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[1] Brendemuehl JP, Kopp K, Altman J. Uterine Inflammatory Response to Frozen Semen is attenuated by Oral Supplementation of a Blend of Omega-3 Fatty Acids (Algal DHA and Flax Seed) in Susceptible and Resistant Mares. Submitted to Theriogenology. [2] Brendemuehl JP, Altman J, Kopp K. Influence of dietary algal N-3 fatty acids on breeding induced inflammation and endometrial cytokine expression in mares bred with frozen semen. J Equine Vet Sci. 2014; 34(1): 123-124. [3] A.M. Adkin, A.V. Muniz, C.J. Mortensen, L.K. Warren. Maternal fatty acid supplementation influences memory and learning ability in yearling and 2-year-old horses. J Equine Vet Sci. 2015; 35: 418-436. [4] A.M. Adkin, L.K. Warren, C.J. Mortensen, J. Kivipelto. Maternal supplementation of docosahexaenoic acid and its effect on fatty acid transfer to the foal (longitudinal study). Equine Vet Sci. 2013; 33: 321-329. t[5] A.M. Adkin, L.K. Warren, and C.A. McCall. Effect of maternal docosahexaenoic acid supplementation on behavior and cognitive development in nursing foals. J Equine Vet Sci. 2013; 33: 321-399.

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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: The good old days?

By Emma Read, DVM, MVSc, DACVS

Dr. Emma Read

Ah, the good old days…when new graduates came to us completely prepared and ready to start their new job; when students and new graduates worked all night without complaining and asked for very little pay; and when graduates stayed in equine for the rest of their career, bought into the practice and never left to pursue other opportunities. We all remember the good old days, right?

Personally, I am not sure I ever saw them, but I have heard an awful lot about them over the years—that golden time when all was good in the world. Kind of like travel used to be before COVID-19 came along.

Twenty years ago, as I finished my residency, I first heard colleagues say that all the issues in equine practice with retention of younger practitioners could be solved if only we had much better graduates. Ouch. It was pointed out that if veterinary schools spent more time recruiting better candidates and then trained them to be more resilient, or if practices and internships spent more time focusing on technical skills and making them into better practitioners, then we would have more suitable colleagues who would purchase practices and remain in the profession while giving it their all.

As one who has spent parts of the last 20 years in private practice, academia and administration, I've been immersed in this issue from all sides. I've heard the criticisms and questions from all corners of the profession. Given the urgency of equine veterinarians leaving equine practice, it's time to refocus our approach around a fresh and unified response.

I'm currently reading "The Burnout Epidemic: The Rise of Chronic Stress and How We Can Fix It" by Jennifer Moss. The author states that there are six factors that inevitably lead to burnout in workers, no matter the industry. I recognize most or all these as being problematic for many of our new graduates in the equine profession, whether they enter practice right away or more typically, and especially, while they work in an internship. The factors are:

1. Heavy workload
2. Perceived lack of control over their own workload or schedule (especially on call)
3. Lack of rewards or recognition for work done
4. Poor relationships at work and outside of work (no time for others)
5. Lack of fairness (bias, favoritism, mistreatment, or unfair compensation)
6. Values mismatch (Perceived overqualification. The graduate expects a job that uses their credentials and skills but instead finds themselves in a job that leaves them feeling deprived.)

For as long as I can recall, the conversation has always been about the loss of the good old days and what can we do to fix the kids who are coming along today. The students. The graduates. The young people. They are the ones who need to change to fit our mold.

Well, the hard cold truth is that they are not the problem. We are the ones who must change. If we don't change us, then we will continue the pain point where practices can't hire enough doctors and where retaining them becomes ever more problematic. We simply don't have many students to recruit, we don't have enough graduates to hire, and the ones we are able to convince to give us a try continue to leave in droves—half of them by the 5-year mark. Putting better students into a broken model will still result in them being broken, disillusioned and ultimately leaving. We need to stop talking and start listening. All of us: practitioners, colleges and organizations!

The AAEP did a lot of listening last year. Dr. Carol Clark and Dr. Rob Trimble headed a task force that listened to more than 50 equine practitioners describe their current challenges. The board of directors heard that feedback at our December meeting in Nashville. Panel sessions at the annual convention opened our eyes and ears to the voices that were speaking loudly about the pain that is happening every day in practice. At our board meeting in January, we continued to determine our operation plan for the upcoming year. We agreed unanimously that this is the most pressing issue our organization faces. We all have a role to play in finding the solutions.

In the next few months, we will be convening a summit meeting of practitioners to discuss the retention task force findings and to strategize about solutions that involve changing us, not them. We will also convene a task force to take a deeper dive into internships and the AAEP's role in this space. Lastly, we want to understand how to best support and mentor our young colleagues. What is it that they need? This is not us offering them advice about how to be more like we want them to be; rather, it is us listening and learning. It is us finding out what it will take for them to want to ride with us and stay there so they can buy our practices, take care of our clients and look after their horses.

