right is thought to represent one margin of the bladder mucosa that has retracted. The haemorrhagic area in the centre may represent deeper layers of the bladder wall possibly supported by other underlying viscera. The yellow regions are assumed to be areas with adherent sabulous material.

Key points

- The risk of bladder rupture needs to be considered when cystoscopy is performed, particularly if there is a risk of urethral obstruction.
- Large bladder tears can heal without surgical intervention.
- Persistent uroperitoneum can be managed medically.

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Clinical Commentary

Management of bladder rupture in mature horses

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Keywords: horse; bladder; urogenital

Summary

Rupture of the urinary bladder of adult horses is rare with both reports of surgical repair and conservative management in the literature. The case report by Gosling *et al*. in this issue describes the successful treatment of an iatrogenic bladder tear in an adult gelding. The aim of this commentary is to review the described treatment options.

Introduction

Bladder rupture is rare in adult horses with a reported incidence of 0.01% in post-partum broodmares (Higuchi *et al.* 2002). Diagnosis is typically straightforward and is described elsewhere (Jenei 2012). Surgical repair is recommended when possible (Schott and Woodie 2012; Pye *et al*. 2018). In some cases, the location of the tear may preclude surgical access and conservative management with secondary intention healing is chosen.

Surgical treatment options

The aims of treatment include stabilising the patient by correcting metabolic derangements, draining uroperitoneum and repair of the defect. Hyperkalaemia is the most important abnormality that should be at least partially corrected prior to surgery. Fluids without potassium (0.9% saline) are administered along with dextrose to drive potassium intracellularly. Calcium is often given to antagonise the negative cardiac effects of hyperkalaemia. The traditional method of bladder repair via ventral midline celiotomy can be very difficult to provide access due to the intrapelvic location of the bladder and depth of the adult abdomen. Also, tears in adult horses often are near the neck of the bladder, rather than at the apex as is the typical, more accessible, location in neonates (Rodgerson *et al.* 1999; Schott and Woodie 2012). A caudal paramedian approach can also be used to gain somewhat better access to the bladder and allow at least partial apposition of the tear.

Repair in standing horses is often advocated due to the difficulties with a traditional celiotomy as well as that these can be high-risk anaesthetic candidates, particularly periparturient mares. These methods include eversion of the bladder with or without a urethral sphincterotomy or through an incision in the vaginal wall (White, 1977; Rodgerson *et al.* 1999; Stephen *et al.* 2009; Higuchi *et al.* 2012). These procedures are not possible in male horses and may not be suitable for caudal tears. The eversion techniques have been associated with complications such as urine dribbling and delayed vaginal wound healing in post-partum mares. Laparoscopic repair is a viable option in both males and females but can be difficult especially in post-partum mares prior to uterine involution (Walesby *et al.* 2002; Rijkenhuizen *et al.* 2008; Tuohy *et al.* 2009; Hendrickson and Lee 2012). More recently, Pye *et al*. (2018) described transurethral endoscopic guided intraluminal closure with a braided lactomer suture. At 60-day recheck cystoscopy, the tears had healed and there was no evidence of calculus or remaining suture. When suturing the bladder, it has been recommended to place sutures without entering the lumen as it may act as a nidus for calculi formation, although these recommendations are largely based on early literature using nonabsorbable suture.

Conservative management

Tears that are in a difficult location to approach surgically can be managed conservatively by correcting metabolic derangements, draining uroperitoneum and urinary catheterisation (Gibson *et al.* 1992; Peitzmeier *et al.* 2016; Gosling *et al*. 2021). Intravenous fluid therapy is implemented as described earlier. Transabdominal drains are placed to allow continuous drainage of urine to help correct electrolyte abnormalities, decrease chemical irritation and to perform lavage. Peritoneal dialysis has been described using a solution of 1.5% dextrose in a balanced electrolyte fluid to create a hypertonic dialysate (Reuss *et al.* 2006). This allows for diffusion of blood urea nitrogen, creatinine and other elevated electrolytes from the bloodstream into the peritoneal dialysate, which is then drained. Serum haematology and biochemistry should be monitored frequently to evaluate hydration and electrolyte status to appropriately adjust the rate and type of intravenous fluids, particularly when peritoneal dialysis is also performed. Urinary catheters are placed in these patients to continually drain urine to decrease tension on the bladder wall and reduce the amount of urine accumulating within the abdomen. Urinary catheters should be placed using strict aseptic technique and a closed or semi-closed system should be used. Catheters should be changed often (approximately every 3 days) and prophylactic antibiotics used to limit the risk of ascending infection. With proper client education and assistance from the referring veterinarian, urinary catheters can be maintained on the farm, which can greatly reduce the duration of hospitalisation and hence expense borne by the client. Although the time for the equine bladder wall to completely heal by secondary intention is unknown, urinary catheters are typically left in place for at least 14 days. The case reported by Gosling *et al.* (2021) showed cystoscopic evidence of urine held within the bladder at 8 days, and a urinary catheter was left in place for an additional 7 days. In male horses, urinary catheters are often placed through a perineal urethrotomy, rather than through the urethral

orifice. This location is often easier to manage and these incisions typically heal without complication.

Conclusion

Cases of bladder rupture warrant surgical repair if accessible to allow for faster healing, direct lavage of the peritoneal cavity, decreased risk of secondary ascending infections and reduced hospitalisation time. When the location precludes adequate access, medical management has proven to be effective with supportive care including catheterisation and drainage of excess peritoneal fluid.

Authors' declaration of interests

No conflicts of interest have been declared.

Ethical animal research

Not applicable.

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Authorship

Both authors contributed to this manuscript and approved the final version.

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Case Report

Upper respiratory signs associated with *Anaplasma phagocytophilum* infection in two horses

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Keywords: horse; *Anaplasma phagocytophilum*; anaplasmosis; upper respiratory; dysphagia

Case 1

An adult Quarter Horse gelding was evaluated for tachypnoea and acute dysphagia. Evaluation revealed hyperthermia (39.4°C), tachycardia (80 beats/min), tachypnoea (40 breaths/min), increased respiratory effort, nostril flare, icteric sclera and small petechiations on the nasal mucosa. Blood analysis revealed a packed cell volume (PCV) of 30% (RR 30–47%), leukocytosis 14.6 × 10^9/L (RR 4.9–11.1 × 10^9/L) characterised by neutrophilia 12.9 × 10^9/L (RR 2.5–6.9 × 10^9/L) hyperfibrinogenaemia 7.4 g/L (RR 0–4 g/L), hyperbilirubinaemia 60 μmol/L (RR 0–136 μmol/L) and hyperglobulinaemia 53 g/L (RR 24–47 g/L). Platelets were clumped but determined to be adequate through an external commercial laboratory.

The horse became acutely dysphagic 24 h after the start of treatment with gentamicin 6.6 mg/kg bwt i.m. q. 24 h and ceftiofur 2.2 mg/kg bwt i.m. q. 24 h. An upper airway endoscopy revealed a feed contaminated pharynx, dysphagia, mucoid contaminated guttural pouches and left laryngeal hemiplegia (**Fig 1**).

The horse was diagnosed with *Anaplasma phagocytophilum* infection using PCR on peripheral blood. Treatment was changed to oxytetracycline 6.6 mg/kg bwt i.v. q. 24 h for two doses, followed by minocycline 4 mg/kg bwt per os q. 12 h for 10 days.

Fig 1: Case 1: Feed contaminated pharynx and larynx.

A repeat upper airway endoscopy revealed improved pharyngeal function and resolved dysphagia. The left laryngeal hemiplegia remained.

Case 2

A 20-year-old QH gelding was evaluated for respiratory stertor and acute swelling of the head. Evaluation revealed hyperthermia (39.5°C), tachycardia (60 beats/min), tachypnoea (40 breaths/min), increased respiratory effort, nostril flare, respiratory stertor and severe diffuse soft tissue swelling of the submandibular and parotid region bilaterally. The horse was a grade 3/5 ataxic on the front and hindlimbs according to the Mayhew's grading scale. A temporary tracheostomy was performed due to concern of upper airway obstruction, acute onset of facial swelling and inability to lift the head.

Blood analysis revealed a PCV of 32%, leukopenia 2.1 × 10^9/L, neutropenia 2.1 × 10^9/L, lymphopenia 0.5 × 10^9/L (RR 1.5–5.1 × 10^9/L) hyperfibrinogenaemia 6.6 g/L, hypocalcaemia 2.58 mmol/L (RR 2.60–3.23 mmol/L), hyperglobulinaemia 53 g/L and thrombocytopenia 32 × 10^9/L (platelets were determined to be adequate by external laboratory). On a blood smear, morulae were identified within neutrophils. PCR was positive for *Anaplasma phagocytophilum*.

An upper airway endoscopy was performed due to swelling of the submandibular region and revealed severe diffuse pharyngeal swelling. The horse was able to swallow when stimulated and no dysphagia was present. The horse was treated with oxytetracycline for a total of three doses followed by minocycline for 14 days and made a full clinical recovery. The tracheostomy was removed 5 days after presentation.

Key points

- In areas with high disease prevalence, emergency clinicians should be aware of this potential cause of respiratory distress in equines with a history of tick exposure, fever, oedema and characteristic haematological changes such as anaemia, lymphopenia and thrombocytopenia.
- This report describes a novel manifestation of *Anaplasma phagocytophilum* infection in horses.
- Other atypical presentations of *Anaplasma phagocytophilum* include cavitary effusion, rhabdomyolysis, recumbency, disseminated intravascular coagulation and death. The pathogenesis of these presentations is not well understood.

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Case Report

Transplacental infection of a foal with *Anaplasma phagocytophilum*

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Keywords: horse; anaplasma; pregnancy; critical care large animal; internal medicine

Summary

A 4-year-old 670 kg Oldenburg maiden mare presented on Day 341 of gestation with a 2-day history of a decreased appetite and a fever of 40°C. She lived in an area endemic for *Anaplasma phagocytophilum* and with a high tick population. The mare was diagnosed with equine granulocytic anaplasmosis, showing morulae of the intracellular bacterium *A. phagocytophilum* within neutrophils. Significant thrombocytopenia was identified with a platelet count of 19 × 10^9/L (rr: 92-253 × 10^9/L). Abdominal ultrasonography was unremarkable for a late-term pregnant mare. Therapy with 7.5 mg/kg i.v. oxytetracycline every 12 h was initiated and adjusted to 10 mg/kg bwt i.v. twice daily post-partum, with the mare treated for 5 days.

The mare became restless at 12.00 am during the evening after presentation, and a filly was naturally delivered at 03.30 am, following 15 min of Stage II labour. Spontaneous breathing was observed immediately following birth with the heart rate increasing to 120 beats/min. Post-partum physical examination was unremarkable for a 52 kg full-term foal.

The mare's placenta was retained for 7 h post-foaling, despite repeated administration of oxytocin, hand-walking and gradual traction by a water-filled glove attached to the exterior portion of the placenta. Following expulsion of the main body of the placenta, the tip of the non-gravid horn remained retained. Uterine lavage was performed, and the residual placenta was weighted resulting in complete expulsion at 8 h post-partum. Histopathology of examined sections of placenta was unremarkable, with no evidence of inflammation.

The filly failed to stand within one hour following delivery, despite a normal gestational length and parturition. Initial blood work showed an elevated PCV, marked hyperlactataemia, hypoglycaemia and hypercreatininaemia. Therefore, 40 mL/kg bwt Plasma-lyte A with 2.5% dextrose was administered i.v. over the following hour. Blood was obtained for culture and anaplasma polymerase chain reaction (PCR), prior to any intake of colostrum (immediately peri-partum). *Anaplasma phagocytophilum* PCR was positive, whilst blood culture yielded no growth.

Four hours after delivery, the filly's vital parameters were normal, but she remained unable to stand unaided. Complete haematology was unremarkable aside from a mild thrombocytopenia of 87 × 10^9/L, low globulin levels, increased indirect bilirubin and elevated creatine kinase. Serum creatinine concentrations had improved, and the initial serum amyloid A (SAA) was normal. Pending blood culture and anaplasma PCR results, the foal was started on oxytetracycline (7.5 mg/kg bwt i.v. q. 12 h) and amikacin (20 mg/kg bwt i.v. q. 24 h).

The foal received 2 L frozen hyperimmune plasma within the first 24 h of life, as the mare lacked colostrum and frozen colostrum was unavailable. The filly was initially fed via an indwelling nasogastric tube. She was frequently assisted to rise and encouraged to nurse, successfully latching on and nursing at 10 h of age. By 18 h post-partum, the foal was urinating normally, with a urine-specific gravity of 1.005. However, her blood lactate remained elevated (3.2–4.2 mmol/L) despite normohydration (PCV 38–40% and total solids 48–52 g/L) and fluid administration (170 mL/kg bwt Plasma-lyte A over 24 h), suggesting type B hyperlactataemia. Adequate immunoglobulin levels were confirmed at 24 h of age, but the SAA had increased to 145 μg/mL, suggesting an ongoing inflammatory or infectious process. Intravenous fluid therapy was discontinued by 36 h of age, as the foal could rise and nurse independently. Subsequently, repeat haematology at 60 h post-partum showed a mild neutrophilia (11.17 × 10^9/L) and progressive rise in SAA (196 mg/L) which decreased by Day 5. Mild hyperlactataemia persisted until 72 h of age.

The filly remained clinically normal with an average daily weight gain of 0.75 kg/day and was discharged on Day 5 with 1 week of minocycline treatment (4 mg/kg bwt orally q. 12 h). The filly was PCR negative for *A. phagocytophilum* at the time of discharge. The mare required no further treatment at home, and both patients recovered uneventfully.

Transplacental transmission of *A. phagocytophilum* was the most likely route of infection in this foal, due to a lack of colostrum intake prior to diagnostic testing. The pathophysiology of intrauterine *A. phagocytophilum* transmission may be associated with a vasculitis, resulting in placentitis, or be facilitated by a species-specific type of placentation. While transplacental, intrauterine or congenital infection with *A. phagocytophilum* has not been previously documented in foals, this filly's post-partum inflammatory response and mild thrombocytopenia are comparable to abnormalities identified in previous reports of neonatal anaplasmosis in other species.

Key points

- This is the first report of transplacental transmission of *A. phagocytophilum* in a mare, based on precolostral confirmation of infection in the foal.
- The affected filly showed signs of perinatal asphyxia syndrome despite normal parturition, alongside an inflammatory response and thrombocytopenia.
- Congenital anaplasmosis should be considered in a foal delivered to a mare suffering from equine granulocytic anaplasmosis during late-term pregnancy.

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Clinical Commentary

Anaplasma phagocytophilum (*Ehrlichia equi*) 50 years later

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Keywords: horse; *Anaplasma phagocytophilum*; *Ehrlichia equi*

The accompanying report of two horses presenting with severe upper respiratory signs and testing positive for *Anaplasma phagocytophilum* further expands the list of potential clinical presentations for this tick-borne infection (Deane *et al*. 2021). It also provides an important lesson for the equine practitioner in the value of expanding traditional thinking and looking for associations not previously made by others, including the 'experts'. A dysphagic horse and a horse with respiratory distress caused by *A. phagocytophilum*? One can imagine the hallway comments—you've got to be kidding! What follows is a commentary—more of a story of how the agent of this disease was first identified and the expanding awareness of the various clinical presentations and information on human infection with this agent (**Fig 1**).

The equine infectious disease formerly termed *Ehrlichia equi* was renamed *Anaplasma phagocytophilum* following DNA sequencing and use of genetic relationships mapping (Dumler *et al*. 2001). The disease was first identified in northern California in the early 1960s when a horse from the Sierra foothills presented to the UC Davis Veterinary Medical Teaching Hospital with fever, limb oedema, lethargy, ataxia and reluctance to move (Gribble 1969). A haematology technician, Rachael Smith, identified distinct inclusion bodies in neutrophils, termed morulae, which resembled inclusion bodies reported in the UK in the early 1950s in sheep (Foggie 1951). Four years following the first identification, a horse with similar signs presented to the VMTH and inclusion bodies were observed on a blood film. A young intern named Tony Stannard drew 100 mL of blood from the horse and injected it i.v. into a research horse. In 72 h, the recipient horse developed a fever and signs progressed over the next 5–7 days to include persistent fever, limb oedema, mild petechiation, icterus, anorexia and reluctance to move. Heparinised blood was collected from the horse and frozen (Stannard *et al*. 1969). A year later, David Gribble began his PhD in comparative pathology and completed 43 horse transmissions and 31 necropsies with a detailed investigation into the pathology and further attempted transmissions in other species (Gribble 1970). Over the next 15 years, a total of six more horses were diagnosed with *A. phagocytophilium*. In 1975, 2 months after graduation from UC Davis School of Veterinary Medicine, a sick horse was brought to a small animal clinic in rural Mendocino County where I was working and I examined the horse in the parking lot of the clinic. It was 2 years old from a 40-horse herd living on wooded pasture. The horse had many ticks present, was febrile, lethargic, ataxic, icteric, but had no limb oedema. An in-house CBC revealed mild anaemia, icterus, neutropenia and lymphopenia, and the platelets appeared less than were generally viewed on a slide. While pondering what to say to the client, I stared at the microscope and went to use oil immersion to obtain more time to come up with something. In several neutrophils were the very characteristic morulae (**Fig 1**). The horse was in Mendocino County far from the central valley foothills, the only location where the infection had been noted in just six horses anywhere in the world. I explained to the owner that the horse had *E. equi* and went next door to the farm supply, bought injectable tetracycline, administered it to the horse i.v. and sent him home with oral tetracycline powder. The horse made a full recovery. I sent the slides to Rachael Smith and David Gribble who confirmed the inclusions were typical *E. equi* inclusions. No PCR or DNA sequencing existed at that time. Little did I know that my career would change based on that diagnosis and I would obtain an NIH grant for 8 years with John Hopkins Medical School following the identification of this aetiological agent as a cause of human infection including fatalities following tick bite exposure. I shared my blood slides with the inclusion bodies with other veterinarians in northern California, all of which indicated they had never seen it. That would change over the next few years and I compiled a case report of 49 cases (Madigan and Gribble 1987). The first reaction of the veterinarians who had practised in the area I was new to, was that I saw something that did not really cause illness in horses and they thought it might be some artefact not seen

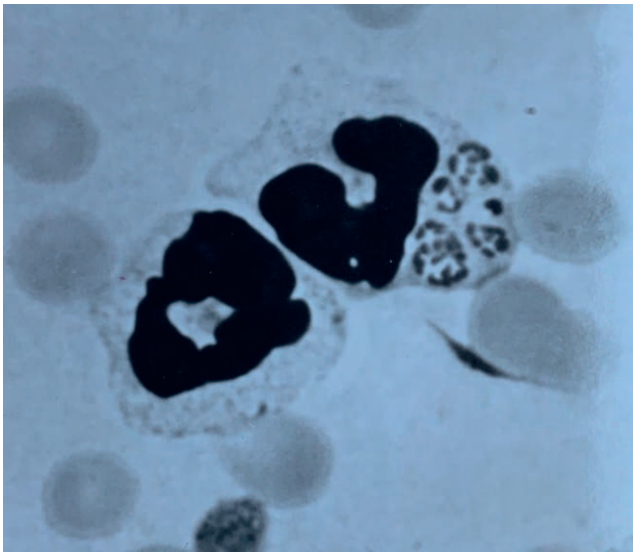

Fig 1: Anaplasma phagocytophilum inclusions bodies in equine neutrophil.

in that region. Likewise, veterinarians authoring the report here chose to look beyond the usual suspects, offer testing that others might consider unnecessary in the two horses and found a different villain as the cause of the horses' presentation. Kudos to them.

When an infectious disease specialist physician in Minnesota named Johan Bakken was examining a woman in the emergency room with clinical signs initially thought to be severe flu-like symptoms, he extracted the history of hiking and tick exposure 2 weeks before the onset of fever. Dr Backen wanted the patient admitted to intensive care, and a protocol required the completion of a sepsis score which included noting the presence of band neutrophils. Backen went to the laboratory and did the viewing for band neutrophils himself and noted inclusion bodies in neutrophils (Bakken *et al*. 1994). Subsequently, human patient blood sent to UC Davis transmitted the infection to a research horse that developed typical northern California *E. equi* clinical infection (Madigan *et al*. 1995). The horse was a natural model for determination of vectors, characterisation of the agent and the development of PCR testing resulting in NIH funding in our group with John Hopkins Medical School. The horse model allowed detection of the tick vector, a source of the organism for characterisation and the first cultivation of the agent in cell culture (Dumler *et al*. 1995; Barlough *et al*. 1996; Goodman *et al*. 1996; Munderloh *et al*. 1996; Richter *et al*. 1996; Chang *et al*. 1998; Vredevoe *et al*. 1999; Foley *et al*. 2009). All of this starting with a sick horse examined in a parking lot in rural Mendocino County.

The infection is now detected in other species and is numerous, found in several areas of the United States and over a dozen countries worldwide with several hundred publications in the literature (Stuen *et al*. 2005, 2013; Silaghi *et al*. 2011; Krämer *et al*. 2014; Elhamiani Khatat *et al*. 2016).

Why did these horses in the EVE report published here develop the first clinical signs of upper airway-related dysfunction? Gribble determined the pathological lesions in horses are vasculitis, often necrotising. A substantial immune component is a part of the pathology in the horse and treatment of experimental horses with only dexamethasone minimised pathology but prolonged the course of infection (Davies *et al*. 2011). Gribble noted that some organs and body regions had more vasculitis than others and reported finding severe vasculitis in testis, ovaries, lung, kidney, brain, heart as well as limbs. Young horses did not develop limb swelling and the magnitude of the pathology was milder than horses older than 5 years (Ziemer *et al*. 1987). Also, 6 of the 31 experimental infections had severe concurrent bacterial infections, and one horse died of *Streptococcus* septicaemia, suggesting the infection can produce a degree of immune suppression, which is not surprising given the haematology findings of neutropenia and lymphopenia. The variations seen in the magnitude of vasculitis-related pathology might explain the account for presentations involving clinical signs of colic, myopathy, ataxia and cardiac arrhythmia (Lepidi *et al*. 2000; Hilton *et al*. 2008). In human infections with the same agent, similar pathologies were reported including acute kidney injury and rhabdomyolysis (Dahlgren *et al*. 2015). In human beings, the risk of death from this tick-borne infection is higher in people over 50 years of age (Bakken and Dumler 2006). Hence, the findings of pharyngeal pathology in the cases reported here might relate to factors including age, co-infection or region-specific vasculitis severity.

Detection of the agent *A. phagocytophilum* can be done visually on blood films (blood smear or buffy coat) and by PCR. One limitation of visualisation is that during the early phase of infection, neutrophils (or eosinophils, which can also contain the organism), are difficult to find due to low numbers of cells affected in peripheral blood. Using a buffy coat smear does aid the concentration of neutrophils on a slide. Giemsa and new methylthioninium chloride are used for staining. It is important not to confuse a Döhle body for an elementary body form of the organism and search for cells containing morulae which are simply clusters of elementary bodies forming a circular cluster within the cytoplasm of neutrophils. Real-time PCR has been demonstrated to be accurate and reliable for the detection of the agent in the blood, even in the early stages of infection (Pusterla *et al*. 1999).

One clinical observation is rather intriguing in that there are no reports of horses with *A. phagocytophilum* infection, including untreated, developing laminitis. Additionally, infected horses treated with dexamethasone in our experimental studies and those treated because of severe ataxia did not develop laminitis. One horse presented with a pelvic fracture from a fall was determined to have *A. phagocytophilum* in neutrophils suggesting the ataxia associated with the infection was a factor in the traumatic event.

When should a veterinarian suspect *A. phagocytophilum* infection? Clues would be the horse originating from an endemic area or having been ridden in the past 10–14 days in an endemic area, exposure to ticks,—especially *Ixodes sp*. ticks, and a fever. The clinical manifestations progress from only a high fever and partial anorexia to further variable clinical signs over the next 2–10 days. Horses which recover without treatment are not carriers of the agent.