The biggest question that remains is whether all of us are up for this challenge. Can we listen to the new graduates and students and start to consider how we can change our mindsets? Do we have it in us to listen, learn and adapt before it is too late? If we continue to do nothing, all we may have left are the memories of the good old days.

Retention strategies materialize at winter board meeting

By David Foley, AAEP Executive Director

David Foley

The AAEP board convened Jan. 18 for its winter meeting with all directors present—one by videoconference. Following is a synopsis of the meeting.

After opening remarks by AAEP President Dr. Emma Read, the board commenced discussion of the strategic plan with the goal of developing operational objectives for the year. Deliberation about **The Profession goal** focused on the retention effort. The board split into three groups to begin work on defining and measuring success for each demographic group—students, new graduates and practice owners. Specific actions taken were approval of motions to:

- form a task force to plan a Practice Owner Strategy Summit (or regional summits) in which invited practice owner representatives participate in a facilitated discussion of potential AAEP action based on data gathered thus far. Dr. Jim Zeliff will chair this task force.
- form a task force on internships to examine the internship process and make recommended changes, if warranted. Areas of consideration include rating systems, AAEP certification, best practices, and a review of models from other professions. Drs. Jackie Christakos and Sarah Reuss will jointly chair this task force.
- consider Peer Group formation with Decade One program founder Dr. Amy Grice, who has discussed with several Decade One participants the potential scalability of the program to accommodate larger numbers as well as inclusion of students as an entry point. Dr. Grice will present a proposal to the board for consideration.

The board wrapped up The Profession goal with a brief discussion of student programs, including the possibility of developing a speaker's bureau and practitioner advisor program for each chapter. No formal action was taken on this particular initiative. It will be revisited at the summer board meeting.

A report on **The Education goal** revealed that the bulk of the initial strategies had been accomplished; however, the Educational Programs Committee intends to meet in-person this summer to re-evaluate AAEP's educational programming based on lessons learned during the pandemic and how that might shape future programs. Key areas of focus are continued improvements in the Annual Convention and increasing both the virtual catalogue of offerings as well as hands-on learning opportunities.

Discussions around **The Horse goal** included an update on Scope of Practice plans as well as potential owner education via webinars and social media, including raising awareness among horse owners of the retention issues facing the profession.

The strategic plan portion of the meeting concluded with approval of the recommendations presented by the Diversity, Equity and Inclusion Task Force, which includes formation of a standing committee on DEI.

The board then received an update from The Foundation for the Horse, specifically related to its comprehensive campaign and the work of its research working group. Specific actions taken included approval of motions:

- to approve the research working group's strategic planning process and recommendations.
- for the board to approve grant disbursements for research and other areas; however, for emergency funding associated with disasters, the disaster medicine working group is authorized to approve requests up to $50,000. Requests exceeding that amount require board approval.

The meeting's focus then shifted to general association issues. The board approved an increase of $25 in annual membership dues for the 2022-23 membership year. This is the first increase in seven years. Following a discussion of the AAEP leadership program that was reinstated last October, the board approved a motion that AAEP LEAD be conducted annually each fall with approximately 10 to 12 invited individuals. The Member Engagement Committee will continue to be involved with applicant selection and post-seminar placement of attendees in volunteer roles; and will be tasked with developing additional volunteer opportunities for attendees. AAEP will continue to work with the Veterinary Leadership Initiative for curriculum development and will solicit input from attendees of the most recent seminar to ensure relevancy.

The board then addressed work group recommendations. Specific actions taken were:

- approval of separate recommendations from the Finance Committee to (1) re-appoint Mr. Drew Buechley and Mr. Eric Krawitt to one-year terms as ex-officio members of the committee, and (2) appoint Mr. John Chalk to an advisory role to the committee for 2022.
- approval of separate recommendations from the Racing Committee to (1) convene an in-person strategic planning session in 2022, and (2) assign the committee chair or their designee to serve on the board of the Racing Officials Accreditation Program, which offered AAEP a seat on its board.

The next board meeting will be July 25 in Lexington, Ky.

5 things to know about AAEP this month

1. Virtual Convention registrants: Your ability to earn CE from on-demand sessions ends March 31. However, you will retain access to all recorded sessions indefinitely.
2. The 2022 season of twice-monthly Virtual Wednesday Round Tables begins in March. Learn more and register for upcoming Round Tables at aaepanywhere.org.
3. Grab one of just 60 spots at Focus on Sport Horse Pre-Purchase Exam, featuring in-person wet labs in Lexington, Ky., May 2–3. Register at aaep.org/meetings.
4. Advanced search capabilities have been incorporated into aaep.org, enabling users to conveniently filter results by publication or document type and sort by date or relevance.
5. Read or download AAEP's updated General Biosecurity Guidelines at aaep.org/document/general-biosecurity-guidelines.

Log on for education, engagement with Virtual Wednesday Round Tables

The second season of the AAEP's Virtual Wednesday Round Tables premieres in March, offering members the opportunity to engage with subject matter experts on important clinical and non-clinical aspects of equine practice.

Available as a complimentary benefit of your membership on the second and fourth Wednesday of each month through October, the Round Tables are virtual discussions similar to convention Table Topics. To participate in a particular session, simply register in advance through AAEP Anywhere at aaepanywhere.org.

Each month's Round Tables feature one clinical and one non-clinical topic. Following is the tentative schedule of upcoming sessions:

March 23 – Keeping Vets in Equine Practice
April 13 – Use of Non-Antibiotic Antimicrobials in Breeding and Mare Management

The 2022 season kicked off March 9 with a session on laminitis. If you were unable to attend this live 90-minute

Round Table, you can watch a recording of this session as well as sessions from 2021 on-demand through AAEP Anywhere. On-demand sessions are available approximately 48 hours following the live session and include mentioned resources such as PowerPoint slides, images and more. CE credit is not offered for the Round Tables.

The AAEP thanks its Virtual Wednesday Round Table sponsors:

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New Practice Life podcast spotlights retention, internship issues

During the February episode of the AAEP Practice Life podcast, entitled, "AAEP Leadership Chat: What's Coming in 2022?" Dr. Mike Pownall hosts a wide-ranging discussion of important association and industry issues with 2022 AAEP President Dr. Emma Read, President-Elect Dr. Rob Franklin and Executive Director David Foley.

Among the topics addressed during the 42-minute episode are examining internship standards and retention issues, engaging veterinary students with an equine interest, promoting the benefits of equine practice, addressing scope of practice issues, and reflecting on other AAEP activities.

Commenting on the recent creation of a task force on internships to address concerns with the internship process and system, David Foley said, "The first question they'll want to ask is 'What is the AAEP's role in the whole internship process? What can we do to improve that situation?' It'll probably be a deconstruction of the current Avenues program and then building it back to hopefully be better suited to interns and to practices."

To hear more, download or listen to the episode at podcast.aaep.org or on iTunes.

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The AAEP Practice Life podcast is sponsored by Boehringer Ingelheim.

New *EVE* podcast looks at equine fluid therapy

In the latest episode of the *Equine Veterinary Education* podcast, Dr. Kate Hepworth-Warren discusses her review article, “Revisiting the use of hydroxyethyl starch solutions in equine fluid therapy.” Download or listen to the 19-minute episode at equineveterinaryeducation.podbean.com.

Nominate a difference maker for an AAEP award

Recognize professional excellence by nominating a colleague for a 2022 AAEP award. The nomination deadline is June 1, and winners will be announced and recognized during the President’s Luncheon at the AAEP’s 68th Annual Convention in San Antonio, Texas, Nov. 18–22.

Nominations are being accepted in the following categories:

AAEP Research Award
Distinguished Educator – Academic Award
Distinguished Educator – Mentor Award
Distinguished Life Member Award
Distinguished Service Award
George Stubbs Award
Sage Kester Beyond the Call Award
The Lavin Cup (The Equine Welfare Award)

Visit aaep.org/about-aaep/annual-awards for nomination forms as well as additional information about each award and the selection process. You may also request a nomination form from Sue Stivers at sstivers@aaep.org or (859) 233-0147.

Dr. Larry Bramlage, right, accepts the 2021 Sage Kester Beyond the Call Award from Dr. Scott Hay during the 67th Annual Convention in Nashville, Tenn.

Calling all photographers

Submit your best shot for a potential *EVE* cover

Have you snapped a horse photo you’re particularly proud of? If so, we’d love to see it and potentially use it on a future cover of *Equine Veterinary Education, American Edition*.

Since 2013, member-taken photographs capturing the beauty and majesty of the horse have graced the cover. Some have depicted horses excelling at specific tasks, others interacting with humans or animals, and a few simply enjoying the serenity of life on the farm.

To be considered for the cover, the photo must be at least 8 x 6 ¼ inches <u>in a landscape orientation</u> at 300 dpi, preferably in a JPG format. Please send your photo along with a brief description to John Cooney, AAEP publications coordinator, at jcooney@aaep.org.