The organism is highly sensitive to tetracyclines, and once-daily treatment i.v. with 7 mg/kg bwt has been highly effective in reducing fever within 24 h. In the author's experience, if the horse has a fever 24 h post-oxytetracycline, the diagnosis of *A. phagocytophilum* should be reconsidered, or a severe secondary infection might be present. Relapses have occurred in horses seen early in the infection and treated for 3–5 days. A course of treatment of 7 days is suggested.

The horse can be a sentinel for risk of human infection by tick exposure in the same environment, and human cases have included fatalities (Bakken and Dumler 2006). Veterinarians working in the field in endemic areas which might get tick exposure during a farm visit should be aware of this risk, and if a fever develops within 10–14 days, inform an attending physician of the risk factor. Human fatalities have been associated with delays in treatment because of failure to consider this particular infection in a febrile sick patient (Bakken and Dumler 2006). The equine practitioners in the EVE article here did not make that error in their patient. Kudos to them and the many field veterinarians who subsequently identified *A. phagocytophilum* infection in horses where it had not been previously reported and therefore expanded awareness of the public health risk in those areas.

Author's declaration of interests

No conflicts of interest have been declared.

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Not applicable.

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Roundtable: Insights on DJD

American Regent Animal Health, makers of Adequan® i.m. (polysulfated glycosaminoglycan), invited eight equine practitioners to discuss the present and future of degenerative joint disease (DJD) diagnosis and treatment.

This group included **Kent Allen**, DVM, owner of Virginia Equine Imaging and a founder of the International Society of Equine Locomotor Pathology (ISELP); **Robin Dabareiner**, DVM, PhD, DACVS, who worked at Texas A&M for 23 years before working at Waller Equine Hospital in Texas; **Christopher E. Kawcak**, DVM, PhD, DACVS, DACVSMR, ACVS Founding Fellow/MIS, director of Equine Clinical Services at Colorado State University; **Zach Loppnow**, DVM, an associate veterinarian at Anoka Equine Veterinary Services in Minnesota; **Rick Mitchell**, DVM, MRCVS, DACVSMR, president of Fairfield Equine Associates in Connecticut and a founding member of ISELP; **Kyla Ortved**, DVM, PhD, DACVS, DACVSMR, the Jacques Jenny Endowed Term Chair of Orthopedic Surgery, University of Pennsylvania's New Bolton Center; **Kelly Tisher**, DVM, managing partner at Littleton Equine Medical Center in Colorado; and **Gary White**, DVM, owner of Sallisaw Equine Clinic in Oklahoma.

All are paid consultants of American Regent, Inc. The opinions expressed by the consultants may not be the opinions of American Regent Animal Health or American Regent, Inc.

KEY TAKEAWAYS

- Allen stated that changes veterinarians are seeing in the **frequency of DJD** are "probably due more to us getting better at diagnosis than the animals getting more disease."
- Kawcak said some categories of horses face **increased incidence of DJD**. "I deal with a fair number of young cutting horses ... I do think in those young, hardworking, active athletes with that big push in their 3-year-old year that the incidence has gone up, especially in stifles and hocks."
- Tisher mentioned the **"diagnosis dilemma"** with young horses: "Where does degenerative joint disease become the diagnosis, when you maybe don't have imaging changes but you do have the strong sense of synovitis, capsulitis and [the] need to manage that horse at a young age?"
- Kawcak said the absence of CT and MRI leads to **under-diagnosing DJD**: "I think we're surprised about how many times a relatively normal-looking joint on radiographs will have fairly substantial changes on MRI or CT."
- The group mentioned the importance of **early joint health intervention**. Mitchell asks clients, "What's it going to cost you to replace this horse? Compare that expense to what it would cost to maintain this horse properly."
- Ortved said providing **targeted education** to help clients understand what veterinarians can do to diagnose and treat DJD is important, as is teaching clients what DJD is.
- Group consensus was that while there might be different abilities to pay for diagnoses and treatments among top-level performers, mid-level athletes and backyard/senior horses, veterinarians should "offer the **best alternative first**, [and] if that's not workable, find out what is," White said.
- The group agreed oral joint supplements are an issue. Tisher summarized the sentiment: "If you add up what your feed-through costs [are with supplements], you may be able to do a box of Adequan i.m. as an FDA-approved product for about half the price."
- Loppnow said, "When it comes to recommending things that I think are going to be interventional and helpful for these horses, it really **falls back on the science** for me."
- Dabareiner said, "I think some of those tough old horses just need a little daily bute [phenylbutazone] … [and] I strongly encourage the use of Adequan [i.m.]."

(For an extended report of this meeting please visit EquiManagement.com/arah)

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EQUINE VETERINARY EDUCATION
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Case Report

A large cyst in the distal femur of a horse

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Keywords: horse; cyst; femur; epiphysis; metaphysis

Summary

A 10-year-old, 636 kg, Warmblood gelding, used for competitive dressage, presented to the referring clinic due to a movement asymmetry related to the left hindlimb, first noted by the owner 2.5 weeks previously. It was grade 1–2/5 lame at the trot on the left hindlimb (subjective lameness scale; 0 = sound, 1 = mild lameness, 2 = moderate lameness, 3 = marked lameness, 4 = severe lameness, 5 = nonweightbearing lameness). Intra-articular anaesthesia of the left medial femorotibial (MFT), lateral femorotibial (LFT) and femoropatellar (FP) joints decreased the lameness and response to proximal limb flexion. Radiographs of the left hind stifle revealed a distinct, well-defined area of radiolucency in the distal femur involving both the medial and lateral condyles and trochleas. In the proximal aspect of the lesion, horizontal mineral opacities were observed (**Fig 1**). The radiolucent lesion was defined as a cyst with an unusual presentation and extreme size. Surgical treatment was attempted. Arthroscopic examination of the cranial and caudal MFT joint, cranial LFT joint and FP joint showed no significant abnormalities. An extra-articular, medial, transcortical approach to the cyst was performed for drainage, curettage, osteostixis and administration of an autologous, cancellous bone graft, gentamicin-impregnated collagen fleeces and injectable steroid. There was no evidence of a cyst lining or obvious septae formations in the cavity. Approximately 550 mL of turbid, dark yellow fluid was aspirated from the cyst. The fluid contained small numbers of cells (0.12×10^9 cells/L), predominantly macrophages (65%). There were no findings consistent with infection, purulent inflammation or neoplasia. The horse was discharged 5 days after surgery. Post-operatively, the horse was treated with first-generation bisphosphonates at 6 weeks, 5 months, 1 and 2 years, respectively. On follow-up radiographs, the cyst became more radiodense; however, complete radiological healing was not obtained. Despite the lack of complete healing, lameness resolved and the horse returned to a higher level of dressage than before surgery.

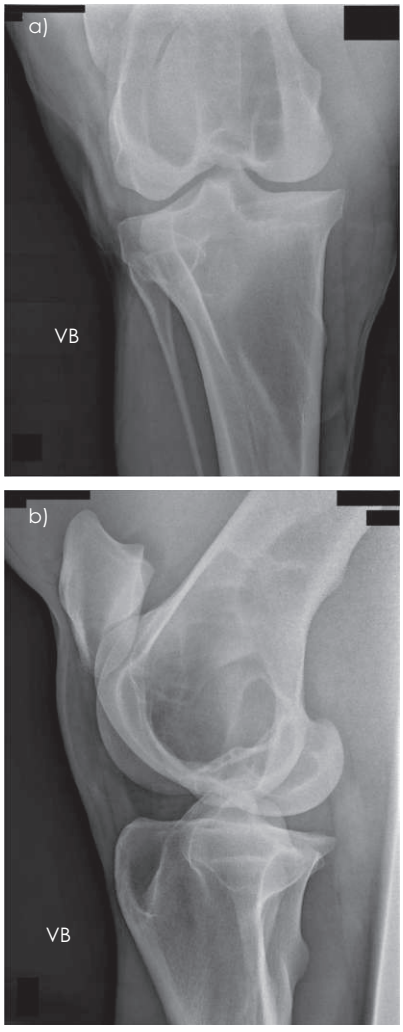

Fig 1: Radiographs obtained at initial examination of the horse showing the size and location of the cyst in the left femur. a) caudocranial view, b) lateromedial view.

Key points

- The aetiology of the cyst remains unknown; however, its presentation most resembles unicameral bone cysts described in humans.
- The cyst most likely caused a painful condition in the stifle since intra-articular anaesthesia decreased the lameness. Communication to the joint cannot be excluded since small communications can be missed during arthroscopy and the caudal LFT compartments were not examined arthroscopically.
- Despite the lack of complete, radiological healing, the horse returned to work. We suspect that the lesion healed with fibrous or partially calcified tissue, as an increase in radiodensity was observed.

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Clinical Commentary

Equine bone cysts: What do we know about them and their treatment?

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Keywords: horse; bone; cyst; unicameral; treatment

Practicing equine veterinary medicine entails an important challenge due to the size and temperament of our patients which, among other things, greatly affects our diagnostic capabilities in several anatomical regions. In addition, equine veterinarians are exposed to a relatively limited caseload compared with physicians or small animal veterinarians. These factors summarise some of the limitations that equine veterinarians encounter to obtain in-depth knowledge and understanding of certain pathological entities, and bone cysts are no exception. Thus, publishing case reports such as the accompanying article by Skov Hansen *et al*. (2021) have still tremendous value to increase our knowledge as a community.

A bone cyst could be defined as a solitary, uniloculated or multiloculated cavity filled with fluid, mucus or gelatinous inflammatory material that develops within the bone and is generally surrounded by a sclerotic rim of variable thickness. These cysts can be of clinical relevance or merely incidental. In human subjects, there are at least five types of bone cysts that could match some of the characteristics of the cyst diagnosed by Skov Hansen *et al*. (2021), including non-ossifying fibromas (NOFs), aneurismal bone cysts (ABCs), unicameral bone cysts (UBCs), intraosseous ganglia and fibrous dysplasia (Remotti and Feldman 2012). Some of their main features are detailed in **Table 1** to facilitate comparison among them and with the reported cyst in the accompanying article. The aetiology for most of these cysts is unknown or unclear but there is vast information regarding their clinical behaviour, diagnosis, histopathological characteristics and treatment (Ovadia *et al.* 2003; Chan *et al.* 2010; Remotti and Feldman 2012; Noh *et al*. 2013; Pretell-Mazzini *et al.* 2014). In contrast, there is scarce information in the equine literature regarding any of the aforementioned cysts other than for subchondral bone cysts (SBCs), and all the publications are case reports (Attenburrow and Heyse-Moore 1982; Lamb and Schelling 1989; Thomas *et al.* 1997; Bonilla *et al.* 2016; Stöcker*et al*. 2017) (**Fig 1**). Different aetiologies are hypothesised for SBCs. Originally, SBCs were considered a type of osteochondrosis lesion (Jeffcott *et al.* 1983). This theory is still plausible for some; however, most SBCs have more likely a traumatic origin, either secondary to cartilage damage, subchondral bone damage or both (Kold*et al.* 1986; Ray *et al.* 1996). Also, it has been suggested that medial femoral condyle SBCs may lead to the appearance of SBCs in the opposing tibia secondary to trauma (**Fig 2**) (Bonilla *et al*. 2016). Similarly, medial meniscal damage has been associated with medial femoral condyle SBCs (Hendrix *et al.* 2010). Lastly, SBCs are considered a precursor of osteoarthritis (OA) in human subjects and commonly occur in the knee secondary to bone necrosis and without requiring the presence of cartilage damage (Crema *et al.* 2010). Nevertheless, due to the absence of subchondral bone involvement in the femoral cyst of the accompanying article, a SBC is unlikely and will not be further discussed.

Knowledge from the human literature can help determine with relative accuracy the pros and cons for the diagnosis of atypical bone cysts as the cyst reported by Skov Hansen *et al*. (2021). Radiographs obtained when the horse was 4 years old revealed that the cyst was eccentrically located in the physeal region and covered by a thin sclerotic rim. This appearance could be compatible with a non-ossifying fibroma, but the location of the cyst (mostly epiphyseal), the lack of a longer cyst diameter parallel to the long axis of the bone, and the liquid content of the cyst reduce the likelihood for this diagnosis (Remotti and Feldman 2012; Noh *et al*. 2013). In contrast, more characteristics compatible with an ABC, fibrous dysplasia or a UBC can be seen. ABC can grow into the epiphysis, are painful and mostly affect the knee in human subjects (Chan *et al.* 2010; Remotti and Feldman 2012). Nonetheless, they tend to have a thick and cellular membrane and are blood-filled neither of which were found in the reported case. Fibrous dysplasia can have a similar radiographic appearance to the reported cyst and be filled with serous fluid. However, cellular fibrous tissue is usually found at the edge of the cyst, and monostotic lesions, as presumptively is this case, tend to affect exclusively the jaw in human subjects (Remotti and Feldman 2012). Unicameral bone cysts share several characteristics with the described cyst. They can be multilocular, have a thin sclerotic rim and internal body ridges and be filled with serous material. On the contrary, they tend to form in the metaphysis of immature individuals, although epiphyseal growth has been reported, they have a delicate fibrous membrane and most are painless (Ovadia *et al.* 2003; Remotti and Feldman 2012; Pretell-Mazzini *et al.* 2014). This membrane was not identified during surgery but may have been missed due to its delicate nature. Thus, UBC could still be considered as the most likely diagnosis.

If the cyst was painless, as with most UBCs, or was truly the source of lameness, it could be argued and obtaining a definitive answer could be challenging. This is often the case with some physeal and diaphyseal lesions, such as enostosis-like lesions, seen in the proximal limb where performing perineural blocks is constrained (Ahern *et al.* 2014). In the case reported by Skov Hansen *et al*. (2021), only the stifle compartments were anaesthetised and this prevents objectively ruling out lameness originating from the distal

TABLE 1: Main clinical features for non-ossifying fibroma, aneurismal bone cyst, unicameral bone cyst, intraosseous ganglia and fibrous dysplasia

	Most affected age groups	Most affected bones	Common location within the bone	Eccentric vs. central	Loculation	Cyst lining and/or surrounding sclerosis	Cyst content	Clinical signs
Non-ossifying fibroma	Children and adolescents	Distal femur and tibia	Metaphysis but adjacent to physis	Eccentric	Uni- or multiloculated	Sclerotic rim	Soft and tan content	Commonly asymptomatic
Aneurismal bone cyst	First 2 decades of life	Femur and tibia	Metaphysis but can involve the epiphysis	Eccentric (diameter wider than epiphyseal plate)	Multiloculated	Thick and cellular membrane. Thin sclerotic margin	Blood-tinged fluid	Painful
Unicameral bone cyst	First 2 decades of life	Proximal humerus and femur	Metaphysis. Uncommonly epiphyseal	Central. Often has a cone shape	Uni- or multiloculated	Delicate fibrous membrane. Sclerotic rim and thins the cortex	Serous or blood-tinged fluid	Asymptomatic or painful
Intraosseous ganglia	Young and mature individuals	Femoral head, proximal and distal tibia and fibula, and medial malleolus	Epiphysis and subchondral bone	Eccentric or central	Uni- or multiloculated	Fibrous wall. Sclerotic rim	Mucoid	Asymptomatic
Fibrous dysplasia	First 3 decades of life	Jaw if monostotic and long bones if polyostotic	Metaphysis and diaphysis	Eccentric or entire medullary cavity	Multiloculated	Cellular fibrous tissue with osteoid particles at the edge. Well-defined sclerotic border	Serous fluid or gritty material	Usually asymptomatic

The information is extrapolated from Ovadia *et al.* 2003; Chan *et al.* 2010; Remotti and Feldman 2012; Noh *et al*. 2013; and Pretell-Mazzini *et al.* 2014.

Fig 1: Sagittal cut of a tibia depicting a subchondral bone cyst (white arrow) and an atypical bone cyst in the proximal metaphysis (black arrow) compatible with an intraosseous ganglion or a unicameral bone cyst in formation. Both lesions appear radiographically as a bone cyst.

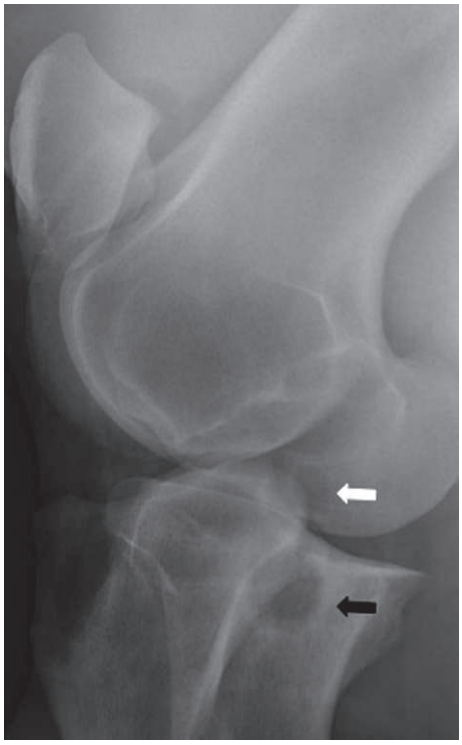

Fig 2: Caudolateral-craniomedial 45° radiographic projection of the stifle region revealing a medial femoral condyle subchondral bone cyst (white arrow) and an opposing subchondral bone cyst (black arrow) in the medial tibial plateau.

limb. It has been recently reported that foot-induced lameness can improve up to 50% in a third of horses after anaesthetising the stifle compartments (Radtke *et al*. 2020), which could be compatible with the amelioration in lameness seen in this case. In addition, the lack of obvious radiographic or arthroscopic communication between the joint and the cyst could prevent an intuitive explanation for the lameness improvement seen. Nonetheless, proximal anaesthetic diffusion to achieve cyst anaesthesia is possible. Finally, the radiographs provided in the article showed mild osteophytosis in the proximal medial tibia which is compatible with mild medial femorotibial OA. In my experience, these radiographic changes can be seen in horses with or without lameness. Thus, either it could be an incidental finding or it could be responsible, completely or partially, for the mild lameness (1–2/5) observed on the horse.

The reported treatment options for equine bone cysts other than SBCs have varied from euthanasia to surgical debridement with or without the addition of autologous bone graft and/or bone substitute (Attenburrow and Heyse-Moore 1982; Lamb and Schelling 1989; Thomas *et al.* 1997; Bonilla *et al.* 2016; Stöcker *et al*. 2017). The question is, do we know what is the ideal treatment? Several treatments are reported for human bone cysts with the goal of preventing or managing a pathological fracture secondary to the cyst and to stimulate cyst healing (Bowers *et al.* 2013; Noh *et al*. 2013; Kadhim *et al.* 2014; Pretell-Mazzini *et al.* 2014; Noordin*et al.* 2018; Muratori *et al.* 2019). Additionally, conservative treatment is often pursued for cysts clinically asymptomatic and without risk of fracture. The main treatment strategies are shared across the board regardless of the type of cyst; thus, treatment discussion that focuses on the management of UCB will follow. Intralesional corticosteroid injections are used with variable rates of success, although the mechanism of action, other than to reduce fluid production, is unclear and recurrence is frequent (Kadhim*et al.* 2014). Historically, surgical debridement and bone grafting was used as the standard method of treatment for UBC but recent studies do not support their use due to healing rates as low as 25–36% (Pretell-Mazzini *et al.* 2014). More recently, excellent results have been obtained after cyst decompression. This technique allows bone regrowth inside the cyst after liquid pressure on the margins of the bone cyst is eliminated (Pretell-Mazzini *et al.* 2014; Noordin*et al.* 2018). This can be done with needles, curets or implants, such as intramedullary pins, which allow cyst decompression and bone stabilisation at the same time. Lastly, a combination of the aforementioned techniques, specifically cyst decompression, curettage and some form of cyst filling (i.e. bone grafting, calcium sulphate pellets, etc), is advocated by some authors. This approach can improve cyst healing up to 80–92% but cyst decompression is still considered key to achieve a successful healing (Pretell-Mazzini *et al.* 2014). The accompanying article used a combined or multimodal approach that included intracystic corticosteroid infusion, cyst decompression and osteostixis, limited cyst debridement and filling of the cystic cavity with autologous cancellous bone graft and impregnated collagen fleeces with

antibiotics. Thus, it is impossible to determine whether the radiographic healing seen in follow-up radiographs was associated with one single treatment approach or with the combination of them. Based on human classifications for UBC healing, this case should be classified as incomplete healing (<80% of cyst ossification), and therefore, physicians would still consider it as at risk of developing a pathological fracture (Pretell-Mazzini *et al.* 2014).

In the accompanying article, bisphosphonates were repeatedly used during the post-operative period and their use for bone cyst treatment and their effect in the reported case are worth discussing. Bisphosphonates have been used for expansile cysts in human subjects; however, there is limited evidence to show that they effectively reduce pain or slow progression and their use is generally discouraged, especially in immature individuals (Simm *et al.* 2018). In horses, the proven benefits of bisphosphonates are limited to a handful of pathologies, including lower hock joints OA and navicular disease (Denoix *et al.* 2003; Gough *et al.* 2010). The benefits seen in those cases are likely due to the anti-inflammatory or analgesic effects of those drugs on bone pain (Kamm *et al.* 2008). Similarly, the lameness resolution of the accompanying case may be associated with these effects either at the level of the cyst or at the level of the medial femorotibial joint, if the osteoarthritis seen radiographically was clinically relevant. A rationale for the use of bisphosphonates in the early phases of bone cyst formation, including SBCs, when cysts are expanding and there is osteoclasts recruitment, could be argued (Von Rechenberg *et al.* 2000). However, once a sclerotic margin surrounds the cyst, the reasoning behind the use of bisphosphonates, other than for their analgesic effects, is unclear and has no scientific backup to date (Simm *et al.* 2018). The intracystic appearance of the cyst from Skov Hansen *et al*. (2021) 2 years after surgery resembles erratic bone healing and is similar to the radiographic aspect of woven (immature) bone rather than lamellar (dense) bone. In fact, bisphosphonate may have hindered appropriate bone healing after the surgical treatment by preventing normal bone remodelling. There is an increasing concern among equine surgeons about the use and abuse of bisphosphonates in horses and particularly in young Thoroughbreds (McLellan 2017). Erratic bone healing is seen by surgeons around the world in horses that have received bisphosphonates during early age which in consequence may jeopardise appropriate bone healing after a fracture occurs. Thus, it is our responsibility as a community to further investigate the use of bisphosphonates with properly designed studies before bisphosphonates can be recommended for the treatment of bone cysts due to the potential local and systemic effects and their long-term repercussions.

Author's declaration of interests

No conflicts of interests.

Ethical animal research

Not applicable.