Updated General Biosecurity Guidelines available on AAEP's website

The AAEP has amended the General Biosecurity Guidelines available on its website. Among the primary revisions are a change to "above 101.5° F" for a temperature to be considered a fever, which is consistent with regulatory agencies and with other AAEP resources; updated resources on Integrated Pest Management; and updated guidelines that clarify the role of regulatory involvement in outbreak situations.

The guidelines document is published as a PDF file and incorporates comprehensive information and step-by-step biosecurity protocols and recommendations in three distinct areas: identification of key personnel, important contacts and reference materials; routine biosecurity protocol; and outbreak response. Links to additional resources are also available.

Visit aaep.org/document/general-biosecurity-guidelines to view the updated guidelines or save them to your phone or tablet for future reference. Additional biosecurity information specific to common situations and locations such as breeding operations, events and travel are available from the Equine Disease Communication Center through the "Biosecurity" link at equinediseasecc.org.

Dr. Nat White

EDCC receives federal grant to promote biosecurity awareness

The Equine Disease Communication Center (EDCC), working with the AAEP, has been awarded a cooperative agreement from USDA-APHIS National Animal Disease Preparedness and Response Program (NADPRP) for $176,960 to increase awareness of biosecurity and help prevent the spread of infectious diseases in horses.

With the NADPRP support, the EDCC will develop tools to improve disease recognition and practical biosecurity while communicating the importance of biosecurity to all horse industry constituents. This will include creation of user-friendly biosecurity information and procedures for distribution throughout the horse community using media and the network of horse organizations and allied industry. The EDCC will also provide ongoing sources of continuing education for distribution by veterinarians to their clients.

Horses are transported more than any other livestock to horse shows, racetracks, sales, breeding farms and international events, creating an increased risk for infectious disease spread within the United States. To decrease this risk, all industry participants—from horse owners to event managers—need to be aware of the need for increased biosecurity and how to use it to mitigate diseases when they occur. To assess the industry's current level of knowledge, the EDCC will complete a survey of horse owners and veterinarians.

"Dealing with Covid-19 has highlighted the need for biosecurity procedures to reduce risk of infection; however, most horse owners are still not fully aware of the threat to their horses from both endemic and foreign animal diseases either at home or when traveling," said Dr. Nathaniel White, EDCC director. "We need to understand the gaps in biosecurity knowledge. Armed with that information, we will create specific plans for facilities and events, enabling the industry to react to domestic and foreign disease threats."

All facets of the horse industry (owners, producers, veterinarians and allied industry) will benefit from the continuing education information and biosecurity templates created during this project. Dr. White and Katie McDaniel, EDCC's communication manager, will work with the AAEP's Infectious Disease Committee to create "how-to" plans and resources which will be available on the EDCC website. These tools will help owners and veterinarians decrease disease risks during horse shows, events, race meets, breeding operations, pleasure horse activities and travel. Infographic designs for signage, visual aids and presentations will be made available through the EDCC, supporting member organizations and allied companies.

"This is the first NADPRP grant awarded for an equine-focused project," said Kentucky State Veterinarian Dr. Katie Flynn. "This is exciting news for the equine industry as the funding will dedicate resources to advancing biosecurity within the equine community. Promoting everyday biosecurity will have significant benefit to the health and welfare of our horses as well as ensuring the economic health of the industry."

Establishing boundaries to minimize ‘client creep’

The benefits to your physical and emotional wellbeing accrued from a healthy disconnect from work when off the clock can boost your focus, engagement and enjoyment of veterinary medicine when on the clock—even when it’s your turn to respond to a late-night emergency.

Establishment, communication and enforcement of clear and effective boundaries is essential to minimizing client infringement on your personal time. To help prevent clients from creeping into your leisure time, following are several client boundary-setting suggestions from members compiled from a recent association podcast and from responses to a question that appeared in the February 1 issue of the Spur e-newsletter.

A blanket ban on client texts

As her Woodside, Calif., practice started to grow and expand, Dr. Kelly Zeytoonian instituted a no-texting policy with clients that has streamlined correspondence between the practice and clients and helped ensure that practitioners can enjoy their days off free from client contact. She explained the rationale for the policy during the January 2022 episode of the AAEP Practice Life podcast.

“There are so many other forms of communication coming in that we’d be setting ourselves up for an onslaught of messages or a missed communication where somebody feels like we haven’t taken care of them,” said Dr. Zeytoonian. “I think that’s been a great way to allow myself and allow the employees to know that when we’re off, we’re off.”

Using technology to protect time off

Similarly, Dr. Yana Sorokurs of Sonoma, Calif., does not give out her cell phone number to clients. Instead, clients must call the practice and can only reach her when she is on duty. During her off times, clients trying to reach her will be helped by someone else in the practice.

“I only give out my work phone number and extension, never my personal cell number,” she said. “We use the Grasshopper app for the extensions, and it is set to only forward to my cell during business hours.”

Grasshopper (and similar apps and services) funnels calls and texts through the practice phone number, which maintains the privacy of practitioner cell phone numbers and helps foster a healthy separation between practice and personal life. Calls and/or texts to clients from a practitioner’s cell phone will display as coming from the practice phone number.

The power of auto-reply

Ambulatory veterinarians often give their cell phone number to clients, which creates a prime opportunity for after-hours, non-emergency texts from clients. Dr. Melissa Kelson of Denville, N.J., simply set up an auto-reply on her phone to manage incoming texts. The auto-reply alerts texters of the number to call for an emergency and that responses to all other inquiries will occur during regular office hours.

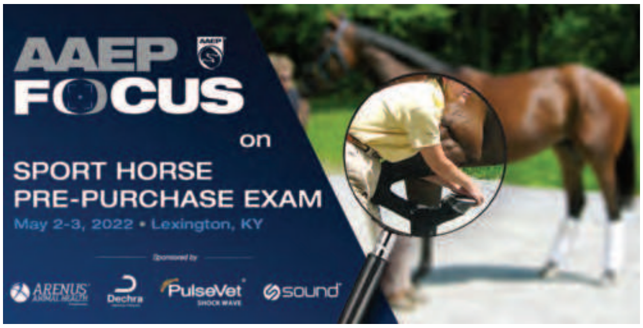
“That way I don’t feel guilty about not getting back to them until the next working day, and they know not to expect an instant reply,” said Dr. Kelson. “It also helps when I’m on call as it prompts those who would normally text me an emergency to call me instead, thus stopping me from constantly having to check for messages. I have all notifications on my phone turned off for my sanity—the only noise my phone makes is for an incoming phone call.”

Dr. Kelson said her personal texting tends to occur via Facebook Messenger so her use of auto-reply has little impact on her personal correspondence. She also doesn’t associate with clients on her personal social media. Befriending clients on social media can blur the line between client and friend, potentially leading clients to think of you as a friend and act as such by disregarding established boundaries.

Client boundaries are an individual decision so you must decide what is important to you and then advocate those choices to clients. When it comes to after-hours communication, it is important that clients are informed of a course of action for reporting emergencies as well as a timeframe for responses to non-emergent calls and texts.

Secure one of the limited spots at Focus on Sport Horse Pre-Purchase Exam

Acquire techniques that will help clients make the call on an acquisition



Provide your sport horse clients with a thorough evaluation of their potential purchase by applying protocols and skills acquired at the AAEP's Focus on Sport Horse Pre-Purchase Exam, May 2–3 in Lexington, Ky.

Covering head to tail, you'll obtain tips and strategies for imaging of key anatomy, identifying abnormalities and potential impact on athletic potential, determining when and how to further investigate irregular findings, recognizing legal considerations, and more.

Using a flipped classroom model, you'll watch recordings of practical talks online in April, which will prepare you to get the most out of your participation in six hands-on wet labs to be held at Spy Coast Farm in Lexington. On-site, you'll observe a thorough and systematic pre-purchase exam demonstration before refining your skills on live horses at stations devoted to:

- Radiography of the neck and back
- Radiography of the foot, hock and stifle
- Radiography of the fetlock, metacarpus and carpus
- Application and evaluation of dynamic gait analysis
- Neurologic vs. lameness
- Practical application of ultrasound in the purchase exam

Tentative CE Hours: 27.5
(Online talks – 17; On-site demo & labs – 10.5)

Meeting participation is capped at 60 participants so early registration is encouraged. The AAEP-member registration rate is $945. Register, book your hotel and view the educational program at aaep.org/meetings. If you need assistance with registration, contact Kristin Walker at kwalker@aaep.org or (859) 233-0147.

The AAEP Focus on Sport Horse Pre-Purchase Exam is sponsored by:

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Recent grads learn new techniques at New Practitioners Symposium

Sixty practitioners who graduated within the past 10 years strengthened and diversified their practical knowledge and skill sets at the inaugural AAEP New Practitioners Symposium, which convened Feb. 19-20 at the University of Florida.

The sold-out meeting featured afternoon wet labs in six key areas coupled with morning sessions focused on expert advice on pertinent medical and non-medical topics important to early-career practitioners. Several photos from the meeting are presented here.

The AAEP thanks CareCredit and Arthramid® Vet for their symposium sponsorship.

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Members in the News


Dr. Bruce Whittle

Dr. Bruce Whittle earns Veterinarian of the Year honors

The Missouri Veterinary Medical Association presented its 2022 Veterinarian of the Year Award to Dr. Bruce Whittle, owner of Honey Creek Veterinary Hospital in Trenton, Mo., for his skill, knowledge, dedication, service and impact on patients, clients, peers and his community.