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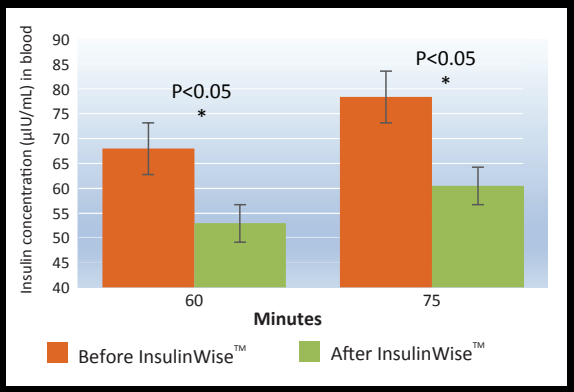

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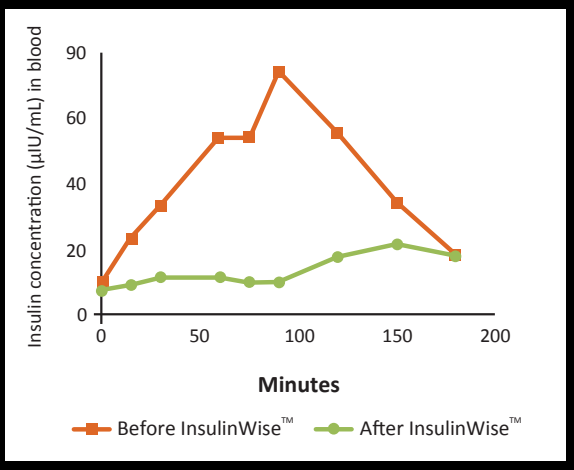

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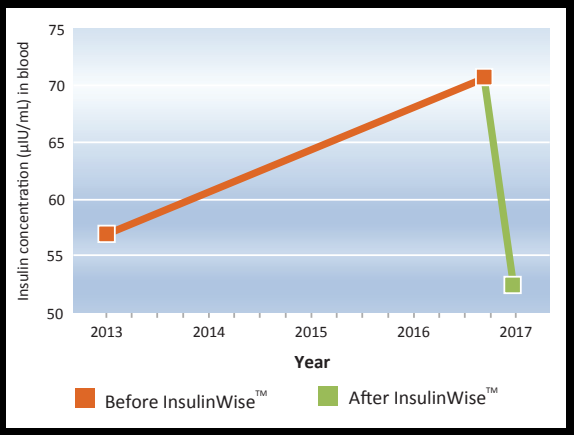

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Original Article

Comparison of outcomes following treatment of septic calcaneal bursitis by needle or bursoscopic lavage: A retrospective study of 29 horses

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Keywords: horse; calcaneal; bursitis; needle; bursoscopic

Summary

Sepsis of the calcaneal bursae (CB) presents significant treatment challenges with limited clinical data available in the literature. The objective of this retrospective cohort study was to assess the clinical outcomes associated with CB lavage using either a through-and-through needle or bursoscopic technique. Clinical records of 29 horses treated for septic calcaneal bursitis using either technique between 2005 and 2019 were reviewed. Fisher's exact test was used to assess statistical significance between first surgical technique and success at first surgery (i.e. not requiring >1 lavage), survival to discharge and return to work (RTW). Bursoscopy was performed in 13/29 (44.8%) cases, and needle lavage in 16/29 (55.2%). In the needle group, 12 (75%) horses were discharged following the first surgery. Four had repeat interventions; two (12.5%) had needle lavage and two (12.5%) had bursoscopy. Of the two horses to have repeat needle lavage, one was subjected to euthanasia and one discharged, and of the two that underwent bursoscopy, one was discharged and one received a third bursoscopy prior to discharge. In the bursoscopy group, seven (53.8%) were discharged and three (23.1%) were subjected to euthanasia following the first surgery. Three (23.1%) received a second bursoscopic lavage with one discharged, one subjected to euthanasia and one having a third bursoscopic lavage prior to discharge. Overall, 18/24 (75%) followed up cases RTW, 10 (55.5%) from the needle group, eight (44.4%) the bursoscopy group. No statistically significant differences between first surgical technique used and success at first surgery (no subsequent lavage(s) required), survival to discharge or return to work were detected. The main limitations of this study are that it is a retrospective study, has a small population with limited statistical power and potential selection bias. No statistically significant differences existed between the outcomes of the two techniques, contrary to the belief that bursoscopic lavage is superior. Larger, multicentred studies, with greater statistical power are required to further assess this relationship.

Introduction

Synovial sepsis, most commonly resulting from contamination from traumatic wounds, is commonly encountered in horses (Schneider *et al.* 1992; Baxter 2004). Within 6–8 h after injury, infection of the affected synovial cavity frequently becomes established, requiring aggressive management with a combination of surgical and medical treatments (Wright *et al.* 2003). The objectives of treating synovial contamination and infection are similar for all synovial structures: the removal of foreign material, debridement of contaminated/infected and devitalised tissue, elimination of microorganisms, removal of destructive enzymes and radicals, promotion of tissue healing and restoration of a normal synovial environment (Wright *et al.* 2003). The prognosis depends on the specific synovial structure involved, whether a concurrent osseous or soft tissue injury is present, and the intended use of the horse (Baxter 2004). Most authors agree that an extended duration between injury and treatment negatively impacts on prognosis; however, there have been conflicting results in published studies.

Injuries to the calcaneal bursae (CB) are usually the result of penetrating wounds (Dyson 2011), such as kick wounds to the plantaroproximal aspect of the tuber calcanei. Damage and sepsis may involve any combination of the three bursae (subcutaneous, intertendinous and gastrocnemius bursae) in addition to the tarsocrural joint, long plantar ligament, tarsal sheath and calcaneus (Post *et al.* 2003). The anatomy of the plantaroproximal aspect of the tuber calcanei is complex and the nomenclature often confusing. For the purposes of this study, the definitions used by Post *et al.* (2007) will be used: the CB comprise of the subcutaneous calcaneal bursa (SCB), the intertendinous calcaneal bursa (ICB) and the gastrocnemius calcaneal bursa (GCB) (Post *et al.* 2007). It should be noted that there is frequent communication between these bursae; the ICB and GCB are reported to communicate in 100% of cases medially and 50% laterally, and the SCB communicates with the ICB in 39% of cases (Post *et al.* 2007; Baxter 2011; Garrett 2014).

Post *et al.* (2003) found no significant association between the time from injury until referral and the survival of 24 horses with septic calcaneal bursitis, which is supported by other reports (Walmsley *et al.* 2011; Milner *et al.* 2014), although they acknowledged that the power of their study was low and prompt referral for treatment was still recommended (Post *et al.* 2003). The literature is sparse in relation to septic calcaneal bursitis, and, to the authors' knowledge, no data exist comparing different treatment options and associated outcomes. However, anecdotally it is thought that endoscopic lavage under general anaesthesia is the treatment of choice for synovial sepsis, in conjunction with appropriate anti-inflammatory and antimicrobial therapy (Ingle-Fehr and Baxter 1998; Wright *et al.* 2003; Baxter 2004; Orsini 2017; Baxter 2019). It is accepted that endoscopy permits more thorough lavage, identification and removal of

foreign material and fibrin, debridement of osseous or tendinous lesions if present, assessment of cartilage and osseous damage, and performance of synovectomy if needed (Baxter 1996; Wright *et al.* 2003). However, endoscopic procedures are more technically demanding and costly than through-and-through needle lavage, and there is limited evidence that they result in superior outcomes. In addition, Loftin *et al.* (2016) found that needle lavage was more effective at removing coloured microspheres from the tarsocrural joint when compared with endoscopic lavage.

This retrospective study aimed to identify clinically significant variations in the outcome of horses treated for septic calcaneal bursitis using either a needle or bursoscopic lavage technique. The authors' hypothesis was that there would be no significant difference in outcome, irrespective of the surgical technique employed.

Materials and methods

Study design and inclusion criteria

Hospital records from 2005 to 2019 were reviewed for horses admitted to Bell Equine Veterinary Clinic in the UK for the treatment of septic calcaneal bursitis using one of the two lavage techniques above, following injury to the plantaroproximal aspect of the tarsus.

Inclusion criteria included a diagnosis of septic calcaneal bursitis and subsequent treatment with a needle or bursoscopic lavage technique. Septic calcaneal bursitis was diagnosed if ≥1 of the following criteria were present: synovial fluid total nucleated cell count (TNCC) $>20 \times 10^9$ cells/L; synovial fluid total protein concentration (TP) >40 g/L; >80% polymorphonuclear cells on cytological examination of synovial fluid; marked increase in the turbidity of synovial fluid so as to obscure reading of print; confirmation of direct communication between a wound with at least one of the three bursae by the egress of sterile fluid from the wound following instillation into the bursa; confirmation of direct communication between a wound with at least one of the three bursae by positive contrast radiography (Morton 2005; Steel 2008; Milner *et al.* 2014; Bryant *et al.* 2018; Rinnovati *et al.* 2018). The degree of lameness was subjectively graded on a 1–10 scale (where 1/10 is very mild and 10/10 is non-weightbearing). Standard radiographic projections of the tarsus were taken on admission and included dorsoplantar, dorsolateral-plantaromedial oblique, lateromedial and a dorsomedial-plantarolateral oblique views. Routine ultrasonographic (US) examination of the region was also performed.

Cases were divided into two groups depending on the technique used for initial lavage; through-and-through needle lavage or bursoscopy. The choice of which lavage technique was used was dependent on the surgeon and owner's preferences and was not controlled or randomised in any way. Clinical data were reviewed including age, sex, mechanism of injury, affected leg, time from injury to referral, degree of lameness at referral, ultrasonographic and radiographic examination findings, results of synoviocentesis, antimicrobial therapy, structures involved, number of lavages required and survival to discharge. A follow-up telephone interview or clinical record search was conducted to assess the horses' return to work following surgery.

The data were analysed for statistical significance using SAS® Studio, University Edition[1] and a Fisher's exact test with statistical significance defined as $P<0.05$. Outcomes for the purposes of statistical analysis were survival to discharge, success after first surgery and return to work following discharge. Success after first surgery was defined as those cases that did not require further lavages following the initial treatment.

Results

General

Twenty-nine horses met the inclusion criteria. A summary of the presenting signs, treatments and outcomes is documented in **Table 1**, and a flow diagram summarising the case progression is shown in **Fig 1**. The study population consisted of 29 horses; 10 (34.5%) geldings, 16 (55.2%) mares and 3 (10.3%) with no sex recorded. The right hindlimb was affected in 15 (51.7%) horses, the left hindlimb in 13 (44.8%) with the affected limb not recorded in one (3.4%). The mean age was 12.9 years (n = 26) (median 10.5 years, range 4–33 years). A known cause of injury was recorded in 15 horses, of which 7 (46.7%) were the result of a kick, one (6.7%) being cast in the stable, one (6.7%) involved in a road traffic collision, one (6.7%) fell on the road, and five (33.3%) sustained unobserved injuries in the field. In 28 of the cases, the time from injury to referral ranged from 0 to 23 days with a median of 0.5 days, where 0 day was considered to be referral on the same day as the injury (mean of 2.96 days). No significant difference was detected between time to referral, mechanism of injury or sex and success at first surgery, survival to discharge or return to work. A statistically significant difference was identified between age and survival to discharge ($P = 0.043$), with older horses having a reduced likelihood of survival to discharge (**Fig 2**). However, there was no significant difference between age and success at first surgery or return to work. Overall, 24/29 (82.8%) of the horses treated survived to the point of discharge from the hospital.

Lameness

The degree of lameness on initial examination varied greatly with a range of 1.5/10 to 10/10 (median 5/10) in the 23 horses where lameness grade was recorded and no previous nonsteroidal anti-inflammatory drugs (NSAIDs) had been administered. In many cases, the degree of lameness on initial examination was recorded as a range and hence the mean of this range was used for statistical analysis. Any horse that received NSAIDs prior to referral was excluded from these figures so as not to skew the results given their reduced lameness grade as a result of this treatment. No statistically significant difference was detected between lameness grade on arrival and success at first surgery or survival to discharge.

Soft tissue and osseous changes identified by ultrasonography and/or radiography

The presence of osseous damage was noted on survey radiographs in 5/29 (17.2%) horses, two (40%) of which had a lucency in the tuber calcanei, two (40%) had evidence of an osseous fragment(s) and one (20%) had a fracture of the fourth metatarsal bone (this case was excluded from statistical analysis as the orthopaedic injury was not directly related to the CB). Statistical significance was demonstrated between the presence of a radiographic abnormality associated with the tuber calcanei and survival to discharge

TABLE 1: Summary of pertinent information from review of case histories of 28 horses treated for septic calcaneal bursitis

Case	Age	Sex	TTR (d)	Surgical technique			No. lavages	Bursae involved			Lameness on admission	STD	Days hospitalised	RTW	Level	Eut	Reason
				1	2	3		SCB	ICB	GCB							
1	5	M	10	B	B		2	✓			3.5	Y	20	Y	↑		
2	6	M	1	N	B		2		✓	✓	2	Y	12	Y	=		
3	28	M	0	N	N		2		✓	✓	8	N	22	N	×	✓	Recurrence
4	29	M	0	B			1					Y	7	Y	=		
5	33	G	0	B			1				4.5	N		N	×	✓	Poor prognosis
6		M	5	B			1		✓	✓	4	Y	10	Y	=		
7	6	G	3	B			1	✓	✓	✓	9	Y	11	L	?		
8			0	N			1		✓	✓	3	Y	9	L	?		
9	6	M	0	N			1		✓	✓	10	Y	7	Y	=		
10	24	M	1	N			1		✓	✓	8	Y	5	Y	=		
11	6	G	4	N	N		2	✓	✓	✓		Y	8	L	×		
12	6	M	2	B			1	✓	✓	✓	10	Y	36	Y	=		
13	12	M	3	B	B		2		✓	✓	10	N		N	×	✓	Recurrence
14	13	M	0	B			1		✓	✓	10	Y	8	Y	=		
15	10	G	0	B	B	B	3	✓	✓	✓		Y	23	Y	↓		
16	5	M	0	N			1		✓	✓	6	Y	9	Y	=		
17	19	G		B			1		✓	✓		N		N	×	✓	Poor prognosis
18	7	G	0	N			1	✓			4.5	Y	5	Y	=		
19	7	M	0	N			1		✓	✓	8	Y	9	L	?		
20	17	G	0	B			1		✓	✓	6	N		N	×	✓	Owner decision
21	13		0	N			1	✓	✓	✓	2	Y	6	Y	=		
22			0	N			1	✓	✓	✓	3	Y	5	L	?		
23	16	G	0	B			1	✓	✓	✓	5	Y	6	Y	=		
24	8	M	22	N			1	✓				Y	10	Y	=		
25	13	M	1	N			1	✓			1.5	Y	7	Y	=		
26	4	M	6	N			1	✓			5	Y	8	Y	↑		
27	9	M	1	N			1	✓			3	Y	6	Y	=		
28	11	G	1	N	B	B	3	✓	✓	✓	5	Y	12	Y	=		
29	23	G	23	B			1		✓	✓	7	Y	6	NF	NF		

Lameness assessment was made using a 10-point grading system, in cases where lameness was recorded as a range, the mean of that range was used.
?, unknown; =, same; ↑, increased; ↓, decreased; ✓, yes; ×, no; Eut, Euthanasia; G, gelding; L, lost to follow-up; Level, level of work returned to; M, mare; N, no; NF, no follow-up; RTW, return to work (Yes or No); STD, survival to discharge (Yes or No); TTR, time to referral (days); Y, yes.

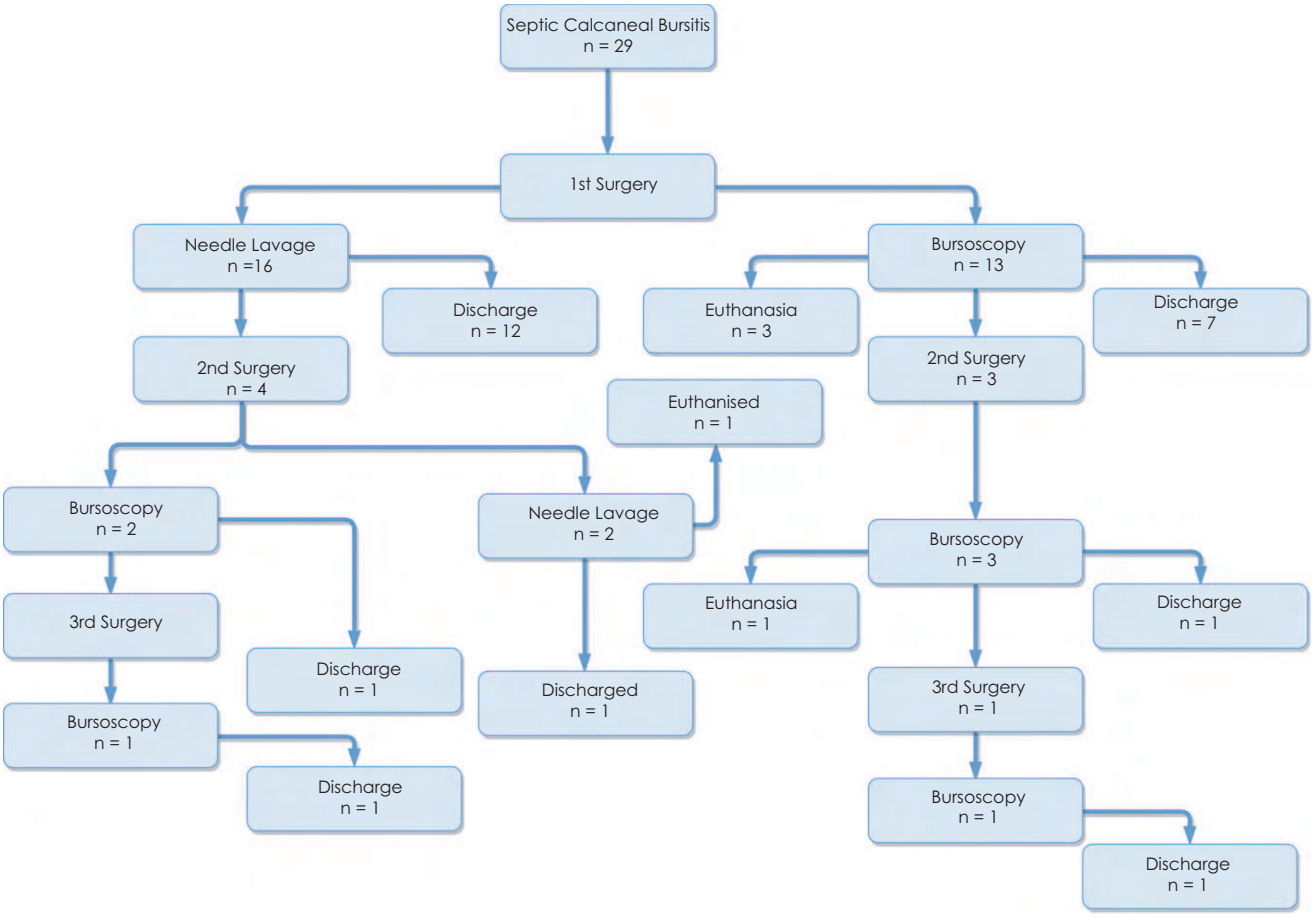

Fig 1: Flow diagram illustrating the case progression following each intervention to final outcome.

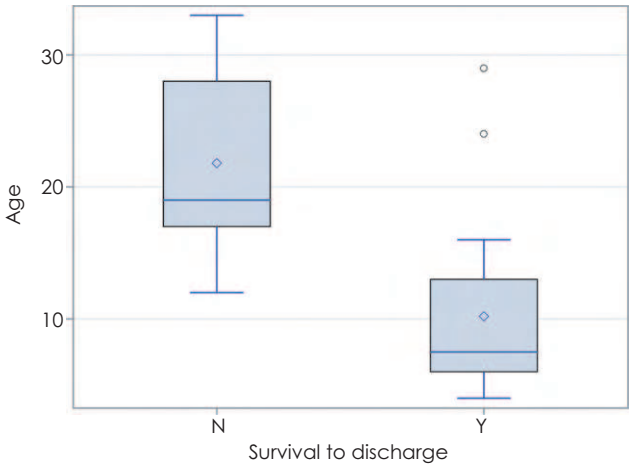

Fig 2: Box and whisker plot illustrating the significance of age and survival to discharge.

(P = 0.024) and success at first surgery (P = 0.0011), with both being negatively affected. Routine US examination findings were recorded in 28/29 (96.6%) cases, which included effusion of the ICB only in eight (28.5%), SCB only in four (14.3%), ICB and GCB in nine (32.1%) and of all three bursae in two (7.1%). One (3.6%) horse had synovial thickening of the ICB and GCB. In two (7.2%) horses, injury to the superficial digital flexor tendon (SDFT) was recorded, and one (3.6%) had an irregular bone surface of the tuber calcanei. In one (3.6%) horse, the US examination was abandoned due to gas artefact associated with the wound.

Bursae involved

In 27/29 (93.1%) horses, the affected bursae were recorded; 6/27 (22.2%) involved only the SCB, 13/27 (48.1%) involved the ICB and GCB and 8/27 (29.6%) had sepsis of all three CB. No significant difference was identified between bursa (e) involved and survival to discharge, success at first surgery or return to work. Of the six cases involving only the SCB, one was in the bursoscopy group (requiring two bursoscopic lavages) and five were in the needle lavage group (each only requiring a single lavage). All six horses returned to work at the same or a higher level following surgery.

Surgical technique

Seven different surgeons were involved with the treatment of these cases. Bursoscopic lavage was the initial treatment in 13/29 (44.8%) horses, and a through-and-through needle technique initially used in 16/29 (55.2%; **Fig 2**). In the needle lavage group, 12 (75%) were discharged from the hospital following initial intervention, two (12.5%) had a repeat needle lavage and two (12.5%) subsequently underwent

bursoscopy. Of the four horses that had repeat interventions, two (50%) were discharged, one (25%) was subjected to euthanasia following repeat needle lavage and one (25%) underwent a second bursoscopy and was successively discharged. The group undergoing bursoscopy in the first instance included three (23.1%) horses that were subjected to euthanasia, seven (53.8%) that were discharged following the first lavage and three (23.1%) that underwent repeat bursoscopy, of which one (33.3%) was discharged, one (33.3%) subjected to euthanasia and one (33.3%) underwent a third bursoscopy and was later discharged. There was no significant difference between the surgical technique used for the first surgical intervention and success at the first surgery, survival to discharge or return to previous athletic performance. In this population, initial bursoscopy was associated with a 69.2% success rate defined as survival to discharge compared with 93.75% for initial needle lavage.

Antimicrobial therapy

In all 29 cases, preoperative antimicrobials were administered: 14/29 (48.3%) received benzylpenicillin sodium (Crystapen)[2] (30,000 iu/kg bwt i.v. q. 8 h) and gentamicin sulphate (Genta-Equine)[3] (6.6 mg/kg bwt i.v. q. 24 h), the remainder received procaine benzylpenicillin (Depocillin)[b] (17.5 mg/kg bwt i.m. q. 12 h) and gentamicin sulphate (6.6 mg/kg bwt i.v. q. 24 h). Total duration of injectable antimicrobial therapy was recorded in all of those horses surviving to discharge (n = 24) with mean duration of 7.24 days (median 5 days, range 3–21 days). In 23/24 (95.8%) cases, the preoperative antimicrobial regime was continued post-operatively, however, in one case for which culture and sensitivity results were obtained, the horse was changed from procaine benzylpenicillin (17.5 mg/kg bwt i.m. q. 12 h) and gentamicin sulphate (6.6 mg/kg bwt i.v. q. 24 h) after 5 days to enrofloxacin (Baytril)[4] (5.5 mg/kg bwt i.v. q. 24 h) and gentamicin sulphate for a further 4 days before discontinuing the gentamicin; this horse was then discharged following a transition to enrofloxacin (Baytil Oral[d], Lanflox[5]) at 7.5 mg/kg bwt per os q. 24 h for 2 days, to continue this therapy at home for a further 7 days.

Intrabursal antimicrobials were recorded as being administered at surgery following lavage in 25/29 (86.2%) of horses with 15 (60%) receiving amikacin (500 mg per communicating bursae), 3 (12%) ceftiofur (Excenel)[6] and 7 (28%) gentamicin. Intrabursal unbuffered, systemic gentamicin was used at a dose of 1000 mg in three horses, 500 mg in two horses and in two horses the dose was not recorded. Ceftiofur was administered intrabursally at a dose of 300 mg in one of the three horses but no dose was recorded for the remaining two.

The majority of horses (23/24, 95.8%) were discharged with oral antimicrobials. Trimethoprim sulphonamide (Trimediazine Plain[7], Norodine 24[8]) (30 mg/kg bwt per os q. 12 h) was most commonly used, (13/24, 54.1%), 2/24 (8.3%) received doxycycline (Karidox[e], Doxycycline[9]) (10 mg/kg bwt per os q. 12 h), 4/24 (16.6%) received enrofloxacin (7.5 mg/kg bwt per os q. 24 h) and 4/24 (16.6%) were prescribed a combination of trimethoprim sulphonamide (30 mg/kg bwt per os q. 12 h) and enrofloxacin (7.5 mg/kg bwt per os q. 24 h). Of these 23 cases, the total duration of oral antimicrobial therapy was recorded in 20 days and ranged from 5 to 35 days (mean 11.5 days, median 8.5 days).

Synoviocentesis

In 17/29 (58.6%) cases the nucleated cell count (NCC) of a synovial fluid sample was recorded on first presentation, with values ranging from 3.9×10^9 cells/L to 300×10^9 cells/L (mean 99.7×10^9 cells/L, median 77×10^9 cells/L). The horse with NCC of 3.9×10^9 cells/L on admission had confirmed communication between the wound and CB.

Euthanasia

Five of the 29 horses were subjected to euthanasia at varying intervals following investigation and treatment. In one horse following a road traffic collision, bursoscopy was performed and a complete laceration of the superficial digital flexor tendon (SDFT) was identified and was subsequently repaired using a three-loop pulley system following lavage of the ICB and GCB. The horse recovered well from general anaesthesia and was comfortable at walk 3 days post-surgery, but the owner elected for euthanasia at this point believing that the horse's temperament would not tolerate prolonged box rest. In a second horse, sepsis within the ICB and GCB recurred following two needle lavages; this horse also had an osseous fragment originating from the tuber calcanei, and was subjected to euthanasia at the owner's request 22 days post-surgery. In another horse, sepsis of the ICB and GCB recurred following two bursoscopic lavages; this horse also had SDFT disruption and was subjected to euthanasia 11 days post-surgery due to the poor prognosis. The final two horses were subjected to euthanasia at the owners' requests following a single bursoscopy due to the recurrence of sepsis in one horse and the presence of multiple osseous fragments with marked contamination in the other.

Return to work

Follow-up information was obtained in 18/24 (75%) of the horses that survived to discharge using telephone interview or clinical notes to identify the number of horses that returned to work following surgery. Five (17.2%) were lost to follow-up as the owners were not contactable, one (3.4%) was not followed up as it was only discharged 2 weeks previously. Of the 18 cases that were known to have returned to work; the level at which they returned was recorded in 15 (88.3%) cases: one (5.6%) returned to a lower level, 12 (66.7%) to the same level and two (11.1%) to a higher level. Statistically there was no significant difference between the first surgical technique used and return to work.

Discussion

To the authors' knowledge, this is the first study to examine the relationship between the initial surgical lavage technique and the outcomes for horses with calcaneal bursa sepsis. The outcomes examined included survival to discharge, successful resolution of sepsis following the initial surgery and return to work. However, additional data on important contributing factors were also collected including the significance of time to referral, degree of lameness, results of synoviocentesis and findings of diagnostic imaging modalities.

The horses treated predominantly represented a low-level competition population with a greater proportion of mares and a wide range of ages. A kick was the cause of injury in 7/15 (46.7%) cases for which a cause was known. This figure

represents a significant proportion given that in one study of all types of injuries in horses, only 44/897 (4.9%) were the result of a kick (Knubben *et al.* 2008). Whilst no significant difference was identified between age and success at first surgery or return to work, there was a significant association between age and survival to discharge, with an inversely proportional relationship with increasing age. In the authors' opinion this is likely (at least partially) to be the result of financial factors, where owners are reluctant to commit to the increasing costs for repeated surgical interventions or prolonged management in older horses.

Time to referral was not found to be a significant factor in the overall outcome of cases in this study, which supports the findings of Post *et al.* (2003). The statistical power of this study is limited due to the small number of cases, therefore, smaller differences are unlikely to be detected, hence, prompt referral for surgical treatment is still recommended in the interests of welfare, as evidence is still conflicting with regards to the true significance of time to referral following synovial sepsis (Ingle-Fehr and Baxter 1998; Wright *et al.* 2003; Walmsley *et al.* 2011; Findley *et al.* 2014; Milner *et al.* 2014).

In this population of horses, the use of either lavage technique was not associated with any statistically significant difference in survival to discharge, success at first surgery or return to work. Sepsis of the CB is historically associated with a fair to guarded prognosis for return to athletic performance (Baxter 2019), however, the findings of this study suggest that the prognosis for returning to the same level of performance or higher is good. The authors found that 93.3% of horses discharged after treatment returned to the same level of work or higher, similar to that found in another large, multicentred, retrospective study where 91.2% of horses returned to the same or higher level of work following bursoscopic lavage (Isgren *et al.* 2017). These outcomes are better than those reported in previous studies of return to work following synovial sepsis in general (Schneider *et al.* 1992; Wright *et al.* 2003; Smith *et al.* 2006). In the current study, 82.8% of horses survived following treatment which is consistent with previously reported survival rates following synovial sepsis (Schneider *et al.* 1992; Wright *et al.* 2003; Smith *et al.* 2006). This evidence is valuable for assisting clinicians in estimating prognosis and for owners in making informed decisions about treatments. However, it should be noted that this population consisted primarily of low-level competition horses that would be expected to return to a much lower level of work compared to that of a high level or international competition horse. In addition, the power of the study must be considered when interpreting these findings. A post hoc power calculation was performed, assessing first surgical technique and survival to discharge. Initial bursoscopy had a success rate of 69.2% compared to 93.75% for needle lavage, but the power of the study was only 36.5% and, hence, small differences between the two techniques would be unlikely to be detected. Increasing the sample size to 76 would return a power of 80% and may form the basis of a future study.

The degree of lameness was assessed on arrival and varied greatly, ranging from mild (1.5/10) to severe (10/10); this could be explained by the presence of an open communication between the septic bursae and wound, facilitating drainage or the fact that many of the cases recorded were referred on the day of injury, some within hours of injury (Morton 2005). Degree of lameness at admission was not found to be a reliable prognostic indicator.

Radiographic abnormalities associated with the tuber calcanei were present in 5/29 (17.2%) horses with two horses noted to have osseous fragment(s) and three a radiolucent area associated with the tuber calcanei. The presence of osseous damage detected on radiographs has previously been associated with a poorer prognosis, and the findings of this study support that association (Post *et al.* 2003). In one horse (Case 2), the small area of bone lysis was only detected prior to the second surgery, 6 days following initial presentation, highlighting the importance of follow-up radiographic examination given the delay in development of bone lysis secondary to osteomyelitis or sequestrum formation, particularly in cases associated with trauma (Richardson and Ahern 2019). Cases where tuber calcanei injury is suspected should include a proximoplantar-distoplantar (skyline) projection, and ideally all cases would have this projection included in the survey radiographic series (Bassage *et al.* 2005). In this study the proximoplantar-distoplantar projection was not routinely documented.

Antimicrobial therapy was non-standardised in this study, given its retrospective nature, therefore, no meaningful statistical analysis was possible to assess the impact of antimicrobial choice on post-operative outcomes. It is well documented that culture is often unrewarding from synovial structures (Madison *et al.* 1991; Schneider *et al.* 1992; Dumoulin *et al.* 2010; Annear *et al.* 2011; Lescun 2011) and the delay in obtaining the results of bacterial culture means that therapy must be initiated before results are available. Systemic broad-spectrum antimicrobials are recommended for treating synovial sepsis until the results of culture and sensitivity are known (Baxter 2004) and, in our cases, a combination of gentamicin and penicillin was routinely used as the initial treatment, as previously recommended (Baxter 2004; McIlwraith *et al.,* 2015). Culture and sensitivity results were only recorded in the clinical records for one of the eight horses that received enrofloxacin, this horse was treated in 2018; the remaining seven horses were all treated during or prior to 2009 when antimicrobial stewardship was still very much in its infancy and a growing theme within veterinary medicine (Dyar *et al.* 2017). Intra-synovial medication with antimicrobials, including gentamicin sulphate and ceftiofur, was undertaken in most of the horses following bursal lavage. This achieves immediate synovial concentrations of antimicrobials above the minimum inhibitory concentration (MIC) for common bacterial isolates (Lloyd *et al.* 1990). However intra-synovial administration of antimicrobials can result in a chemically induced synovitis or 'joint flare' (Steel 2008), and the use of unbuffered gentamicin has been associated with an increased risk (Lloyd *et al.* 1988).

Surgeon preference was a major factor in this study, with seven different surgeons contributing to the treatment of the 29 cases. The decision to use a through-and-through needle versus a bursoscopic lavage technique is somewhat controversial and in many cases the technique chosen is that preferred by the surgeon performing the surgery. Whilst it is recognised that bursoscopy has advantages in terms of identification and removal of foreign material and fibrin, debridement of osseous or tendinous lesions if present, assessment of cartilage and osseous damage, and performance of synovectomy (Baxter 1996; Wright *et al.* 2003;

McIlwraith *et al.* 2015), the necessary instrumentation and expertise is not always available and at many clinics (including the authors') the cost of treatment using bursoscopic lavage is higher than that of through-and-through needle lavage. Such factors, as well as others including the expected degree of bursal contamination or associated osseous or soft tissue damage, need to be considered when deciding on which procedure is appropriate on a case-by-case basis. Many of these variables were not considered in this study given the retrospective nature and reliance on historic case records. Although the results of this study will inevitably suffer from significant bias relating to surgeon preferences, the findings suggest that through-and-through needle lavage can achieve comparable outcomes for the treatment of CB sepsis to bursoscopic lavage. However, these results need to be confirmed or refuted by a prospective controlled study with larger case numbers.

Conclusions

In conclusion, the prognosis for a return to previous athletic performance following CB sepsis was good in this population of horses which predominantly represented a low-level competition population. Time to referral and degree of lameness on admission had no notable impact on outcome, unlike the presence of abnormalities on survey radiographs that was as a negative prognostic indicator. Whilst bursoscopic evaluation following CB sepsis may be of added value, particularly in visually assessing osseous and tendinous structures, it must be noted that the needle lavage technique was adequate in the management of septic CB, and may be an appropriate option, particularly in those cases managed under financial constraints.

Authors' declaration of interests

No conflicts of interest have been declared.

Ethical animal research

Not applicable.

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Authorship

M. Duggan contributed to study design and execution. M. Duggan and T. Mair contributed to data analysis and interpretation and also contributed to the preparation of the manuscript. Both authors gave their final approval of the manuscript.

Owner informed consent

Not required, however was obtained in those cases followed up via telephone interview.

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[6]Zoetis, Leatherhead, Surrey, UK.
[7]Vetoquinol, Paulesbury, Towcester, Northamptonshire, UK.
[8]Norbrook Labs Ltd., Corby, Northamptonshire, UK.
[9]Bova, London, UK.

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Original Article

The development of safe and effective rehabilitation protocols for horses

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Summary

Rehabilitation has become an important aspect of equine practice. Unfortunately, there is limited knowledge or awareness of the general principles and methods used to develop safe and effective rehabilitation programmes. By following a few basic principles, appropriate rehabilitation programmes can be developed for individual horses with a wide range of injuries and sources of musculoskeletal pain or dysfunction. This article provides an outline of general guidelines to help practitioners interested in developing rehabilitation programmes or working with sports medicine and rehabilitation experts to provide the best possible treatment for individual horses with injuries at different stages of healing.

Introduction

There has been a recent proliferation of rehabilitation approaches and modalities with claims of effectiveness for treating musculoskeletal and neurological disorders in horses (Kaneps 2016; Schlachter and Lewis 2016; Wilson *et al.* 2018b). There is also a growing body of evidence that some of these modalities do have a level of safety and efficacy in specific applications (Nankervis *et al.* 2016; Haussler 2018; Holcombe *et al.* 2019). Unfortunately, there has been a long history of practitioners and lay people using various forms of rehabilitation without a good foundation of physical therapy principles, knowledge of tissue healing properties, or understanding of the basic mechanisms of action of the applied treatments. In addition, there is a tendency to treat all horses the same (i.e. one-size fits all approach) and to rarely have clear outcome measures or goals for the treatment programme. There is a critical need to provide guidelines for the development of safe and effective rehabilitation plans based on the type, location, severity and chronicity of tissue injuries with clearly defined rehabilitation issues and goals for progressing (or regressing) in the programme (Chiarotto *et al.* 2015). This article provides an outline of general guidelines to help practitioners interested in developing rehabilitation programmes or working with sports medicine and rehabilitation experts to provide the best possible treatment for individual horses with injuries at different stages of healing.

Rehabilitation principles

Developing an effective rehabilitation programme requires teamwork and collaboration between the rehabilitation practitioner, primary veterinarian, owner/trainer, other allied-health specialists, farrier and the patient. If everyone is not on the same page with regard to time, costs, layup, risks for reinjury, etc., then there will likely be challenges to developing and successfully executing effective rehabilitation programmes. Another important aspect of developing a rehabilitation programme is that there are no standardised, evidence-based treatment protocols that meet all patient needs (i.e. there is no cookbook or recipe to follow). Unfortunately, many rehabilitation programmes are often designed as a one-size fits all approach and the individual needs or specific tissue healing aspects are not fully addressed. Rehabilitation programmes should be based on current research and evidence-based practice. Substantial advancements in developing the knowledge base of equine rehabilitation and the evidence of efficacy for some commonly used modalities have been made; however, there is a long way to go to establish a broad-based foundation or understanding of the mechanisms of action and prescribed dosage parameters for each of the physical modalities, therapeutic exercises and manual therapy options that are routinely incorporated into equine practice. The clinical decision-making process for selecting appropriate modalities for treatment is often based on the acuity and stage of tissue injury, perceived mechanisms of action, and practicality of application based on individual needs.

Progression through each stage of rehabilitation must be based on objective criteria and associated modifications in treatment plans. The detrimental effects of immobilisation should be minimised or prevented during each stage of tissue healing; however, caution to not overly stress healing tissues during recovery should be respected. Immobilisation of healing tissues has direct and immediate detrimental effects impacting muscle function, articular cartilage degeneration, impaired joint stability and flexibility, and the production of excessive fibrosis (van Harreveld *et al.* 2002). Medical and surgical advances have facilitated more rapid returns to sporting activities; however, tissue healing and neuromuscular control must be addressed to prevent recurrence of injuries (Stover 2017). If neuromuscular coordination, strength, and endurance are inadequately restored, then ligaments, muscles, and bones are exposed to greater or abnormal tissue loading that places repaired tissues at risk for reinjury (Brandt 2004). The role of stall rest or confinement must also be considered in the context of altered bone remodelling and soft tissue deconditioning in horses that have a high

mental drive to compete or race (Hitchens *et al.* 2018). Finally, clearly defined rehabilitation priorities and goals need to be established and followed throughout the treatment period.

Motor behaviour

A conceptual framework is needed to better understand the complexity of interactions that occur within the active and passive tissues of the musculoskeletal system and the control mechanisms that regulate the locomotor apparatus (**Fig 1**) (van Dieen *et al.* 2017). The passive tissues of the musculoskeletal system include bones, articulations, ligaments and fascial coverings. The active tissues consist of muscles and their tendinous insertions, which have a motor innervation that activate sarcomeres to induce muscle contraction and subsequent joint movement. Additionally, passive and active musculoskeletal tissues also have a rich sensory innervation to constantly monitor joint position and velocity (proprioception), tissue lengthening (muscle spindle fibres) and tension (Golgi tendon organ). The integration of motor and sensory information is critical to the production of efficient movement and the protection of associated tissues from supraphysiological loading and risk of injury (Reeves and Cholewicki 2013). Awareness of these system interactions is needed to fully develop and implement safe and effective rehabilitation protocols.

Rehabilitation protocol development

An effective rehabilitation programme is only as good as the diagnosis upon which it has been founded. Rehabilitation protocols should be based on a clearly defined problem list that has been created from a collection and analysis of subjective and objective data from the individual patient (**Table 1**). The primary rehabilitation priorities that are most evident on the day of evaluation drive the treatment plan for that session. Primary rehabilitation goals are based on functional assessments and can be categorised into general issues of pain, range of motion, proprioception, motor control, strength and endurance (**Fig 2**). Within each of these categories, more specific aspects can be defined, such as acute pain, chronic pain, soft tissue pain, bone pain or neuropathic pain, for which individualised pain management approaches should be designed. Functional assessments often relate to global measures of the patient's ability to perform a task, which is in contrast to pathoanatomical diagnoses that are more commonly used in veterinary medicine. As an example, impinged spinous processes at T13–T15 is a pathoanatomical diagnosis, whereas bilateral epaxial muscle pain and hypertonicity with moderately restricted lateral bending throughout the entire trunk would provide a functional diagnosis. The functional diagnosis would then specifically help guide rehabilitation protocol development.

The stage of tissue injury also needs to be delineated as acute, subacute or chronic. Similarly, the tissue healing response needs to be characterised as having inflammatory, proliferative or remodelling features (**Table 2**). In the acute or inflammatory phase of tissue healing, pain management, limiting tissue damage and maintaining some level of tissue or joint motion are the primary issues dictating development of a rehabilitation programme. Therefore, pain management, swelling control, and soft tissue and joint mobilisation are often incorporated during this phase of healing. In the proliferative phase of tissue healing, limiting impairment and restoring function are important treatment goals. Exercises that stimulate proprioception, flexibility, and early strengthening, predominate in this phase of rehabilitation, which might include standing a horse on foam balance pads, aquatic therapy with variable water levels and treadmill velocity, and work over ground poles or cavelletti on a lunge or long line. Finally, the tissue remodelling phase focuses on conditioning tissues to physiological loading, restoring tissues to structurally and functionally meet sports-specific demands, and more importantly reducing the chance of reinjury. Exercises that stimulate higher levels of endurance and strength are included in this final phase of recovery and often incorporate ridden exercise over different ground surfaces, inclines (hill work), and duration and intensity of work. For all stages of tissue healing, the sports-specific aspects of training need to be considered and exercises or

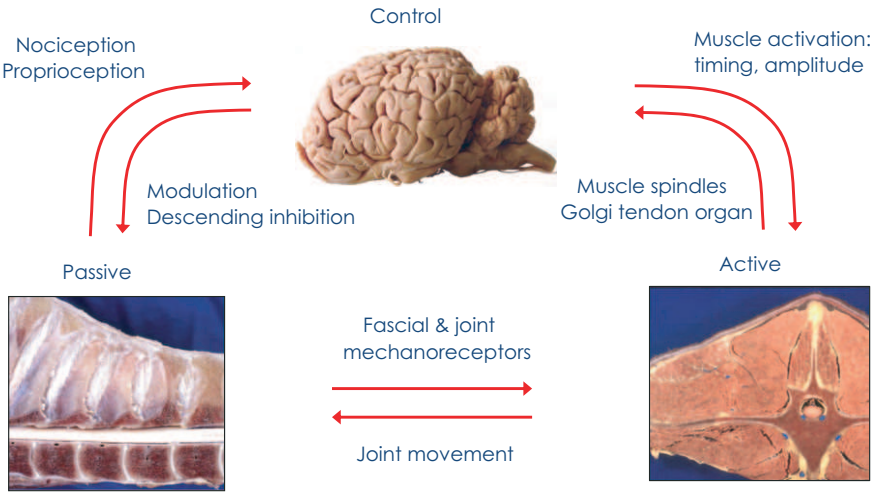

Fig 1: Simplified model of the interactions between passive, active and neurological mechanisms responsible for joint movement and locomotion.

TABLE 1: Issues to be considered in the development of safe and effective rehabilitation protocols

Develop a problem list
Based on the most accurate diagnosis as possible
Based on both structural and functional assessments
Identify the primary functional rehabilitation issues
Pain, stiffness, muscle hypertonicity
Incoordination, weakness, fatigue
Identify the phase of tissue healing
Acute, subacute or chronic
Inflammatory, proliferative or remodelling
Develop a treatment plan to address the current primary functional rehabilitation issue
Approach: Manual therapies, therapeutic exercises or physical modalities
Dosage: Intensity, frequency, duration and periodicity
Assess treatment efficacy and safety
Clinical assessment
Diagnostic imaging
Objective outcome measures
Modify treatment as needed to meet rehabilitation goals
Dosage: Increase, decrease or continue at current level
Approach: Add and remove applied therapies as judged appropriate
Assess return to function and athletic capabilities
Minimise recurrence of injury and maladaptive compensatory issues
Assess return to a prior level of competition
Optimise performance

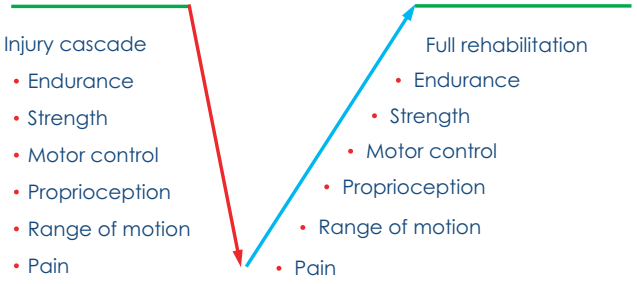

Fig 2: Schematic representation of the cascade of events associated with acute musculoskeletal injury and disability with the subsequent steps required to address specific rehabilitation issues in order to achieve full rehabilitation and return to athletic performance of prior levels of activity.

modalities that focus primarily on stimulating proprioception, flexibility, strength, speed, agility, endurance and restoration of the functional movements required for specific athletic disciplines.

Once the primary goals for rehabilitation have been defined and the stage of tissue healing assessed, the practitioner can then effectively select specific physical modalities, therapeutic exercises or manual therapies to address the issues at hand (**Table 3**). A single treatment or modality (i.e. monotherapy) may be selected, but often a collection of different therapies with overlapping mechanisms of action (i.e. multimodal) are incorporated into comprehensive rehabilitation plans. The clinical reasoning or justification for modality selection is critical for successful rehabilitation of most injuries. If the wrong therapy is applied at the wrong time or for the wrong indication, then either the treatment is not going to be effective or worse, the treatment

TABLE 2: List of treatment goals for each of the tissue healing phases that include inflammation, proliferation and remodelling

Inflammatory phase
Reduce bleeding
Prevent further tissue injury
Resolve underlying pathology
Pain management
Control inflammation
Reduce joint loading
Stabilisation
Proliferative phase
Manage pain (as needed)
Increase circulation
Control fibrosis
Increase proprioceptive awareness and balance
Promote function
Protect integrity of repaired tissue
Restore full range of motion
Increase muscle strength and endurance
Maintain and improve cardiovascular fitness
Restore normal gait patterns
Reduce compensatory gait patterns
Remodelling phase
Maximise tissue loading
Monitor closely for signs of reinjury
Restore maximal balance and coordination
Regain strength and endurance
Promote cardiovascular fitness
Optimise motor control and core stability
Prescribe sports-specific exercises that reproduce the demands of competition

will actually exacerbate the injury and delay tissue healing. For each modality, the physical properties and physiological effects need to be clearly identified and judged appropriate to address the rehabilitation issue of interest. For example, cryotherapy is indicated for acute pain and inflammation and is known to have analgesic and anti-inflammatory tissue effects (van Eps and Orsini 2016). Therefore, applying heat to acutely inflamed tissues is likely a poor treatment choice. Unfortunately, the precise mechanisms of action or known physiological effects for common modalities used in equine practice often lack sufficient levels of evidence of efficacy. Therefore, most indications, contraindications and precautions in equine practice are borrowed from human physical therapy research and clinical applications.

Dosage considerations

Each component of the rehabilitation programme needs to have clearly defined parameters of intensity, duration, frequency and periodicity. The dosage of the applied treatment is an important concept to consider since if too low of an applied stimulus is applied then it is less likely to be as effective as possible. On the other hand, if too intense of a treatment is applied, then the risk for injury or safety is increased. There is a need to constantly assess if the applied treatment is both safe and effective for the individual patient at their specific stage of tissue healing and phase of recovery.