Dr. Whittle received his veterinary degree form the University of Missouri and has been an organized veterinary medicine advocate throughout his career. He has served as president, board chair and on multiple committees with the Missouri VMA. In addition, he is a former chair and member of the AAEP's Welfare and Public Policy Advisory Council.


Dr. Jim Hamilton

Dr. Jim Hamilton elected to Brooke USA board

Dr. Jim Hamilton, partner and co-owner of Southern Pines Equine Associates in Southern Pines, N.C., has been elected to the board of directors of Brooke USA, a non-profit dedicated to alleviating the suffering of working equines and the people they serve in the developing world.

Dr. Hamilton is a founding board member of Brooke USA, having served on the board between 2007–2019. He received his veterinary degree from the University of Georgia and previously served as chair of the AAEP's Emergency and Disaster Preparedness Committee and as a member of the Professional Conduct and Ethics Committee.

AAEP mourns the loss of three members


Dr. Nancy Cook

Dr. Nancy L. Cook

Dr. Nancy L. Cook, respected theriogenologist who was among the pioneers of equine oocyte aspiration and transfer, died Dec. 14 at the age of 62.

Dr. Cook earned her veterinary degree from Colorado State University in 1991, followed by a residency and master's degree in equine reproductive science. She practiced equine reproductive medicine for 25 years in Colorado and California, including as owner of Advanced Equine Reproduction in Solvang, Calif. Dr. Cook also served on the AAEP's Reproduction Committee in the late 1990s.


Dr. Ronald Fessler

Dr. Ronald L. Fessler

Honor Roll member Dr. Ronald L. Fessler, the Virginia Horse Council's 2019 Veterinarian of the Year, died Jan. 23. He was 79.

Dr. Fessler received his veterinary degree from Iowa State University in 1967. Throughout his career, Dr. Fessler worked with prominent racehorses at Castleton Farm in Lexington, Ky., and treated a myriad of horses, donkeys, mules and companion animals at his Windhaven Equine Clinic in Forest, Va. He served on the AAEP's Farrier Liaison Committee from 1984–1988 and received an outstanding service award in 2012 from the Virginia Veterinary Medical Association.


Dr. Howard Gill

Dr. Howard E. Gill

Honor Roll member Dr. Howard E. Gill, co-recipient of the AAEP's Distinguished Educator Award in 2007, died February 7 at the age of 95.

After receiving his veterinary degree from Kansas State University in 1952, Dr. Gill served on faculty at his alma mater and later at Michigan State University before founding Pine Bush Equine in Pine Bush, N.Y. Dr. Gill specialized in reproduction and surgery, and he serviced many of the area's Standardbred farms. Dr. Gill also volunteered with the AAEP in the 1980s and early 1990s on the Resident Veterinarian Committee and the Constitution and Bylaws Committee.

Benefit: Enlist colleagues' expertise in AAEP's online communities

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Highlights of recent clinically relevant papers

Drug penetration into ocular fluids

This study by Hanneke Hermans and co-workers in the Netherlands investigated the penetration and local concentrations of topically applied dexamethasone and prednisolone in normal equine ocular fluids and serum.

Twenty-one Shetland ponies without ophthalmic disease were treated bilaterally topically every 2 h for 24 h to obtain steady-state drug concentrations. One eye was treated with 0.15-mg dexamethasone disodium phosphate (0.1%), and the other eye was treated with 1.5-mg prednisolone acetate (1%). Serum samples were taken prior to induction of general anaesthesia. Aqueous and vitreous humour samples were taken during euthanasia at time points after administration of the last dose (t = 5 min, t = 15 min, t = 30 min, t = 60 min, t = 90 min, t = 120 min and t = 180 min). Each pony was randomly assigned to one time point, and three ponies were sampled per time point. Dexamethasone and prednisolone concentrations were measured by liquid chromatography–mass spectrometry.

The mean $\pm$ standard deviation (SD) dexamethasone concentration in aqueous humour was 32.4 $\pm$ 10.9 ng/ml, and the mean $\pm$ SD prednisolone concentration was 321.6 $\pm$ 96.0 ng/ml. In vitreous and serum samples, concentrations of both corticosteroids were below the limit of detection (LOD 2.5 ng/ml).

Potentially effective dexamethasone and prednisolone concentrations were measured in the anterior chamber, but vitreal concentrations were negligible and systemic uptake was low. Therefore, treatment with only topically administered corticosteroids is deemed insufficient in horses in cases of posterior uveitis.

Fluid therapy after colic surgery

This study by Gessica Giusto and co-workers in Italy compared goal-directed fluid therapy (GDFT) and 'liberal' fluid regimens (LFRs) in horses undergoing small intestinal surgery.