Intensity is defined as how much of a stimulus is applied given the rehabilitation goals and tissue healing phase (**Table 4**). The speed of exercise (i.e. walk, trot or canter) and the resistance or workload (e.g. unridden versus ridden

TABLE 3: Tools available for use in equine rehabilitation programmes

	Examples	Indications
Physical modalities		
Thermal modalities	Heat, cold, radiofrequency, therapeutic ultrasound	Pain, hypertonicity, inflammation
Electrical stimulation	TENS, muscle stimulation	Pain, hypertonicity, muscle atrophy
Mechanical stimulation	Vibration, extracorporeal shockwave therapy, therapeutic ultrasound	Pain, hypertonicity, tissue healing
Photic modalities	Low-level laser therapy	Pain, hypertonicity, tissue healing
Magnetic stimulation	Pulsed electromagnetic therapy	Muscle pain, hypertonicity, inflammation
Aquatic therapy	Underwater treadmill exercise	Buoyancy, flexibility, strength
Bariatric therapies	Hyperbaric oxygen therapy	Ischaemia, endotoxaemia
Therapeutic exercises		
Balance retraining	Foam pads	Proprioception, core stability
Ground poles	Straight, angled, elevated	Flexibility, coordination, agility
Gait retraining	Inclines, treadmill	Motor control
Therabands	Equicore system	Core stability, strengthening
Elastic tape	Rocktape, Vetkine	Cutaneous proprioception, lymphatic drainage, decompression
In-hand work	Lunge, longline	Motor control, core stability
Training programmes	Collected work	Flexibility, agility
Conditioning programmes	Aerobic, anaerobic capabilities	Cardiovascular fitness, coordination
Manual therapies		
Stretching	Active, passive	Stiffness, muscle hypertonicity
Massage	Superficial, deep	Muscle hypertonicity, fibrosis, myofascial reintegration
Mobilisation	Soft tissue, joint	Stiffness, fibrosis, pain modulation
Manipulation	High-velocity, low-amplitude	Stiffness
Adjunctive tools		
Pharmaceuticals	NSAIDs, muscle relaxants	Pain, muscle hypertonicity
Acupuncture	Electroacupuncture	Pain
Biological therapies	IRAP, PRP, stem cells	Inflammation, tissue repair
Tack	Saddle fit, girth tension	Pain, poor performance
Diagnostic imaging	Ultrasound, endoscopy	Monitor tissue healing
Clinical pathology	Muscle enzymes, synovial fluid, biomarkers	Assess tissue damage, healing
Corrective hoof trimming	Mediolateral hoof capsule balance	Restore proper solar angles
Therapeutic shoeing	Corrective shoe	Collateral ligament desmitis
Surgery	Arthroscopy	Diagnosis or treatment

TENS, transcutaneous electrical nerve stimulation.

exercise) are common determinants of intensity. Other examples include different temperatures of applied cold therapies (i.e. cold water hose versus ice immersion) or intensity of electrical stimulation. Duration is defined as how long a specific modality is applied (**Table 5**). For example, stretching exercises are typically held for 20-30 seconds to allow for tissue hysteresis and creep to help support increased collagen extensibility (Apostolopoulos *et al.* 2015; Opplert *et al.* 2016). The frequency or number of repetitions are important features for some modalities, such as the number of shocks applied during extracorporeal shockwave treatments (**Table 6**). Additionally, frequency is often based on desired outcome for an applied treatment (e.g. agility versus endurance) and the needed recovery time after the applied exercise or therapy. The periodicity defines how often the treatment is applied (**Table 7**). Some treatment modalities may be applied 3–4 times a day (e.g. cryotherapy), others may be applied once a day (e.g. stretching) and others may be applied every 4–6 weeks (e.g. acupuncture or manual therapy).

In addition to determining specific modality parameters, treatment can also be applied locally, regionally or systemically, depending on the disease process or overall needs of the patient (**Table 8**). For focal tissue injures, local treatment might be the most effective and economical approach. For systemic disease processes or general fitness or conditioning, whole-body treatments are needed. For example, horses with type 1 polysaccharide storage myopathy often require a high-fat, low-carbohydrate diet and consistent, low-grade exercise (McKenzie and Firshman 2009). Force–velocity relationships can also be considered in rehabilitation protocol development. High-force and low-velocity exercises (e.g. piaffe) are designed to develop

TABLE 4: Examples of low, medium and high intensity or amplitudes of treatment across several modalities

Modality	Low	Medium	High
Cryotherapy	Ice pack	Ice immersion	Salt water spa
Acupuncture	One needle	Aquapuncture	Electroacupuncture
Stretching	25% ROM	75% ROM	100% ROM
Lungeing	Walk, large circle	Trot, medium circle	Canter, small circle
Laser therapy	25% duty, low	50% duty, medium	Continuous, high
Ground poles	One pole	5 poles, wide spacing	Obstacle course
Jumping	Cavelletti	0.7 m	1.5 m

TABLE 5: Examples of low, medium and high duration of treatment across several modalities

Modality	Low	Medium	High
Cryotherapy	5 min	30 min	2 h
Acupuncture	1 min	10 min	30 min
Stretching	5 s	15 s	30 s
Lungeing	5 min	15 min	30 min
Laser therapy	30 s/site	1 min/site	2 min/site
Ground poles	2 min	5 min	10 min
Jumping	5 min	10 min	15 min

TABLE 6: Examples of different levels of repetitions depending on the individual needs or capabilities of the patient

Repetitions	Treatment goals or patient response
1–2 times	If difficult, strenuous or challenging
4–5 times	If need more training, flexibility or strength
8–10 times	If easy to do, but need to retrain motion
20–30 times	If easy to do, and need to develop motor learning or endurance

TABLE 7: Examples of different levels of periodicity depending on the individual needs or capabilities of the patient

Periodicity	Treatment goals or patient response
2–3 times a day	If need aggressive rehabilitation or training
Once a day	If need to improve a skill
2–3 times a week	Maintenance, cross-training
Once a week	To maintain fitness, strength

maximal strength. Medium force and medium velocity exercises (e.g. jumping over 0.7 m obstacles) help to develop power and impulsion. Finally, low-force and high-velocity exercises (e.g. reining spin and cutting in Quarter Horses) help to develop speed, agility and coordination.

Implementation of rehabilitation protocols

When developing a rehabilitation programme, the practitioner or team of providers must decide what is most appropriate for the patient given a specific type of injury and functional impairment. The first stage is often viewed as the theoretical stage where the optimal treatment programme with defined mode, intensity, frequency, duration and periodicity is determined. The second stage is the practical stage when the practitioner determines what is actually feasible for the owner to do. This includes discussions about time commitments, financial concerns, owner receptivity and physical ability to follow the treatment plan, and if the needed facilities, equipment and resources are available to accomplish the outlined treatment goals and perceived outcomes. The third stage is the realistic stage which is what actually can be done or accomplished. For example, not all horses will tolerate the applied therapies and in some situations, owners may incorporate certain treatments that are completely in contradiction to what was discussed with the practitioner (e.g. ridden versus unridden exercise), or the individual patient may be unable to physically or mentally complete the assigned task due to pain, weakness, fear or confusion. Therefore, home care instructions are often needed as a means to provide consistent treatment, monitoring of progression and limiting costs for the owner. Finally, a careful selection of modalities or interventions is needed to ensure that owners are applying the recommended therapies appropriately and monitoring for possible complications.

TABLE 8: Examples of local, regional and systemic applications of treatment depending on the individual needs of the patient

Site of application	Examples
Local	Cryotherapy, electrical muscle stimulation, manual therapy (mobilisation, manipulation)
Regional	Electroacupuncture, limb stretching, massage
Systemic	Underwater treadmill exercise, lungeing, ridden exercise

If multiple rehabilitation issues are identified and all factors are judged to be significantly important to address on a single visit, then the primary goals should be prioritised and ranked. For example, a chronically infected wound may require debridement, pain management, antimicrobials or some form of immobilisation. In this case, wound management may take priority; however, pain management and immobilisation cannot be ignored. Another principle is to use modalities with multiple mechanisms of actions so that more than one rehabilitation issue can be addressed with a single modality. A good example is the use of underwater treadmill exercise where limb unweighting (tissue protection), increased joint range of motion (flexibility) and resistance (strengthening), all play important roles in the rehabilitation of limb injuries. Also, when using a combination of therapies, they can either be applied sequentially or simultaneously. For example, a horse standing in ice immersion boots can also undergo weight-shifting exercises or even acupuncture at the same time, depending on patient tolerance or compliance.

Structural and functional assessments

As the treatment plan is carried out, regular clinical examinations and the use of outcome measures are needed to 1) determine if significant progress is being made; 2) if there is delayed tissue healing and no functional improvements; or 3) the condition is worsening. Based on these functional assessments, the treatment is modified as needed to either increase, decrease or continue at the current level of intensity, frequency, duration and periodicity. Diagnostic imaging modalities are used throughout the rehabilitation process to help guide protocol development, monitor the progression of tissue healing (i.e. structural assessments), and to ensure a successful return to function. Finally, the patient is assessed to determine whether the overall treatment goals and desired outcomes of rehabilitation have been attained as the return to work and progression in athletic capabilities are closely monitored to prevent the recurrence of injury and harmful compensatory issues (e.g. acute back pain due to chronic hindlimb lameness).

Methods used to assess goals during rehabilitation may be categorised into subjective and objective data collection. Subjective or qualitative measures may include lameness scores, pain scores or assessing muscle tone. Objective or

quantitative measures include limb circumference, stride lengths or joint range of motion to assess flexibility (Levine *et al.* 2009; Scott *et al.* 2010; Adair *et al.* 2016). Another form of categorisation is structural versus functional assessment. Structural measures are often provided by body condition scores, conformation evaluation, dual-energy X-ray absorptiometry (DEXA) or diagnostic imaging modalities (e.g. cross section area of a tendon), but may have little correlation with the tissue function or the pain status of the patient (Quiney *et al.* 2018). Therefore, functional assessment tools have been developed in an attempt to capture the clinical features of musculoskeletal and neurological activity within affected patients. Functional measures include visual analog scales, behavioural scoring (e.g. grimace scores), postural and proprioceptive evaluation, assessing strength and scoring the overall aesthetics of movement (King *et al.* 2013; van Loon and Van Dierendonck 2015).

The most commonly used methods of assessing tissue injury and inflammation are the subjective evaluation of heat, swelling or pain responses to palpation. These parameters can be objectively monitored with thermal imaging, circumferential limb or joint measures, and pressure algometry, respectively (Sullivan *et al.* 2008; Buchner *et al.* 2017). Additional measures of pain or lameness can include limb flexion, hoof testers, ground reaction forces and inertial sensor devices (Moorman *et al.* 2014; Faramarzi *et al.* 2017). Video analysis of gait and body movements during functional activities is another economical way to measure progress with rehabilitation and can easily be performed with the use of portable cameras (Guest and Cunliffe 2014). Measures of proprioception include neurological examination, limb advancement and placement, weight-shifting exercises, postural stability, and the ability to navigate cavelletti or ground poles (Goehring 2011). Flexibility and joint range of motion can be readily assessed using goniometers to measure joint angles or baited stretches to assess both the quantity (range of motion) and the quality (ease and freedom of movement) of spinal motions (Liljebrink and Bergh 2010; Adair *et al.* 2016). Lameness is commonly assessed with visual observation, but can also be evaluated with motion capture systems, force platforms, inertial sensors and electromyography; however, the cost and time required for this type of assessment is prohibitive in most rehabilitation settings (Tabor and Williams 2018). Video-based software programs and pressure mat sensors are now available that are user-friendly and can capture the basic movement patterns of most gaits (Murray *et al.* 2013). Pedometers are very useful for counting steps and monitoring overall activity and have seen a recent growth in popularity (McDuffee *et al.* 2000).

Objective measures of strength continue to be a challenge in equine practice. The most commonly used method to subjectively assess strength is the resistance and ability to correct after sudden, lateral traction on the tail. Basic levels of assessing strength include the ability to stand unassisted, three-legged balance with and without perturbations, induced hopping, and the duration of activity and distance travelled during specified activities. Additional strength assessments include the ability of a horse to sustain an isometric (static) muscle contraction during applied digital pressure over the sternal or croup regions associated with induced spinal reflexes. Moderate challenges used to assess weakness might include the ability to navigate incline and decline surfaces, navigate ground obstacles, or the subjective assessment of impulsion or core stability (Dyson and Murray 2003). Advanced and more objective measures of strength and endurance include assessing jump heights, time for completing events (e.g. eventing or endurance), and race times for Standardbred or Thoroughbred patients (Wilson *et al.* 2018a). Measures of cardiovascular fitness often include heart and respiratory rates, core temperatures, blood lactate and calculating VO_2 max parameters (McKeever *et al.* 2010). Clinical pathology is also used to assess joint health (e.g. synovial fluid), muscle function (e.g. muscle enzymes, biopsies), and occasionally serum and synovial fluid biomarkers (McIlwraith *et al.* 2018).

Rehabilitation progression

Unlike most medical or surgical approaches that incorporate a set treatment parameter (e.g. mg per kg of body weight) or single treatment event (e.g. arthroscopic surgery), rehabilitation protocols often require progressive gradations in treatment intensity, duration, frequency and periodicity to achieve desired outcomes and prescribed goals. This concept may be difficult for owners or trainers to fully understand or accept as their primary goal is often to get their horse back to ridden exercise or return to athletic performance as soon as possible. Veterinarians may also fall into this trap as the pain associated with lameness may have resolved; however, the flexibility, proprioceptive, motor control, strength and endurance of the individual patient may not have been acknowledged or addressed in any meaningful way. An example is going from 0 to 100% without any consideration of assessing if the patient can perform adequately at 20, 40, 60 or 80% effort or intensity. The analogy of the progression through different levels of education is helpful for some owners to understand stages of rehabilitation or capabilities within individual patients (**Table 9**). A low-level skill or movement requirement (e.g. walk in a straight line) would be considered a kindergarten-level exercise, whereas jumping at 1 metre with rapid changes in speed and direction might be considered a college-level exercise.

For each individual exercise, there is also a progression in the speed or intensity, duration, frequency and periodicity. Intensity can be scored as low, medium and high. Speeds can be slow, intermediate or fast. Levels of difficulty can be simple or complex depending on the strength or agility required. Surface stability can be modified from firm, stable surface (e.g. asphalt) to unstable surfaces (e.g. gravel, sand, proprioceptive pads) with static or dynamic perturbations (e.g. pushed off balance) added to increase levels of difficulty for developing proprioceptive, coordination and balance skills. Select exercises can also include limited or blinded vision to maximise proprioceptive stimulation and balance requirements (King *et al.* 2013). Early stages of rehabilitation should include exercises that are slow and simple, require minimal tissue loading, and are predictable (e.g. standing balance, rhythmic perturbations, underwater treadmill exercise). Later stages or more advanced exercises incorporate complex movements at high-velocity and high tissue loads and are more unpredictable (e.g. walk, trot, gallop on hills or uneven surfaces, jumping obstacles).

When to modify or discontinue therapy

The same indicators that were used to determine the need for rehabilitation are used to assess if the rehabilitation programme was successful or not. The rate of recovery is

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[1] American Association of Equine Practitioners. Parasite Control Guidelines. https://aaep.org/guidelines/parasite-control-guidelines. Accessed June 1, 2019.

zoetis

TABLE 9: Examples of progression through increasing levels of physical or mental difficulty for different types of therapeutic exercise

Demands	Exercise	Indication
Easy	Straight, flat, firm ground	Minimal demands
	Uneven or soft ground	Increased proprioception
	Underwater treadmill	Unweighted tissues, Increased resistance
Moderate	Add circles	Balance, flexibility
	Add ground poles, obstacles	Proprioception, coordination
	Add inclines	Caudal weight shifting, strength
Difficult	Add cavelletti, jumps	Agility with speed, impulsion
	Increase speed	Increased tissue loading, strength
	Land treadmill	Increase cardiovascular fitness
	Added weight	Weighted surcingle, weighted saddle
	Ridden exercise	Start again at the top of this list and progress downwards

variable between patients and is often dependent upon the type, location, severity and chronicity of injury (**Table 10**), and the overall adherence to the rehabilitation programme. When assessing pain, if there are no signs of physical or behavioural issues related to pain, then that component of treatment can be considered accomplished and the next phase or rehabilitation goal is pursued. Flexibility is judged as the restoration of normal soft tissue and joint motion, which can be assessed from a local, regional or whole-body perspective. Balance, coordination and agility incorporate both proprioceptive (afferent) and motor control (efferent) mechanisms. Dynamic perturbations (e.g. lateral tail pull exercises) require a fully functional proprioceptive system as well as the strength and coordination required to resist the applied forces. Proprioception is judged based on repeatable foot and limb placement, general body awareness, posture and core stability. Motor control includes aspects of balance, posture, coordination, core stability, strength and endurance. Balance is defined as the ability to remain upright and steady, with controlled body movement upon perturbation. Postural control involves the support of the body against gravity both statically and during dynamic movements. Coordination includes body movements that produce an intended action with a functional level of precision. Core stability stabilises the axial skeleton during movement. Strength is a measure of the capacity to do work, and endurance is the ability to continue that activity for extended periods of time. Strength and endurance are features that are constantly developed and required for skilled athletic function.

Obstacles to safe and effective rehabilitation

Two of the biggest challenges to manage in any rehabilitation facility or practice are 1) the high costs required to incorporate skilled care from educated practitioners and 2) the intensive, hands-on time required to successfully design and implement most treatment plans. Costs are not limited to equipment needs, but also a dedicated facility or work-space, infrastructure to support the equipment (e.g. underwater treadmills, hyperbaric chambers and treatment modalities), available housing for prolonged stays, and staffing needs for applying treatments and monitoring responses with objective outcome measures. If dedicated rehabilitation facilities are not available, then practitioners typically have to provide repeated farm calls with added time and travel costs. Compliance is often an issue with home care for both the owner and the patient. What practitioners are able to do or recommend may differ substantially from how the owner or trainer actually applies the therapy. Some horses may be impaired with multiple disease processes (e.g. metabolic syndrome and laminitis) or multiple affected limbs. As with any medical or surgical approach, managing end-stage disease can be extremely challenging and unrewarding at times. One of the most significant obstacles to delivery of effective rehabilitation is a practitioner's lack of knowledge or awareness of the current literature or general standards of clinical practice. Unfortunately, there is limited research funding in this specialty area of veterinary practice and there are few individuals with the training and facilities required to conduct the studies needed to expand the rehabilitation knowledge base. Many of the modalities used are based on unsubstantiated claims of effectiveness or indications for treatment. For example, visiting websites of laser manufactures can be quickly overwhelming and extremely confusing for even the most educated individual. Rehabilitation centres may also employ lay people without the needed veterinary oversight or rehabilitation expertise needed to create, implement and monitor effective treatment programmes. In addition, some equine rehabilitation centres may have strong treatment biases based on their perception that all horses need underwater treadmill exercise, irrespective of the tissue healing phase or individual needs of the patient. If treatment is not progressing as expected, then the diagnosis needs to be reassessed or the selected therapy and its application (e.g. timing, duration, frequency) need to be reconsidered (**Table 11**). Finally, if repeat clinical assessments and outcome parameters are not used consistently throughout the rehabilitation programme, then assessing the progression or the need to discontinue therapy for an individual patient becomes challenging.

TABLE 10: Estimates of time for training adaptations within tissue types and the resolution of select rehabilitation issues

Rate of adaptation			
Days to weeks	Weeks to months	Several months	Months to years
Skin Synovium	Muscle Ligament	Joint capsule Peripheral nerve	Tendon Spinal cord
Pain Flexibility	Bone Proprioception	Meniscus Coordination	Cartilage Motor control
	Balance	Speed	Work capacity
	Strength Sports-specific endurance		

TABLE 11: Guiding principles for the development of safe and effective rehabilitation protocols

Establish the right medical, structural and functional diagnoses
Identify specific target tissues and pathologic processes
Utilise appropriate diagnostic imaging
Incorporate functional assessments of the musculoskeletal and neuromuscular systems
Select the right treatment
Monotherapies tend to be less effective than combined therapies
Working knowledge of anatomy, biomechanics, disease processes, athletic demands
Apply at the right time
Stage of tissue healing
Appropriate phase within the training or competition schedule
Patient selectivity
Select treatments that are most effective to meet the individual patient's needs
Maximise owner and patient compliance
Provided by the most qualified practitioners
High level of professionalism with extensive clinical expertise
Expert clinical reasoning skills even in situations of ambiguity
Open, supportive communication style
Team approach to care
With the right follow-up
Objective outcome parameters used to monitor treatment progression
Meet clearly defined and achievable rehabilitation goals

Summary

The development of safe and effective rehabilitation programmes requires extensive thought and planning, consideration of individual patient needs, and monitoring of tissue healing and functional capabilities. Rehabilitation programmes should be based on the need to address pain, proprioception, flexibility, strength, endurance and functional demands. The phases of tissue healing are important drivers for both the creation and implementation of treatment plans. Finally, objective outcome parameters and specific treatment goals are needed to ensure that horses are progressing appropriately through their individual programmes and able to return to prior levels of activity or competition with minimal risk for reinjury.

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Review Article

Weight reduction and possible implications for the rehabilitation of horses with ambulatory difficulties

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Summary

Equine musculoskeletal injuries, or other causes of reduced movement, can have a poor prognosis partially due to the secondary complications that may develop during recovery or rehabilitation. These can include supporting limb laminitis due to excessive weightbearing on healthy limbs and also problems associated with ventilation or perfusion due to prolonged recumbency. The risk of these complications is reported to increase with increasing body weight. While many methods have been attempted to reduce load and prevent complications, there is no current standard practice when managing horses with ambulatory difficulties. One critical consideration with load reduction devices is maintaining sufficient mobility to allow for blood flow and the prevention of muscle wasting. One of the most challenging obstacles with any weight reduction method or device is preventing pressure sores/ulcers or other tissue trauma because load is redistributed away from the limbs and onto regions of the body unaccustomed to weightbearing. Reported methods to aid in recovery and rehabilitation include rescue slings, forced recumbency, flotation tanks, water treadmills and aquatic therapy. While these methods have been successful in some horses, significant complications have also been reported. If too much weight is removed, muscle wasting or osteopenia occurs; conversely, if insufficient weight is lifted blood flow is hindered. The optimal load reduction is not known because each individual horse will have different requirements depending on the severity of the injury. The goal would be to restore normal weight distribution on the noninjured limbs, while supporting the weight that would normally be placed on the injured limb.

Introduction

Common musculoskeletal conditions in horses include fractures, septic joints, tendon and ligament lesions and laminitis (Singer *et al.* 2008; Gaschen and Burba 2012; Hill *et al.* 2015). These problems affecting ambulation can have a poor prognosis, partly due to secondary complications that arise during treatment of the initial injury or disease (Hutchins *et al.* 1987; Baxter and Morrison 2009). Secondary complications, such as supporting limb laminitis (SLL) (associated with decreased mobility and increased load) (Orsini 2012), can lead to euthanasia and, therefore, are a significant welfare concern for the equine industry (Baxter and Morrison 2009; van Eps *et al.* 2010; Gardner *et al.* 2017). Horses cannot lie down for prolonged periods to prevent these secondary complications because remaining in lateral recumbency for an extended period risks the development of complications including ventilatory compromise, perfusion problems, nerve damage, or – after hypoxic episodes – paralysis or brain damage (Schatzmann 1998). Furthermore, horses are flight animals and may avoid lying down for behavioural reasons, if they are stressed or unsure that they can stand back up (Morresey 2006). For these reasons, horses must remain upright and, therefore, need a support device to reduce load and prevent complications (Smith 1981). Establishing and maintaining weight reduction or redistribution of load when treating musculoskeletal conditions continues to be a significant challenge in equine rehabilitation. Reported methods used for weight reduction include rescue slings, forced recumbency, flotation tanks, water treadmills and aquatic therapy (e.g. Smith 1981; Hutchins *et al.* 1987; McClintock *et al.* 1987; Wattle *et al.* 1995; King *et al.* 2013). While many of these methods have been successful in individual studies for treating the initial injury and preventing SLL, significant complications were observed in most cases. At present, there is no standard method of establishing weight reduction that consistently produces successful outcomes with no or minimal complications. One significant consideration while reducing load is to maintain mobility to allow for sufficient blood flow and prevent muscle wasting or osteopenia (Hutchins *et al.* 1987). If too much weight is removed, these complications can occur, but if not enough weight is lifted, blood flow may be hindered (McClintock *et al.* 1987; van Eps *et al.* 2010). A major challenge with any weight reduction method is preventing tissue trauma when redistributing load away from the limbs and onto regions of the body not typically associated with weightbearing, such as the thorax and abdomen (Ishihara *et al.* 2006a). When significant weight is immediately applied to an injured leg after repair, reinjury can occur resulting in a failed repair along with the development of other complications unrelated to the initial injury (Smith 1981; Bowman 1995; Baxter and Morrison 2009; Clark-Price 2013). The complications associated with increased weightbearing indicate that reducing the load supported by the limbs may result in greater successful outcomes when treating musculoskeletal injuries.

Several studies have tested methods to reduce body weight in horses to aid in rehabilitation from fractures, laminitis, injured tendons or other lesions of the soft tissue (Smith 1981; Hutchins *et al.* 1987; McClintock *et al.* 1987). As stated by van Eps (2012), 'The development of strategies aimed at redistributing or relieving body weight during laminitis development may be an overlooked but realistic therapeutic goal: novel sling technology or further development of previously described forced recumbency techniques are potential solutions that are worthy of further investigation'.

Therefore, a standardised procedure could be beneficial in veterinary practice and equine rehabilitation. This review will discuss the indications for load reduction in the rehabilitation of injuries requiring ambulatory support and possible methods that can be used to reduce the load supported by the limbs. The presence of complications when treating horses with musculoskeletal conditions provides evidence that a device to reduce load is needed. Such a device could prevent the unnecessary euthanasia of horses with a compromised musculoskeletal system.

Indications for controlled weight reduction: musculoskeletal conditions and consequences of weight re-distribution

When a horse has a compromised musculoskeletal system, it can lead to a poor prognosis as recovery from these injuries can result in complications associated with their large size (Smith 1981). Laminitis is an example of a condition where ambulation can be severely compromised making euthanasia necessary for the welfare of the animal (Morgan *et al.* 2016). Severe laminitis results in a loss of mechanical support within the hoof causing laminar detachment from overloading of tissues, vascular ischaemia, loss of structural integrity and separation of the coffin bone, which is further exacerbated by the biomechanical load of the horse's weight (Hunt 2008; Morgan *et al.* 2016). Endocrinopathic laminitis is the most prevalent form of laminitis accounting for up to 90% of laminitis cases (Morgan *et al.* 2016; Patterson-Kane *et al.* 2018). The causal mechanisms of endocrine disturbances resulting in laminitis are still unknown, but dysregulation of blood flow is believed to be a possible link (Morgan *et al.* 2016). SLL is also believed to result from blood flow dysregulation, specifically decreased blood flow secondary to reduced foot movement, resulting in constant load support by the affected limbs (load-induced ischaemia) (Orsini 2012; van Eps 2012; Belknap and Durham 2017; Gardner *et al.* 2017). There have been many recent studies performed attempting to bring a greater understanding to the mechanisms involved in laminitis, but laminitis pathophysiology is still not fully understood.

The horse's natural compensatory response to painful limbs is to redistribute the weight away from the injured limb(s), thereby overloading other limbs. The amount of weight redistributed can increase with time and has been shown in one study by Gardner *et al.* (2017) to result in approximately 33% more weight on the opposing limb in a preferential weightbearing model. This is a well-known problem that can lead to the development of complications during treatment of musculoskeletal injuries (Hood *et al.* 2001; Maliye *et al.* 2015). This abnormal weightbearing can cause changes in musculature and muscle wasting (Hood *et al.* 2001). In an attempt to transfer weight away from the injured limb, the frequency of cyclic weight distribution between limbs is also reduced (Hood *et al.* 2001). A tool to support this redistributed weight is much needed to prevent complications such as SLL and muscle wasting. SLL may be more painful than the initial injury (van Eps *et al.* 2010; Virgin *et al.* 2011), causing the horse to transfer weight back to the injured limb; due to a poor prognosis after the development of SLL, euthanasia may become necessary (Redden 2004; van Eps *et al.* 2010). The mortality rate following the onset of SLL is reported to be between 50% and 75% (Gardner *et al.* 2017). The incidence of SLL increases with increasing weight of the horse and length of recovery (Smith 1981; Ishihara *et al.* 2006a; Baxter 2017). With each additional week spent in recovery, there is a 20% increase in the risk of SLL (Virgin *et al.* 2011).

Current SLL preventative techniques are focused on increasing blood flow, encouraging movement and the periodic cyclic loading and unloading of the supporting limbs (Belknap and Durham 2017). Redden (2004) suggested that even slight weightbearing and movement around the stall may significantly reduce the development of SLL. Similarly, shifting of weight may be sufficient to reduce the risk of SLL; healthy horses have been shown to shift weight between the forelegs one to five times per minute, aiding in blood flow to the foot (Baxter and Morrison 2009; van Eps *et al.* 2010). Therefore, decreasing the weight supported by the limbs is an essential consideration in the prevention of SLL and in rehabilitation from laminitis or painful musculoskeletal injuries (Taylor *et al.* 2013).

Current methods of weight reduction in horses

The ability to reduce weight to treat musculoskeletal conditions in horses is not a new concept. Many methods have been developed, but there is still no standard protocol for weight reduction. The methods are reviewed below.

Rescue slings

The use of slings to remove the load from the horse's legs dates back to 300–360 Common Era (Schatzmann 1998), but none have been developed for long-term use. The currently available slings are intended for short-term use in rescue situations or to lift recumbent horses (Ishihara *et al.* 2006a). Most slings are static, without the ability to alter the amount of load reduction, and place significant weight on the abdomen (Gimenez *et al.* 2008; François *et al.* 2014). Conventional slings have one pick-up point attaching it to a mechanical hoist to suspend the animal with two options, complete load reduction of all limbs or no load reduction (Hutchins *et al.* 1987). The PM Horse Swinglifter has been developed to allow for a partial mechanical load reduction, but only has one pick-up point (Puhl n.d.). Partial weight reduction is desirable because removing too much weight can lead to muscle wasting and decreases in bone density (McClintock *et al.* 1987; van Eps *et al.* 2010). Control of the amount of weight reduction allows for a gradual increase in weight supported by the horse's limbs throughout the recovery period. The currently available slings also do not allow individual control over the forelimbs and hindlimbs, which normally support different amounts of weight (60% and 40%, respectively) (Clayton 2016). Such individual control would enable tailoring the support to the injury, for example allowing the hindlimbs to continue to support full weight, while removing weight from an injured forelimb. Additionally, rescue slings require constant supervision to avoid walking out of, sliding or twisting in the sling (Hutchins *et al.* 1987); this is a significant problem highly limiting the use of many weight reduction methods. Rescue slings can be used to reduce load, but their application is often

difficult and requires a tolerant horse. Despite these limitations, slings are still used in veterinary practice and rehabilitation, despite the recognised risks, not only to reduce weightbearing but also to facilitate bandage changes, trimming and shoeing, and for equine rescue (Hunt 2008), proving their versatility and importance.

Slings can be valuable tools in treating challenging neurological or musculoskeletal disorders (Ishihara *et al.* 2006b). They have been successfully used in many situations including in small horses, such as ponies and foals, to improve muscle atrophy and severe limb deformities, and in larger horses to improve tendon contractions during exercise, avoiding further injury or fatigue, and to immobilise horses after fracture repair or other musculoskeletal injuries. They have also been used to restrain horses and maintain a natural standing position with regular head carriage, which are limitations in flotation tanks (reviewed below). Horses can learn to tolerate the sling and maximise its use, eventually resting and sleeping in the sling to relieve pressure on their limbs (Ishihara *et al.* 2006a). In one study, 95% of horses were successfully recovered from general anaesthesia using a full-harness and sling system (Ishihara *et al.* 2006a). Lift support systems have been used in recovery from anaesthesia when there is increased risk for further injury (Taylor *et al.* 2005) and also to speed up recovery time, allowing the horse to stand sooner with support from the sling (Clark-Price 2013). When horses attempt to stand after lateral recumbency following anaesthesia, they are often unsuccessful and uncoordinated, causing stress to the axial skeleton resulting in possible recovery-related fractures or other injuries (Taylor *et al.* 2005). The use of the Anderson Sling during recovery of 24 horses proved to be successful in 23 of the horses in one study (Taylor *et al.* 2005). This study stated that 0.9% of recoveries from anaesthesia resulted in fatalities; 24% of those fatalities were due to recovery-related fractures, while 9% were from post-operative myopathies (Taylor *et al.* 2005). Another study also found 0.9% fatality after surgery, with 23.3% of the fatalities resulting from fractures and 7.1% from myopathies (Bettschart and Johnston 2012). These studies, however, only focused on short-term recovery assistance.

Disadvantages of slings include the requirement for intensive care and the possibility of causing stress for the horse during long-term use, such as management of fractures (Ishihara *et al.* 2006a). Other disadvantages involve intolerance, expensive equipment, equipment failure, injury to the surgical site and an increased need for trained personnel (Clark-Price 2013). However, some studies disagree over the above complications seen with rescue slings (François *et al.* 2014). A common belief is that these devices place weight on the abdomen resulting in compromised respiration and placing significant pressure on abdominal organs, which is thought to affect heart and lung function (Gimenez *et al.* 2008; François *et al.* 2014). There is also a concern of decreased venous return from the head, neck and legs if the webbing or ropes are too tight or misused, thereby making personnel training on the application of the sling essential (Gimenez *et al.* 2008). While studies demonstrated the complications of sling use, they did not look for a possible solution to these problems. Some authors claimed that horses generally do not tolerate slings well and they cannot be used long term (Smith 1981; Belknap and Durham 2017), while others found horses tolerate slings well (Ishihara *et al.* 2006a; Fürst *et al.* 2008). These differences may in part be a result of the different indications in which slings have been used and different temperaments of the animals. Although there are both advantages and disadvantages to the use of slings, they are still used due to the need for a system to aid in ambulatory support of horses in equine rehabilitation, as discussed.

The U.C. Davis-Anderson Sling has increased versatility, in comparison to other equine rescue slings. The rectangular support frame overhead allows for levelling adjustments; leg supports help to minimise pressure placed on the abdomen; the head restraint aids in the safety of individuals working with the horse, and the horse itself, by controlling the head and neck movements (Ishihara *et al.* 2006b). The Anderson Sling aims to distribute weight evenly by targeting the skeletal system and can lift either the front, hind or individual legs, through adjustment of the frame using hydraulics or manual adjustment of the straps of the sling (Rush *et al.* 2004). While the Anderson Sling is very valuable for supporting horses, it is relatively complex and poses a significant challenge in the placement of the sling without heavy sedation and experienced personnel to ensure proper application (Rush *et al.* 2004). The sling supports the skeleton through mesh panels and cross-straps intended to prevent respiratory compromise, pressure points or excessive abdominal pressure. Suspension in the Anderson Sling after recumbency showed increases in cardiopulmonary function and recovery quality (François *et al.* 2014) when compared to lateral recumbency. When in recumbency for long periods, possible risks include the development of respiratory, muscular, neurological or gastrointestinal compromise, as well as skin and other soft tissue injuries (Gimenez *et al.* 2008). The Anderson Sling is considered the safest for long- or short-term vertical lifts (Gimenez *et al.* 2008), but when increased time is spent in the Anderson Sling, decreased venous return from the head, neck and legs could occur, especially if applied inappropriately (Taylor *et al.* 2005). Therefore, close monitoring during the use of the Anderson Sling is essential.

The Liftex Sling is used in veterinary practice to assist with the short-term management of recumbent horses due to its straightforward application to the horse (Rush *et al.* 2004). The Liftex large animal sling is simple, can be quickly and safely applied to the animal, is lightweight, adjustable and made with soft materials to reduce skin abrasions. The chest and tail straps aid in the positioning of the horse and reduction of pressure sores through greater pressure distribution (Ishihara *et al.* 2006b). The Liftex Sling has also been used in both induction and recovery of anaesthesia and surgery, as well as rescue and emergencies, proving the variety of uses in large animal practice. However, the Liftex Sling, similar to the Anderson Sling, can be challenging to place in difficult situations and applies pressure to the abdomen (Gimenez *et al.* 2008) making longer-term use during rehabilitation prohibitive.

The UC-Davis Large Animal Lift is a modification of the simple figure-eight sling system used in emergency response, clinical and rescue situations. It is easy to place on a recumbent horse, supporting its body using only a few straps around the legs and abdomen. It is meant to be used only for short-term rescue scenarios because it causes interference with respiration (Gimenez *et al.* 2008).

The Becker Sling is made of heavy-duty materials, tested for shear and tensile strength. It has a variety of uses in various situations from emergency to daily veterinary

practices. It has quick-release snaps for rapid release of the animal once the lift is complete, but the Becker Sling cannot be used long term, due to significant pressure on the abdomen (Gimenez *et al.* 2008).

The Sling–Shell System was developed for recovery from anaesthesia. It is made of two customised glass-fibre-enhanced shells for adult horses, which are connected by a short girth. One piece contours to the animal's chest, while the other piece fits around the ventral thorax behind the elbows. This system is not known to cause damage from pressure on soft tissue or interfere with the expansion of the rib cage during respiration. Girths extending in front of and behind the hind legs aid in support of the hindquarters. The rigid shell imposes a limitation reducing the versatility of the sling, due to the need for customisation to accommodate size and body shape (Gimenez *et al.* 2008).

In conclusion, while there are many problems with slinging horses, the basic principles and potential benefits have been known and used for centuries, illustrated by the many versions of rescue slings to assist horses effectively. While materials changed over the years, the basic principles have stayed the same. Slings have been used in many situations to keep horses standing upright or immobile after treatment. Furthermore, complications during anaesthesia in lateral recumbency, such as ventilatory or perfusion disturbances in the lungs, muscles and nerves along with myositis, paralysis of nerves and brain damage from hypoxic episodes, can potentially be avoided with the use of a sling. Essential advantages to a good sling are proper immobilisation of the horse, weight distribution over a large surface and control over positioning. With proper tools and resources, slings can be life-saving (Schatzmann 1998). It is important to remember that while slings have great potential to assist many horses, not all horses will tolerate every method and customisation to each case may be needed for best results (Schatzmann 1998; Nankervis *et al.* 2017).

Forced recumbency

Prolonged recumbency can occur as a result of a disease or injury, but one research group studied forced recumbency for recovery from musculoskeletal problems, such as laminitis (Wattle *et al.* 1995). Wattle *et al.* (1995) believed that if the displacement of the distal phalanx was due to weightbearing in laminitis, then the displacement could be counteracted by eliminating the effects of body weight through forced recumbency.

Wattle *et al.* (1995) created a unique situation where ponies were forced to remain in recumbency, with the ability to alternate between lateral and sternal recumbency, for 48 h by creating a lower ceiling making it impossible for the horse to stand up. Complications in cardiopulmonary function have been of concern in many studies of recumbent horses during general anaesthesia, but this study reported no complications. These results cannot be directly applied to recumbent horses, as the ponies in forced recumbency were able to change positions, which may not be possible in recumbent horses. The researchers indicated this method could be useful in the case of an acute attack of laminitis due to no sign of complications at 48 h. A limitation of this method was the specialised set-up (i.e. the ability to lower the ceiling), with a high risk of injury to both horse and handler in the event of an emergency. This study was only short term. Since long-term recumbency tends to be associated with significant complications, long-term studies are needed to evaluate the treatment of laminitis.

One of the primary challenges with managing recumbent horses is the development of pressure ulcers and other tissue trauma, such as neuropathies and myopathies; tissue necrosis tends to develop over bony prominences with constant pressure. Necrosis can also occur at a deeper level during extended periods of recumbency, due to compartmental syndrome, which may develop as soon as 2 h into recumbency due to the weight of the animal (Rush *et al.* 2004; Ishihara *et al.* 2006a). Rush *et al.* (2004) indicated that gastrointestinal complications are another concern, and reduced motility can occur within 24 h due to the inability to exert enough abdominal pressure and defaecate regularly. Horses should be lifted every 6–8 h (to avoid compartment syndrome and myonecrosis) and maintained there if possible, to promote perfusion. Horses should also be rotated from left to right lateral recumbency and sternal recumbency. Recumbent horses are challenging to treat; common complications include damage to musculoskeletal, pulmonary, urinary and gastrointestinal systems. Many of these conditions may be minimised through the use of a support sling to maintain the horse upright or frequently lifting the horse several times a day (Rush *et al.* 2004).

Flotation tanks

Flotation tanks have been used to aid in the recovery of horses from injuries through load reduction (**Fig 1**) with the buoyancy of the water supporting the weight of the horse. The buoyancy of water can reduce the weight of a 450 kg horse to 100 kg minimising load-associated complications. Based on this information, a flotation tank was developed to test the theory that weight reduction through buoyancy could result in an improved chance of successful recovery of limb injuries (Smith 1981). The system reduced the need of the horse to lie down, which prevented pressure ulcers. However, other complications, such as hair loss on submerged areas, heavy faecal and urine contamination, muscular atrophy and stiffening of the ligamentum nuchae, occurred (Smith

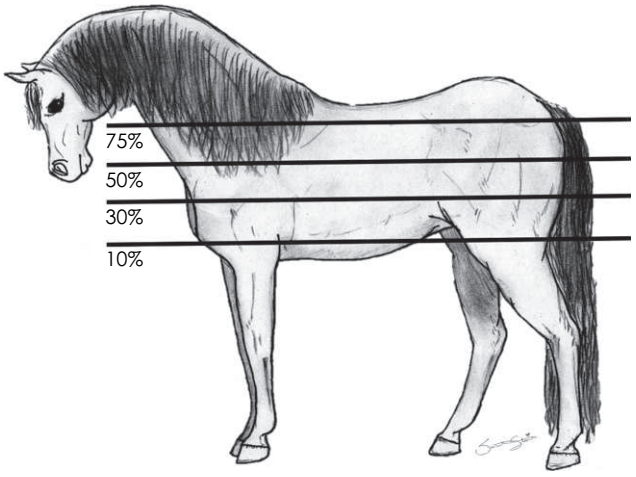

Fig 1: Approximate percentage body weight reduction reference points (10% at the elbow and/or stifle, 30% at the scapulohumeral joint, 75% at the tubera coxae (Nankervis et al., 2017)) when estimating weight reduction through buoyancy. Adapted from McClintock et al. 1987 and Nankervis et al. 2017.

1981). Smith (1981) successfully recovered over 40 horses in 2- to 8-week time periods through water flotation.

Hutchins *et al.* (1987) also placed horses in a flotation tank, but for 10–13 weeks assisting in the recovery and management of fractures. Through effective weight reduction, complications in the opposing limb were not observed (Hutchins *et al.* 1987). The most significant complications with flotation were associated with the respiratory tract and the inability of the horses to lower their heads to clear pulmonary secretions due to water level and design of the flotation tank. This led to mucous accumulation and regional obstructive pulmonary collapse (Hutchins *et al.* 1987; Ishihara *et al.* 2006a). After leaving the tank, horses had to re-acclimate, had rapid respiratory and heart rates for 2–3 days, had high temperatures (40°C) and were unable to sweat, which seemed to be linked to the temperature of the water in the tank (Hutchins *et al.* 1987). Muscle weakness was another significant concern when 75% weight reduction (**Fig 1**) was used in the flotation tank (Hutchins *et al.* 1987). McClintock *et al.* (1987) found that a 75% weight reduction may be unnecessary, likely because a sufficient weight reduction would be maintaining the load that had been supported before the injury occurred; for example, for one forelimb in a 500-kg horse, this would be 150 kg (60% of 500 kg = 300 kg; 300/2 = 150 kg). Therefore, the load on the opposing forelimb should not exceed 150 kg.

In the study by Hutchins *et al.* (1987), four out of seven cases had successful outcomes. Complications observed included respiratory distress; pulmonary oedema; euthanasia due to a fall when leaving the flotation tank, sustaining another fracture; economic problems; jumping out of the tank; and development of traumatic laminitis after removal from the tank, resulting in contralateral limb collapse or reinjury leading to euthanasia. Only three horses remained in the tank for 10–13 weeks (Hutchins *et al.* 1987). The complications present in the studies by Hutchins *et al.* (1987) and McClintock *et al.* (1987) demonstrated similar results to Smith's (1981) study.

There will likely be minor complications with any method used for load reduction, but the severity, ability to modify them, the prevalence in comparison with other methods and cost should all be taken into careful consideration. Flotation may provide another means of weight reduction, but more horses need to be treated before the technique can be standardised (Hutchins *et al.* 1987). Disadvantages to water recovery include cost, number of experienced personnel required, skin abrasions, incisional infections and pulmonary oedema along with the risk of alopecia (hair loss), osteopenia (low bone mineral density) and respiratory disorders (Ishihara *et al.* 2006a). The use of flotation tanks would also require specialised facilities. The above studies demonstrated that transporting the horses to and from the tank without sustaining further injuries was challenging. These studies were performed in the 1980s, and flotation tanks are not currently standard practice for rehabilitation, only being used minimally in recovery from anaesthesia. The lack of use could indicate that they are not easily applied in veterinary practice and complications could be too great to use for standard practices.

Water treadmills and water therapy

According to Nankervis *et al.* (2017), treadmills are increasing in popularity, but little evidence supports their use during rehabilitation of injuries. Water treadmills act through buoyancy, much like flotation tanks, to reduce weight distribution on the limbs. Water level changes the amount of weight reduction through buoyancy (**Fig 1**) with the body weight of the horse reduced by 30% at the scapulohumeral joint and 75% at the tubera coxae. Increasing water height decreases vertical ground reaction forces (vGRFs), which can load and unload limbs during rehabilitation. Water levels too high can increase risk of injury, causing the horse to lose stability and 'roll' (i.e. loss of stability shifting weight to thoracic limb and increasing the risk of the horse rolling over in the high water). Water exercise also widens the horse's abdomen caudally moving the centre of buoyancy behind the centre of mass further shifting weight towards the thoracic limbs (Nankervis *et al.* 2017).

Water has a greater drag force than air due to its higher viscosity, which creates resistance or drag opposing the motion, applying greater stress to structures supporting locomotion. The force increases with increasing speed of movement, which could increase risk of injury to such structures (muscles, tendons, ligaments) (King *et al.* 2013; Nankervis *et al.* 2017). Furthermore, any orthotic devices, shoes or boots may be problematic during treadmill exercise, especially in water (Nankervis *et al.* 2017).

One limitation of water treadmills is the inability to control weight reduction of forelimbs and hindlimbs separately. The only way to apply different weight compensations to the fore and hindlimbs is to incline or decline the treadmill, which is very limited in land treadmills and often not possible with water treadmills (Nankervis *et al.* 2017). The complications observed are similar to water flotation.

Other factors in water can be altered for an added benefit during rehabilitation, including temperature, osmolality and hydrostatic pressure. Changes in water temperature can result in vasodilation or vasoconstriction, increasing circulation or restricting blood flow and inflammatory mediators; immersion in water applied a circumferential compression promoting venous return and lymphatic drainage reducing oedema and soft tissue swelling, increasing joint range of motion and decreasing pain; exercising in high solute concentrations appears to have anti-inflammatory, osmotic and analgesic effects reducing tissue inflammation and swelling. Buoyancy, hydrostatic pressure and viscosity can provide resistance to movement increasing joint stability and reducing weightbearing on muscles and joints preventing overloading of injured tissues (King *et al.* 2013). More studies in aquatic therapy are needed in horses to assess treatment plans (water level, duration and speed) and assess potential benefits (King *et al.* 2013). With limited evidence of aquatic therapy benefits in horses, King *et al.* (2013) discussed human studies, implying that more studies need to be completed in horses in the future to examine possible benefits of water therapy and its applications.

Discussion

In order to overcome the limitations of current weight reduction techniques, new devices are needed. Currently, the most versatile commercially available option for weight reduction is a rescue sling; however, many of the available slings apply pressure to the abdomen, which is not designed to support weight (Gimenez *et al.* 2008; François *et al.* 2014; Montgomery *et al.* 2018, 2019); a harness avoiding pressure on the abdomen would be beneficial.