Eighteen horses subjected to small intestinal surgery were matched according to the surgical lesion, type of anastomosis, length of resection and duration of clinical signs. Horses in the LFR group were administered intravenous (IV) fluids for at least 24 h. In the GDFT group, IV fluids were administered only when considered necessary based on clinical parameters. Post-operative reflux (POR), packed cell volume, total protein, heart rate, venous lactate level, complications and long-term survival rates were compared.

Three horses in the LFR and one in the GDFT group developed POR. Horses in the GDFT group had a shorter time interval to first oral water intake and shorter hospitalisation time. Post-operative complication rates and survival were not different between groups. Further studies are necessary to set guidelines for the evaluation of hydration status and to plan post-operative fluid administration; however, GDFT may be a valid alternative to liberal fluid therapy after colic surgery.

Hybrid jejuno-ileo-caecal anastomosis

In this case study, Marco Gandini and Gessica Giusto, based in Italy, performed a combination of end-to-end jejuno-ileal anastomosis and side-to-side incomplete ileocaecal bypass (hybrid jejuno-ileo-caecal anastomosis) following subtotal ileal resection.

Seven horses (3 geldings, 2 mares and 2 stallions) were examined because of acute colic caused by small intestinal obstruction involving the aborad portion of the jejunum and orad portion of the ileum. All horses underwent a routine colic examination on arrival and had a diagnosis of strangulating obstruction of the small intestine.

All horses underwent emergency exploratory laparotomy, in which the affected aborad portion of the jejunum and orad portion of the ileum were resected; in five horses, a hand-sewn end-to-end jejuno-ileal anastomosis was combined with a hand-sewn incomplete ileocaecal bypass to produce a hybrid jejuno-ileo-caecal anastomosis. In two horses, the hand-sewn end-to-end jejuno-ileal anastomosis was combined with a half-stapled, half-hand-sewn incomplete ileocaecal bypass. The procedures restored continuity of the small intestine with partial bypass of the ileocaecal valve. All horses survived to hospital discharge, and none developed colic or ileus during the post-operative period. Follow-up revealed that six horses were living and had no subsequent signs of colic (4–17 months after surgery), and one was subjected to euthanasia because of colic 17 months after surgery.

Results for these horses suggested the hybrid jejuno-ileo-caecal anastomosis could be considered as an option for the resolution of small intestinal strangulating lesions involving the orad portion of the ileum. Studies are needed to assess short- and long-term effects of the procedure in horses.

Gastrointestinal treatments

This study by Rebecca Bishop and co-workers in the USA aimed to establish the efficacy of sucralfate or omeprazole used prophylactically in horses exposed to a combined feed-fast and nonsteroidal anti-inflammatory drug (NSAID) administration and equine gastric ulcer syndrome (EGUS) induction protocol.

Horses, with equine glandular gastric disease (EGGD) and equine squamous gastric disease (ESGD) scores $\leq$2 on initial endoscopy (n = 14), received either omeprazole (1 mg/kg per os q. 24 h) or sucralfate (20 mg/kg per os q. 8 h) while undergoing the feed-fast/NSAID protocol (alternating 24-h periods of feed and fasted for 7 days, and 5 days of 1.1 mg/kg flunixin meglumine IV q. 12 h), were allowed an 8-week washout period and then administered the alternate treatment. Serial gastroscopy (Days 2, 4 and 7), ultrasound and haematology documented treatment effects.

ESGD and EGGD scores increased over time under both treatments. There was a significant effect of treatment on EGGD scores, with post-treatment EGGD scores higher for horses receiving sucralfate (median 3; interquartile range 2.25,3) than omeprazole (1; 1,1). The effect of treatment on ESGD scores just achieved significance, with post-treatment ESGD scores higher for sucralfate (4; 3,4) than omeprazole (2;

2,3). In this study, omeprazole was superior to sucralfate for mitigating gastric lesion severity in healthy horses exposed to a feed-fast/NSAID model.

Seasonal effects on enteric pathogens

In this study, Jaclyn Willette and co-workers investigated the effects of season and geographic location on the detection of nucleic acids of potential enteric pathogens (PEPs) or their toxins (PEP-Ts) in faeces of horses ≥6 months old in the United States.

Results of 3343 equine diarrhoea PCR panels submitted to IDEXX Laboratories for horses ≥6 months old were reviewed. Submission months were grouped into four seasons, and states were grouped into four geographic regions. Logistic regression was performed to assess effects of season and region on detection rates of PEPs and PEP-Ts. Agresti-Coull CIs were determined.