Our research group has completed the initial short-term testing of a new rehabilitation harness (**Fig 2**) allowing 46% of the weight to be removed from the forelimbs and 40% from the hindlimbs (Steinke *et al.* 2018, 2019). The harness has been designed as one piece for easy application or removal with only two pick-up points to attach to the lift for quick release in an emergency. This greatly reduces the time that is needed to apply the harness in comparison with rescue slings, which have numerous straps and separate pieces. It also reduces the need for supervision through close fit and lightweight material, decreasing the risk of the horse being tangled or caught-up in straps. Both slings and water devices require constant supervision and multiple personnel not only to apply the device, but also throughout the entire rehabilitation process to ensure safety of the animal due to the inability to move in static devices or the need for constant movement on treadmills. This need for constant supervision and multiple personnel is a critical issue in weight reduction devices in veterinary practice. Additional design features are under development to periodically alter pressure applied to the skin in an attempt to increase comfort and reduce the risk of tissue trauma during long-term use (Steinke *et al.* 2018, 2019). The harness is used in combination with a computer-integrated dynamic weight compensation system previously tested by our research group (Montgomery *et al.* 2018, 2019). This system has been designed for individual control over the forelimbs and hindlimbs, allowing for different, incremental weight compensations to be applied to the forelimbs or hindlimbs separately. Welfare concerns (pain; intolerance; stress; risk of further injury; compromised respiration and pressure on abdominal organs; skin and soft tissue injuries; increased risk of infection; muscle atrophy; and neck stiffness (Smith 1981; Ishihara *et al.* 2006a; Gimenez *et al.* 2008; Clark-Price 2013; François *et al.* 2014; Nankervis *et al.* 2017)) and time commitment of personnel with past devices were considered in design of the harness and development of the weight reduction device. Currently, the system can be manually operated to move the horse around the stall with plans to have the system automatically move with the horse. This reduces the need for constant supervision, allowing normal movement around the stall with a percentage of weight supported by the beams of the lift, while avoiding painful complications such as SLL through mobility. The individual control over forelimbs and hindlimbs attempts to avoid muscle wasting and bone density loss through application of the normal amount of weight supported by the limbs, while still removing weight from the injured limb.

Fig 2: Equine rehabilitation lift and model horse used for initial testing to ensure material strength and safety. The computer-controlled lift, designed and built by RMD Engineering, Inc., and installed at the Western College of Veterinary Medicine (WCVM), allows for separate front- and hindlimb support (labelled as "Front" and "Rear"). A rehabilitation harness for use with the lift is under development, with one prototype shown here. Photo: Christina Weese (Foxtailstudio.net) for WCVM.

Conclusion

When treating horses with ambulatory difficulties, many factors need to be considered such as the nature of the injury, possible recovery-associated complications and quality of life after recovery. These factors highly depend on the resources available to the owner, support staff and veterinarian expertise. With currently available technology, it is difficult to prevent recovery-associated complications, which may ultimately lead to euthanasia. Many weight reduction devices require constant supervision and multiple personnel throughout the rehabilitation process to ensure safety, which can make it challenging to implement in a veterinary practice where multiple animals are treated by one or two personnel. Even though there have been many attempts to find a solution, there is still currently no standard solution to the challenge of supporting the weight of horses and the problem of excessive weightbearing on healthy limbs, leading to SLL. Reducing and re-distributing load supported by the limbs during recovery from musculoskeletal injuries can minimise complications, such as failure of a fracture repair or development of SLL. The continued use of rescue slings and water buoyancy for support indicates that there is a need for tools that aid in load reduction during the management of horses with ambulatory difficulties. While many methods have been used in the past, the best method depends on the factors associated with each individual case and available resources at time of treatment. Ongoing research is attempting to address shortcomings of currently available devices aiming for a solution to the challenge of treating horses with problems affecting ambulation while allowing individual customisation of weight reduction and mobility.

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No conflicts of interest have been declared.

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Authorship

S. Steinke is a graduate student in biomedical engineering supervised by J. Montgomery. The field of research is equine rehabilitation. J. Carmalt is a member of S. Steinke's graduate committee. The idea was conceived by all authors based on the finding that such a comprehensive review of different

weight reduction strategies does currently not exist in the literature. The initial draft was written by S. Steinke and edited by both J. Carmalt and J. Montgomery. The final version of the manuscript has been approved by all authors.

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Review Article

Local anaesthetics for regional and intra-articular analgesia in the horse

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Keywords: Horse; lidocaine; mepivacaine; bupivacaine; ropivacaine

Summary

During the course of a lameness examination, intra-articular or perineural administration of a local anaesthetic is often necessary to isolate the source of pain causing lameness. Local anaesthetics are useful for intraoperative and post-operative pain relief and may allow for elimination of, or a decrease in, general anaesthesia. Within recent years, new information has become available concerning the use of local anaesthetics for localisation of pain and for palliation of pain. New information indicates that

- **Lidocaine is less efficacious than mepivacaine or ropivacaine in ameliorating lameness caused by pain.**
- **After administering a nerve block, loss of skin sensation may not correlate with loss of pain causing lameness.**
- **Local anaesthetic solution must be deposited within the sheath of the neurovascular bundle to be effective.**
- **The dose of a local anaesthetic, which is a factor of volume and concentration, affects potency and duration of a nerve block.**
- **Local anaesthetics are toxic to chondrocytes and synoviocytes. Lidocaine and bupivacaine appear to be more toxic than mepivacaine or ropivacaine. The clinical significance of the toxic effect of a single intra-articular injection of local anaesthetic is yet to be determined.**
- **Sodium bicarbonate can be added to a local anaesthetic solution to increase its potency and speed of onset.**
- **Epinephrine added to local anaesthetic solution prolongs and intensifies its analgesic effect.**
- **Mixing quick-acting, short-duration and slow-acting, long-duration local anaesthetics will not result in a quick-acting, long-duration drug combination.**

Introduction

Localisation of pain during the course of a lameness examination can often be accomplished only by administering a local anaesthetic perineurally or intra-articularly to identify the site of pain. Local anaesthetics are useful for intraoperative and post-operative relief of pain and may allow for elimination of, or a decrease in, general anaesthesia. Within recent years, new information has become available concerning the use of local anaesthetics for localisation of pain and for palliating pain. Equine clinicians should be familiar with the positive and negative features of different local anaesthetics, methods of enhancing their action and their potential toxicity.

A brief history of local anaesthetic drugs

Local anaesthesia was the 'holy grail' of surgeons for many years before it became a practical method of ameliorating pain. Early attempts at producing local anaesthesia included the application of numbing cold in the form of ice, ice water or ether spray, and nerve compression (Wildsmith 2013). An early attempt at drug injection near a nerve was made by Alexander Wood, who in 1853 designed a hypodermic needle and syringe to inject morphine near a nerve. Although the morphine injections were erroneously thought to be efficacious (the effect of morphine was likely central rather than peripheral), this experiment leads to the concept of drug injection near a nerve to cause desensitisation of a region. A Spanish Jesuit priest in 1653 wrote of the numbing effects of the coca plant that he chewed to relieve a toothache. In 1860, a German scientist produced, from the plant, pure white crystals, which he named cocaine. The first use of cocaine as a local anaesthetic was for surgery of the eye, and after a report of this use by Carl Koller in 1884, the value of cocaine for peripheral nerve blocks was quickly realised. Within several months of Koller's report, William Halstead, considered by many to be the 'Father of Modern Surgery', had demonstrated the effectiveness of cocaine for most regional nerve blocks. In 1885, cocaine was used by a Pennsylvania veterinarian to desensitise the limbs of a horse (Steffey and Booth 1995).

Cocaine, because of its addictive properties and short duration of action, was obviously an unsatisfactory local anaesthetic (Halsted suffered from a lifelong addiction to cocaine because of self-experimentation with the drug.) Procaine, which was developed in 1904 as a substitute for cocaine, is relatively safe and stable with no addictive properties, but because procaine has a short duration of action and can induce an allergic reaction, the search for improvements in local anaesthetics continued. Löfgren, a Swedish chemist, synthesised lidocaine in 1943. Lidocaine was approved for use in Sweden and the United States in 1948 and marketed under the name Xylocaine (Gordh *et al.* 2010). Since the advent of lidocaine, which is still commonly used today, over 50 local anaesthetics have been developed, each having different positive and negative qualities (Boothe 1982).

Types of local anaesthetics

A local anaesthetic is composed of hydrophilic and hydrophobic (lipophilic) portions separated by an intermediate ester or amide linkage (Tucker and Mather 1988). The first local anaesthetics, including cocaine, were esters; of these, procaine, tetracaine and chloroprocaine are

still in use in people, but because of the common occurrence of allergic reactions to para-aminobenzoic acid, the metabolite of ester-type local anaesthetics, their use is not common (Covino 1988; Berde and Strichartz 2010). Esters have largely been replaced by the amide-type local anaesthetics such as lidocaine, mepivacaine, prilocaine, bupivacaine, levobupivacaine and ropivacaine.

Mechanism of action

Local anaesthetics temporarily block sodium channels in the nerve membrane, thus preventing propagation of the nerve action potential along the axon (Berde and Strichartz 2010). Sodium channels exposed to a local anaesthetic become less likely to open in response to a depolarising stimulus. In neuronal conduction, depolarising current moves along nodes of Ranvier which are gaps in the myelin sheath that are exposed to the extracellular space for exchange of ions involved in generation of the action potential (Berde and Strichartz 2010). Two to three of these nodes must be successively blocked to prevent conduction (Catterall and Mackie 2006; Franco 2009). When the nerve is large, the nodes of Ranvier are widely spaced. Thus, to stop conduction of impulses when the nerve is large, the length of nerve that must be exposed to a local anaesthetic is longer and more slowly covered by the local anaesthetic solution (Catterall and Mackie 2006).

Nerve fibres have been categorised into three major classes, A, B and C fibres (Strichartz 1988; Colvin 2013). The A fibres are further divided by size into four additional categories: alpha, beta, gamma and delta (**Fig 1**). Some fibres transmit sensations of touch, pressure and temperature; others are involved with motor function and proprioception. The majority of neurons involved in the transmission of pain are the C fibres and A delta fibres (Colvin 2013). Fibres in each class and subclass have different sensitivity to local anaesthetics (Colvin 2013). After administration of a local anaesthetic, pain is usually the first sensation to disappear, followed in order by the loss of sensations of cold, warmth, touch, deep pressure and, finally, loss of motor function (Gadsden 2011). During recovery from local anaesthesia, return of sensations occurs in reverse order (i.e. motor function returns first and sensation of pain returns last).

Choice of local anaesthetic

The local anaesthetic agents used most commonly for diagnostic and surgical analgesia in horses in Europe and the United States are 2% lidocaine and 2% mepivacaine. In other parts of the world, mepivacaine is less readily available, and local anaesthetic agents such as 2% lidocaine, 0.5% or 0.75% ropivacaine and 0.5% bupivacaine, are used for diagnostic anaesthesia of horses (Silva *et al.* 2015). In people, ropivacaine appears to be clinically equivalent to bupivacaine in onset and duration of action and potency (Salinas *et al.* 2008). Besides commercial availability, the choice of local anaesthetic agent for use in the horse may depend upon the agent's onset and duration of action, potency, tendency to cause local tissue reaction and chondrotoxicity.

Intrinsic potency

Potency correlates with lipophilicity; the more lipid soluble the local anaesthetic, the more potent it is (Berde and Strichartz 2010; Aguirre *et al.* 2012; Becker and Reed 2006). Lipophilicity

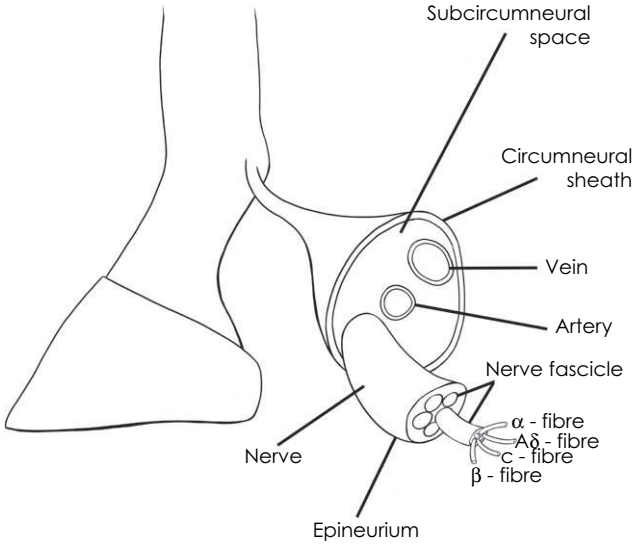

Fig 1: Nerve fibres have been categorised into three major classes: A, B and C fibres. The A fibres are further divided by size into four additional categories: alpha, beta, gamma and delta. Some fibres transmit sensations of touch, pressure and temperature; others are involved with motor function and proprioception. The majority of neurons involved in the transmission of pain are the C fibres and A delta fibres. For nerves invested with a circumneural sheath, local anaesthetic solution must be deposited within the sheath (i.e. the subcircumneural space) to be effective.

facilitates penetration through the lipidic neuronal cell membrane. The more potent local anaesthetics, ropivacaine and bupivacaine, are more lipophilic than the local anaesthetics of intermediate potency, mepivacaine, lidocaine and chloroprocaine (Berde and Strichartz 2010). Few studies have considered the intrinsic potency of local anaesthetic solutions administered for nerve blocks in horses. When administered as a palmar digital nerve block, bupivacaine and ropivacaine showed greater analgesic efficacy than did lidocaine, in ameliorating experimentally induced foot pain in horses (Silva *et al.* 2015). In another study, 2% lidocaine administered as a palmar digital nerve block was found to be unreliable in its ability to resolve lameness caused by induced foot pain (despite complete loss of skin sensation), while 2% mepivacaine reliably eliminated lameness (Hoerdemann *et al.* 2017). When a nerve block results in only amelioration rather than resolution of lameness, the clinician must decide whether the injection was accurate, or whether the possibility of concurrent pain at another site on the limb should be investigated. Results of recent studies indicate that poor efficacy of the local anaesthetic agent administered for a nerve block should also be considered as a cause of incomplete resolution of lameness (Silva *et al.* 2015; Hoerdemann *et al.* 2017).

It has been claimed that once a bottle of local anaesthetic is opened, the potency of the drug diminishes rapidly (Adams 2012; Fürst 2012). A recent study, however, demonstrated that solutions of local anaesthetics used in equine practice are stable for at least 16 months after opening the vial, even in field conditions where temperatures range greatly (Adler *et al.* 2016). Refrigeration of a multidose vial of local anaesthetic to delay loss of potency is contra-

indicated because refrigeration inactivates a preservative (methylparaben) that prevents bacterial growth in the solution (Lehmann 1977).

Onset of action

Rapidity of onset of local anaesthesia is dependent on several factors: the innate properties of the local anaesthetic, the proximity of local anaesthetic to the nerve, size of the nerve, the dose of the local anaesthetic (which is determined by concentration and volume), the pKa of the local anaesthetic and characteristics of the tissue surrounding the nerve (Covino 1988; Salinas *et al.* 2008; Franco 2009; Berde and Strichartz 2010; Aguirre *et al.* 2012).

The arrangement of fibres within the nerve affects the pattern of onset of nerve blockade. Fibres to and from the most distal structures run at the nerve's core and fibres innervating more proximal structures lie on its periphery (Strichartz 1988; Weir and Strichartz 2013). As a local anaesthetic diffuses into a nerve, it affects the fibres at its periphery first and those at its core last. The larger the nerve trunk, the longer it will take local anaesthetic to penetrate to the centre (Strichartz 1988; Weir and Strichartz 2013). Large nerves such as the median, ulnar, tibial and peroneal (fibular) often require 20 minutes for onset of a significant analgesic effect after these nerves are blocked with 2% mepivacaine (Bassage II and Ross, 2011). However, 5 minutes or less is required for a significant analgesic effect achieved by blocking the smaller digital nerves (Wright *et al*. 1995; Barr 1997; Bassage II and Ross 2011; Fürst 2012).

For nerves invested with a fascicle sheath (**Fig 1**), local anaesthetic solution must be deposited within the sheath to be effective (Thompson and Rorie 1983; Boezaart 2014; Boezaart *et al.* 2015). Studies that radiographically examined the sites of palmar digital nerve blocks performed at the base of the proximal sesamoid bones (basisesamoid nerve block) (Nagy *et al.* 2009) and palmar and palmar metacarpal nerve blocks performed at the level of the distal extremity of the second and fourth metacarpal bones (low 4-point nerve block) (Nagy *et al.* 2010) after injection of radiodense contrast medium found that 11% and 22% of the injections, respectively, appeared to be outside the fascicle sheath. The investigators suspected that similar inaccurate injections of local anaesthetic would result in a delayed or decreased effect of the local anaesthetic. One of the authors of this article (J.S.) found that an injection of 2% mepivacaine HCL outside of the sheath of the palmar digital nerve at the base of the proximal sesamoid bones of horses with foot pain caused a marked delay in amelioration lameness when horses were examined over 45 min (Schumacher *et al*. unpublished data, 2019). Some investigators have named the sheath surrounding the neurovascular bundle, the circumneural sheath and, the space it encloses, the subcircumneural space (Boezaart 2014; Boezaart *et al.* 2015) (**Fig 1**).

The dose of local anaesthetic affects not only speed of onset, but also potency and duration of the nerve block (Covino 1988; Datta *et al.* 2010). The dose of a local anaesthetic is determined by volume and concentration (Covino 1988; Datta *et al.* 2010). The larger the volume, the longer the segment of nerve covered and the more profound the block will be. The higher the concentration of the local anaesthetic, the more molecules of local anaesthetic will be available for diffusion into the nerve (Berde and Strichartz 2010). The most commonly administered local anaesthetics administered by veterinarians are 2% solutions of lidocaine and mepivacaine. A 3% solution of lidocaine has been recommended for peripheral nerve blocks in the horse (Wyn-Jones 1988); however, 3% solutions of lidocaine or mepivacaine are either not commercially available or not available in multidose vials in the United States. A 3% solution of chloroprocaine is commercially available in multidose vials and was shown to speed the onset and intensify the plane of analgesia of median and ulnar nerve blocks in naturally lame horses compared to 2% mepivacaine (Boone *et al.,* 2019a). To reduce the time of onset of analgesia after administering proximal limb nerve blocks, the use of 3% chloroprocaine should be considered (Boone *et al.,* 2019a, 2019b). Chloroprocaine is more expensive than commonly used local anaesthetics and has a short shelf life.

The pKa of local anaesthetic solutions plays a critical role in the kinetics of local anaesthetics. By definition, the pKa is the pH at which 50% of the drug is ionised (water-soluble) and 50% is nonionised (lipid-soluble). Local anaesthetics exist in equilibrium between these two forms (Becker and Reed 2006). The closer the pKa is to physiologic pH, the higher the percentage of local anaesthetic exists in the lipid-soluble form (Becker and Reed 2006; Drasner 2011). The higher the percentage of local anaesthetic that exists in the lipid-soluble form, the quicker will be the penetration of the neurilemma by molecules of the local anaesthetic to speed the onset of action (Achar and Kundu 2002; Becker and Reed 2006; Drasner 2011). Local anaesthetic solutions are prepared as water-soluble hydrochloride salts and generally have a pH of 5-6 (Aguirre *et al.* 2012). When a local anaesthetic is injected into tissue, buffers in the tissue increase the pH of the solution so that more of the lipid-soluble form becomes available for penetration of the lipidic nerve cell membrane (**Fig 2**). To increase the amount of lipid-soluble compared to water-soluble ions for quicker onset, the pH of a local anaesthetic can be made more basic by adding sodium bicarbonate before it is injected (Datta *et al.* 2010; Frank and Lalonde 2012) (see Additives/sodium bicarbonate, below).

Onset of action and potency of the nerve block are greatly affected by the character of the tissue at, or close to, the site of injection. Injection of local anaesthetic into infected tissue is contra-indicated because of the risk of spread of infection (Bassage II and Ross 2011). A nerve block administered in inflamed tissue is likely to be ineffective because inflammation causes a lowered local pH, which increases the proportion of local anaesthetic in the ionised form that cannot permeate the nerve membrane (Bieter 1936; Becker and Reed 2006; Checketts 2013) (**Fig 2**). An additional explanation for the decreased effects of local anaesthetics in the presence of inflammation is that inflamed tissue produces peroxynitrite, an oxidising agent that interacts with local anaesthetics to decrease their activity (Ueno *et al.* 2008).

Duration of anaesthesia

Duration of desensitisation caused by a local anaesthetic is markedly influenced by the vascular effect of the local anaesthetic (Becker and Reed 2006; Berde and Strichartz 2010; Aguirre *et al.* 2012). Most local anaesthetics cause some degree of vasodilation. In general, the greater the

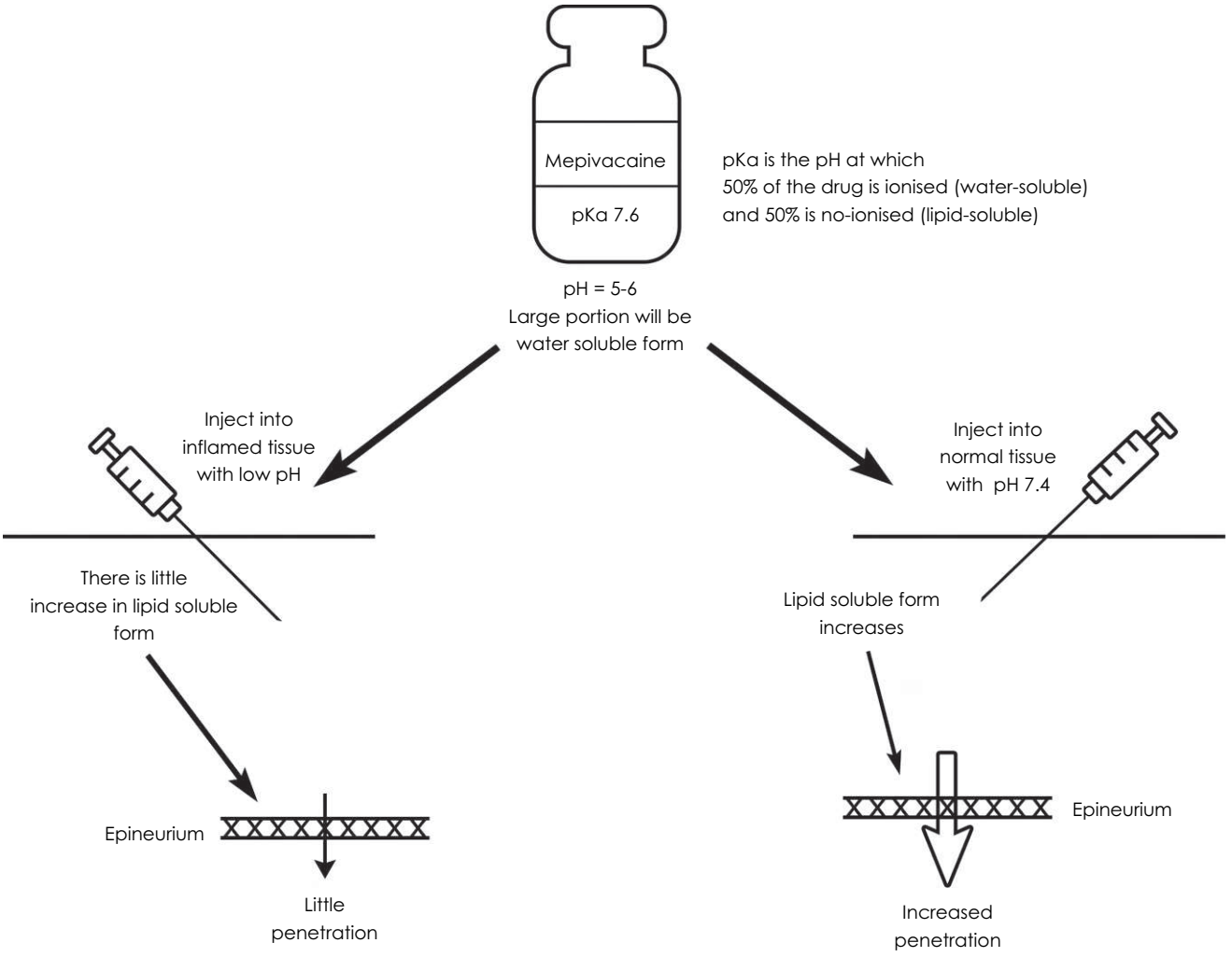

Fig 2: A nerve block administered in inflamed tissue is likely to be ineffective because inflammation causes a lowered local pH, which increases the proportion of local anaesthetic in the ionised form that cannot permeate the nerve membrane.

degree of vasodilation, the shorter the duration of analgesia is. Lidocaine causes more vasodilation than mepivacaine (Berde and Strichartz 2010; Becker and Reed 2006). Ropivacaine has mild vasoconstrictive activity, which might contribute to its long duration of effect (Datta *et al.* 2010). To counteract the vasodilatory effects of local anaesthetics, a vasoconstrictor can be added to the local anaesthetic solution. The most commonly used vasoconstrictor used for this purpose is epinephrine (see Additives/epinephrine, below).

The duration of action of local anaesthetics is also influenced by the fraction of drug bound to protein in plasma [bupivacaine (95%) = ropivacaine (94%) > mepivacaine (75%) > lidocaine 65%) > procaine (5%) and chloroprocaine (negligible)] (Franco 2009). Plasma protein binding correlates closely with the degree of protein binding on the neuronal membrane (Salinas *et al.* 2008). Highly protein-bound local anaesthetics are removed from the nerve at a slower rate, resulting in prolonged duration of action (Salinas *et al.* 2008). Procaine and chloroprocaine have a very short duration of anaesthesia; lidocaine, mepivacaine and prilocaine have moderate duration of anaesthesia, and bupivacaine and ropivacaine have the longest duration (Berde and Strichartz 2009; Drasner 2011).

Opinions differ concerning the duration of effective anaesthesia of local anaesthetics in horses, and these differences may be influenced by the nerve involved or the intensity of pain the local anaesthetic is expected to ameliorate (Bassage II and Ross 2011). For localisation of pain during a lameness examination, lidocaine is claimed to provide effective anaesthesia anywhere from 30 min to 3 h, mepivacaine from 90 min to 3 h, and bupivacaine from 3 to 8 h (Wyn-Jones 1988; Andreen *et al.* 1994; Bidwell *et al.* 2004; Bassage II and Ross 2011; Silva *et al.* 2015). Ropivacaine administered as a palmar digital nerve block reliably ameliorated lameness for 3 h in horses with experimentally induced foot pain (Silva *et al.* 2015). When single limb lameness is investigated, the duration of desensitisation may not be important unless subsequent blocks that are more specific might be of value; a short-acting local anaesthetic would allow a more rapid return to lameness for administration of a more precise nerve block. When multiple limb lameness is investigated, it is important to use a long-lasting local anaesthetic and to be aware of

the limits of reliable desensitisation provided by the local anaesthetic.

Volume of local anaesthetic

The lowest volume possible for effective desensitisation should be used when injecting local anaesthetic solution for diagnostic purposes. Unfortunately, recommended volumes for administration of 2% solutions of local anaesthetic vary widely for some nerve block procedures and are based only on clinical experience rather than demonstrative evidence of efficacy. When a large volume of local anaesthetic solution is injected perineurally, it may be forced an excessive distance proximally inside the neurovascular bundle, consequently causing desensitisation of structures proximal to the intended region of anaesthesia (Claunch *et al.* 2013). When synovial structures are distended with an excessive amount of local anaesthetic solution, subcutaneous leakage at the injection site or increased diffusion of local anaesthetic from the synovial structure can occur, causing desensitisation of unintended structures and leading to misinterpretation of the nerve block (Dyson and Romero 1993; Jordana *et al.* 2014; Pilsworth and Dyson 2015). Although the dose of a local anaesthetic is determined by both volume and concentration, there is evidence that concentration is more important than volume in acquiring potency. With the same dose of local anaesthetic, a higher concentration but smaller volume will result in a more potent and long-lasting nerve block than the same dose acquired by using a lower concentration, but higher volume (Nakamura *et al.* 2003; Lifeld *et al.* 2009). It has been suggested that when nerves cannot be palpated for an accurate nerve block, larger volumes of lesser concentration may increase the chance of a successful nerve block (Nakamura *et al.* 2003). This advice seems inappropriate for anaesthesia of nerves enclosed within a circumneural sheath considering that, for a nerve block to be effective, local anaesthetic solution must be deposited within the subcircumneural space (Boezaart *et al.* 2014; Boezaart 2015). It is probable that even large amounts of local anaesthetic solution deposited outside the circumneural sheath of the neurovascular bundle will be ineffective.

Detrimental effects of local anaesthetics

Local anaesthetics used for peripheral nerve blocks can be considered risk free for causing damage to nerves (McCartney 2013), but some can cause significant inflammatory reaction in surrounding tissue. Most clinicians believe that lidocaine causes more tissue reaction than does mepivacaine (Day and Skarda 1991; Bassage and Ross 2011; Baxter and Stashak 2011). Two studies have compared the inflammatory effects of lidocaine and mepivacaine administered into the middle carpal joint, and each found that lidocaine caused a greater inflammatory response than did mepivacaine (Specht *et al.* 1988; Adler and Verwilghen 2016). In one of the studies, horses administered intra-articular lidocaine showed clinical signs and synovial fluid parameters mimicking those of septic synovitis (Adler and Verwilghen 2016).

Inadvertent nerve puncture and intraneural injection associated with perineural anaesthesia is known to cause nerve damage (Selander *et al.* 1979). However, 21 human patients who were unintentionally injected intraneurally (104 nerves in total) with a mixture of bupivacaine, lidocaine and epinephrine showed no signs of neurologic injury when examined 6 months later (Bigeleisen 2006). The investigator of that study pointed out that a peripheral nerve contains a large quantity of fat and connective tissue and that there is high probability of puncturing a peripheral nerve without contacting a fascicle or damaging neurons (**Fig 3**). It is the experience of some anaesthesiologists that intraneural injections frequently occur during regional anaesthesia in people but are often not harmful (Server *et al.* 2018; Vlassakov *et al.* 2018). Equine clinicians sometimes experience a violent response during needle insertion during a regional nerve block that is interpreted as needle/nerve contact. The authors, however, are not aware of reports of neurologic injury as a result of this complication.

Local anaesthetics are toxic to both chondrocytes and synoviocytes. Chondrotoxicity of local anaesthetics became evident over a decade ago when pain pumps were used for intra-articular infusion of bupivacaine for control of postoperative joint pain in people (Gulihar *et al.* 2015). Joint damage caused by this method of pain control led to lawsuits and numerous investigations into the detrimental effects of local anaesthetics on cartilage. The detrimental effects of administration of local anaesthetics on cartilage appear to be related to the type and dose of the local anaesthetic and its duration of contact with cartilage (Kreuz *et al.* 2018). Local anaesthetics were shown to cause more severe chondrocyte damage in osteoarthritic cartilage compared to intact cartilage (Breu *et al.* 2013). Bupivacaine and lidocaine are identified in several in vitro studies as being local anaesthetics most detrimental to human and equine articular cartilage (Park *et al.* 2011; Breu *et al.* 2013; Kreuz *et al.* 2018). A recent in vitro study concluded that even single low doses of mepivacaine or bupivacaine in contact with equine chondrocytes and synoviocytes are toxic (Rubio-Martínez *et al.* 2017). Ropivacaine appears to be less detrimental to chondrocytes than mepivacaine (Breu *et al.* 2013; Jayaram *et al.* 2019).

What is less clear is the effect of a single intra-articular dose of local anaesthetic for diagnostic analgesia or short-term relief of pain. Piat *et al.* (2012), in an in vivo study, examined the effects of 2% lidocaine or 0.5% bupivacaine

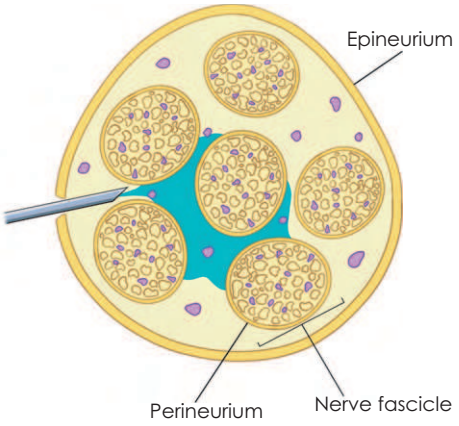

Fig 3: A peripheral nerve contains a large quantity of fat and connective tissue, and therefore, there is high probability of puncturing a peripheral nerve without contacting a fascicle or damaging neurons.

administered intra-articularly to horses. After measuring biomarkers of cartilage metabolism, they concluded that a single injection of local anaesthetic solution into normal joints has a limited effect on collagen degradation markers and suggested that local anaesthetics are safe when used as a single injection. Another in vivo study examined the effect of a single injection of 0.5% bupivacaine into the stifles of rats (Chu *et al.* 2010). When the joints were studied 6 months after injection, reduced chondrocyte density without gross or histological change in chondral surfaces was observed. The authors of that study concluded that the toxic effects of bupivacaine following a single injection would be difficult to detect clinically but conceded that with fewer chondrocytes to repair and maintain matrix, development of chondrosis may eventually occur even though it may not happen for years. Because the onset of osteoarthritic symptoms may not develop for months or even years after single exposure of a joint to a local anaesthetic, there is suspicion that the incidence of local anaesthetic chondrotoxicity is under-reported (Gulihar *et al.* 2015). There may be a 'Catch-22', therefore concerning intra-articular administration of a local anaesthetic to identify joint disease as a cause of lameness. By administering a local anaesthetic intra-articularly to diagnose joint disease, the clinician may possibly cause joint disease in normal joints and exacerbate disease in joints that are osteoarthritic. The long-term effect of single-dose local anaesthetics on cartilage in equine joints, however, has not been determined by any study. More in vivo studies need to be performed to determine the clinical significance of the toxicity of local anaesthetics.

Simultaneous administration of local anaesthetic and corticosteroid is often used to treat osteoarthritis in people because the combination provides fast and prolonged relief of joint pain (Farkas *et al.* 2010). In vitro and in vivo studies in people and dogs, however, indicate that corticosteroids (betamethasone phosphate or acetate, methylprednisolone acetate, dexamethasone sodium phosphate, or triamcinolone acetonide) potentiate the deleterious effects of a local anaesthetic on chondrocytes following a single exposure (Farkas *et al.* 2010; Syed *et al.* 2011; Braun *et al.*, 2011; Sherman *et al.* 2015). These findings led some investigators to conclude that concomitant administration of a local anaesthetic and a corticosteroid to treat osteoarthritis in people should be avoided (Sherman *et al.* 2015). In the horse, diagnosis of osteoarthritis is often made with an intra-articularly administered local anaesthetic and followed by intra-articular administration of a corticosteroid (Zubrod *et al.* 2006; Kay *et al.* 2008). In the light of new information, perhaps a wiser course of action might be to diagnose joint disease using regional anaesthesia and diagnostic imaging; confirmation of the diagnosis could be made by observing a positive response to an intra-articularly administered drug (especially if that drug will be a corticosteroid).

Because of the increasing evidence of the toxicity of local anaesthetics to tissues in the joint, the search for a nontoxic analgesic drug or a drug that will modify the negative effects of local anaesthetics is underway. Magnesium sulphate and/or morphine, alone or in combination with various local anaesthetics, have been investigated for intra-articular administration for treatment of postoperative joint pain (Elsharnouby *et al.* 2008; Baker *et al.* 2011; Elkousy *et al.* 2013; Radwan *et al.* 2013; Zeng *et al.* 2016; Rubio-Martínez *et al.* 2017). In vitro studies of the effects of a combination of either magnesium sulphate or vitamin C and local anaesthetics on human chondrocytes indicated these drugs are able to attenuate the toxic effect of the local anaesthetics (Baker *et al.* 2011; Tian and Li 2016). Another in vitro study found, however, that local anaesthetics alone or in combination with magnesium sulphate had cytotoxic effects on equine articular tissues (Rubio-Martínez *et al.* 2017). When administered intra-articularly, clonidine, an alpha-2-adrenergic agonist, was shown to ameliorate post-operative joint pain in people (Gentili *et al.* 1996). Detomidine, administered into the distal interphalangeal joint, was effective in ameliorating experimentally induced solar pain in horses (Sardari *et al.* 2005). We are not aware of other studies that have evaluated, in any species, the use of an alpha-2 adrenergic agonist or magnesium sulphate administered intra-articularly alone or combined with a local anaesthetic for the purpose of diagnostic analgesia.

Local anaesthetic additives

Vasoconstrictors, buffers, corticosteroids and alpha-2-adrenergic agonists can be added to a local anaesthetic solution to increase potency and prolong duration of regional nerve blocks (**Fig 4**).

Sodium bicarbonate

The addition of sodium bicarbonate to local anaesthetic solution increases both the potency and the speed of onset of the local anaesthetic and decreases the pain of injection (Becker and Reed 2006; Datta *et al.* 2010; Frank and Lalonde 2012). By altering the pH of the local anaesthetic solution to a more basic solution before it is injected, the amount of lipid-soluble form in relation to water-soluble form will increase, which will speed onset of the nerve block (Becker and Reed 2006; Drasner 2011; Frank and Lalonde 2012). 8.4% sodium bicarbonate (NaHCO3) can be added to mepivacaine or lidocaine at a ratio of 1:9 or 1:10 to raise the pH of the local anaesthetic solution (Frank and Lalonde 2012). This mixture was shown to be efficacious after preparation for at least 1 week (Bartfield *et al.* 1992). When median and ulnar nerve

Fig 4: Vasoconstrictors, buffers, corticosteroids and alpha-2-adrenergic agonists can be added to a local anaesthetic solution to increase potency and prolong duration of regional nerve blocks.

blocks were performed in horses using either a mixture of mepivacaine and sodium bicarbonate or mepivacaine alone, amelioration of lameness occurred earlier and was more profound for horses administered the buffered solution (Boone *et al*. 2019b). There would likely be little advantage for using NaHCO3 mixed with local anaesthetic solution to speed onset of nerve blocks of the lower portion of the limb because onset of significant analgesia after these nerve blocks occurs quickly, often within 5 min (Wyn-Jones 1988; Fürst 2012). Bupivacaine and ropivacaine cannot be alkalinised because they precipitate above a pH of 6.5 (Franco 2009).

Epinephrine

Epinephrine added to local anaesthetic solution prolongs and intensifies the analgesic effect of the local anaesthetic by counteracting the vasodilatory nature of most local anaesthetics on neural vasculature resulting in slower local anaesthetic clearance and increased neural uptake (Franco 2009; Berde and Strichartz 2010; Datta *et al*. 2010). The duration of ropivacaine, however, which has intrinsic vasoconstrictor properties, is not altered by the addition of epinephrine (Weber *et al*. 2001; Schoenmakers *et al*. 2015). In human medicine, lidocaine solutions containing epinephrine fell out of favour for digital anaesthesia in the middle of the 20th century because their use was associated with skin necrosis and gangrene (Krunic *et al*. 2004). Many veterinary textbooks (Mueller and Hay 1999; Stashak 2002; MacDonald *et al*. 2006) caution that use of local anaesthetic solutions containing epinephrine for regional nerve blocks in horses could cause severe swelling, skin necrosis and growth of white hair, and some authors advised against their use (Owen 1974; Barr 1997; Mueller and Hay 1999; Stashak 2002). Other authors claim that local anaesthetic solutions containing epinephrine at a dilution of 1:100,000 or 1:200,000 are unlikely to cause necrosis when used for regional anaesthesia in horses, but might result in the subsequent growth of white hair (MacDonald *et al*. 2006). A review of human medical literature indicates that local anaesthetics containing epinephrine at a concentration of 1:200,000 or less do not cause necrosis and are safe to use for regional anaesthesia (Krunic *et al*. 2004; Franco 2009). Furthermore, local anaesthetics containing epinephrine at concentrations >1:200,000 appear to offer no advantage in terms of prolonging regional anaesthesia in human patients (Dagher *et al*. 1997; Becker and Reed 2006). Most commonly, epinephrine is added to a local anaesthetic solution at a dose of 5 μg/mL (1:200,000 concentration) (Berde and Strichartz 2010). To make a 1:200,000 concentration of epinephrine, 0.1 mL of 1:1000 (1 mg/mL) epinephrine is added to 20 mL of a local anaesthetic solution (Skarda *et al*. 2009). Commercially prepared local anaesthetic solutions containing epinephrine are less potent than are solutions to which epinephrine has been added shortly before use (Skarda *et al*. 2009). This is because commercially prepared local anaesthetic solutions that contain epinephrine also contain an antioxidant (sodium metabisulphite) to maintain epinephrine stability (Covino 1988). Sodium metabisulphite decreases the pH of the solution. As the pH of a solution decreases, the percentage of nonionised local anaesthetic available to diffuse through the nerve membrane and facilitate onset and quality of a regional block also decreases (Becker and Reed 2006). When epinephrine is added to an unbuffered solution of local anaesthetic, the mixture is stable for at least 24 h (Robinson *et al*. 2000). However, when epinephrine is added to local anaesthetic solution buffered with sodium bicarbonate, epinephrine concentration decreases markedly over the same time period, leading to the recommendation that epinephrine be added to pH-adjusted local anaesthetic solution immediately before use (Robinson *et al*. 2000; Skarda *et al*. 2009).

Epinephrine added to 2% lidocaine (dilution, 1:100,000 solution) used for palmar nerve blocks in the proximal portion of the metacarpus caused substantial tissue swelling (Spoormakers *et al*. 2004). In another study, the addition of epinephrine (dilution, 1:200,000) to a 1% lidocaine solution immediately before administering a palmar digital nerve block (PDNB) was shown to improve the efficacy and prolong the duration of the nerve block in horses with naturally occurring forefoot lameness compared with the efficacy and duration of PDNBs performed by administering a 1% or 2% lidocaine solution without epinephrine (Velloso Alvarez *et al*. 2018). In that study, swelling at the injection site was not observed. When injection sites were examined 3 months after administering the nerve blocks, white hair was not seen.

Dexamethasone

Dexamethasone, administered perineurally along with a local anaesthetic, has been shown to prolong and improve the quality of peripheral nerve blockade in people (Pehora *et al*. 2017). The mechanism of action is unknown, but dexamethasone may attenuate nociceptive activity of C-fibres (Johansson *et al*. 1990). A systematic review and meta-analysis of perineural dexamethasone for peripheral nerve blocks in people showed that dexamethasone increased the mean duration of local anaesthesia of short- or medium-duration local anaesthetics by slightly over 2 h and over 6.5 h for long-term action local anaesthetics, and it slightly reduced the time to onset of action (Albrecht *et al*. 2015). In these studies, doses of either 4 or 8 mg dexamethasone sodium phosphate were administered along with the local anaesthetic; the 4 mg dose was found to be as efficacious as the 8 mg dose. To the authors' knowledge, there are no reports of this drug combination being used in the horse.

Alpha-2-adrenergic agonists

Alpha-2-adrenergic agonists have been shown to inhibit both C fibres and A delta fibres and to modestly inhibit clearance of local anaesthetics (Eisenach *et al*. 1996; Valverde 2010). Dexmedetomidine is an effective post-operative analgesic when administered intra-articularly to people after arthroscopic knee surgery (Al-Metwalli *et al*. 2008). When added to local anaesthetic solutions, alpha-2-adrenergic agonists prolong and intensify sensory blockade during regional anaesthesia to a degree comparable to that produced by epinephrine (Aguirre *et al*. 2012). Horses with solar foot pain created with setscrews had significant amelioration of lameness after administration of 20 μg/kg bodyweight of detomidine HCl, diluted with normal saline to a volume of 6 mL (Sardari *et al*. 2005), presumably because detomidine was able to anaesthetise the palmar digital nerves which lie in close proximity to the palmar pouch of the distal interphalangeal joint.

Mixtures of local anaesthetics

Quick-acting, short-duration local anaesthetics are sometimes mixed with slow-acting, long-duration anaesthetics to obtain

the optimal benefit of rapid onset and long duration. When local anaesthetics are mixed, however, the onset, potency and duration of the mixtures becomes unpredictable (Ribotsky *et al.* 1996). Although the suggestion for combining lidocaine and bupivacaine is common in veterinary medicine, it has been largely debunked as an effective strategy (Lawal and Adetunji 2009; Lizarraga *et al.* 2013; Vesal *et al.* 2013).

Failure of local anaesthetics to attenuate pain

There are instances where local anaesthetics fail to significantly attenuate pain despite accurate administration. Horses with severe foot pain caused by fracture, subsolar abscess or laminitis often show little response to regional anaesthesia of the foot (Pilsworth and Dyson 2015). Horses with joint pain caused by severe osteoarthritis may show little response to intra-articularly administered local anaesthetic solution (Dyson 1986; Pilsworth and Dyson 2015). Joint pain results from inflammation of capsular soft tissue and from stimulation of nociceptive nerve fibres in subchondral bone during weight bearing (Niv *et al.* 2003). Because subchondral bone receives innervation from nerves that lie within the medullary cavity of bones comprising the joint, intra-articularly administered local anaesthetic may have little effect on joint pain caused by nociceptive innervation of subchondral bone (Niv *et al.* 2003).

Conclusion

A great deal of new information concerning local anaesthetics has been published in recent years. Some of that information may enable the equine practitioner to more effectively use local anaesthetics for regional anaesthesia and interpret results of regional anaesthesia more accurately. Recent studies have raised questions concerning the safety of local anaesthetics for intra-articular administration. The equine practitioner is encouraged to keep abreast of research concerning the clinical significance of the intra-articular toxicity of local anaesthetics.

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No conflict of interests have been declared.

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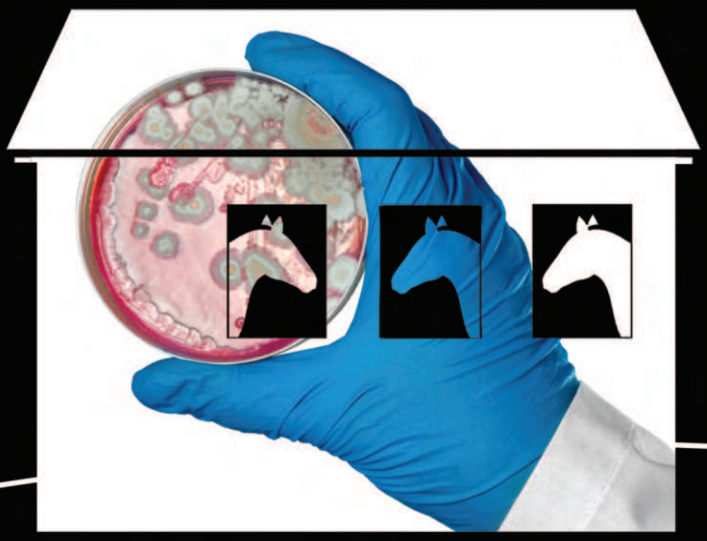

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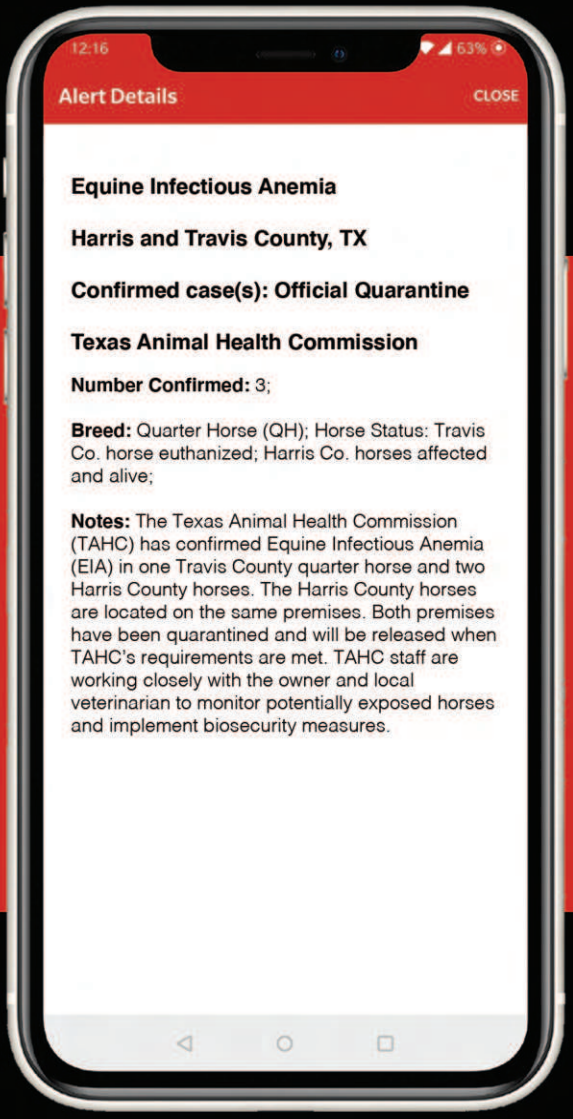

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