The detection rate of *Salmonella enterica* was higher in the South in summer compared to all in other regions and was also higher in the South in fall than in the Midwest and Northeast. The *Neorickettsia risticii* detection rate was lower during summer in the West and higher in fall in the Midwest. The detection of *Cryptosporidium* spp. was lower during spring, summer and winter in the West. Differences were not identified for detection rates of *Clostridioides difficile*, *Clostridium perfringens*, *Lawsonia intracellularis*, *Rhodococcus equi*, equine rotavirus and equine coronavirus. The data from this study support seasonal and regional differences in detection rates of *S. enterica*, *N. risticii* and *Cryptosporidium* spp. in horses ≥6 months old in the United States.

Parasagittal groove changes in Thoroughbreds

This study by Georgina Johnston and co-workers in Australia investigated imaging and gross parasagittal groove (PSG) findings in racing Thoroughbreds and the comparative use of different imaging modalities to detect PSG changes.

Cadaver limbs were collected from 20 deceased racing/training Thoroughbreds. All fetlocks were examined using radiography, low-field magnetic resonance imaging (MRI), computed tomography (CT), contrast arthrography and gross pathology.

Horses with fetlock fracture were more likely to have lateromedial PSG sclerosis asymmetry and/or lateral PSG lysis. PSG lysis was not readily detected using MRI. PSG subchondral bone defects were difficult to differentiate from cartilage defects on MRI and were not associated with fractures. The clinical relevance of PSG STIR hyperintensity remains unclear. Overall, radiography was poor for detecting PSG changes.

Some PSG changes in Thoroughbred racehorses are common; however, certain findings are more prevalent in horses with fractures, possibly indicating microdamage accumulation. Bilateral advanced imaging is recommended in racehorses with suspected fetlock pathology.

Plantar fasciotomy and neurectomy

This study by Alexandra Scharf and co-workers in the USA aimed to determine the short-term effect of plantar fasciotomy and neurectomy (PFN) of the deep branch of the lateral plantar nerve on the proximal suspensory ligament (PSL) and cross-sectional area (CSA) in 21 horses with hindlimb proximal suspensory desmopathy (PSD).

Records of horses with chronic PSD treated by PFN were included if a preoperative, and at least one post-operative, ultrasonographic examination was available. One masked observer measured the ultrasonographic cross-sectional area (CSA) of the PSL. Intraobserver reliability was determined by repeatedly measuring a subset of 127 ultrasonographic images. Two masked observers measured the CSA of the PSL (PSL-CSA) on preoperative proton density (PD)-weighted transverse high-field magnetic resonance images of 19 horses. Agreements for PSL-CSA between preoperative ultrasonographic and MRI measures and between the two MRI observers were assessed. Follow-up considered the horses' ability to return to exercise and their owners' satisfaction.

The reliability of the ultrasonographic measurement of the PSL-CSA was excellent. Agreement between ultrasonographic assessment and MRI assessment of PSL-CSA was good. No difference was detected between preoperative and post-operative PSL-CSAs. At a median of 12 months (4–33 months), 16/20 owners reported the horse was 'better' and 15/20 functioned at or above preoperative levels.

Ultrasonographic measurement of the PSL-CSA was reproducible and in good agreement with MRI measurement. The PSL-CSA was not influenced by PFN and cannot be used to guide return to function.

S. WRIGHT
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Case Report

Successful cardiopulmonary resuscitation in an adult horse following cardiovascular collapse on recovery from general anaesthesia in the Trendelenburg position

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Keywords: horse; cardiopulmonary; resuscitation; Trendelenburg; arrest

Summary

An 11-year-old Thoroughbred mare was admitted to Lisadell Equine Hospital for surgical repair of a chronic, 10 cm long ventral laceration of the cervix. The mare was not known to have any underlying health issues and was assigned an ASA status of 1.

Premedication was performed with acepromazine, xylazine and butorphanol. General anaesthesia was induced with ketamine and diazepam and the mare was positioned in dorsal recumbency. Anaesthesia was maintained with isoflurane in oxygen. The mare was mechanically ventilated.

After routine aseptic preparation, the mare was transitioned to Trendelenburg position for the surgical procedure. A variable rate infusion of dobutamine was administered and MAP maintained between 72–75 mmHg for the majority of the anaesthetic duration. Following completion of the surgical procedure, the mare was transitioned from Trendelenburg back to dorsal recumbency. The mare was disconnected from the breathing circuit and the endotracheal tube left in place; she was moved to the recovery box and placed in right lateral recumbency. One minute 10 s after positioning in the recovery box, it was noted that the mare was apnoeic. Clinical examination revealed mydriatic pupils, absent corneal and palpebral reflexes, and absent peripheral pulses. Cardiac auscultation confirmed asystole 3 min 55 s after the mare was placed in the recovery box.

Intermittent positive pressure ventilation (IPPV) was commenced immediately at 9–10 breaths/min with tidal volume of 5 L. Simultaneously, thoracic compressions were started using the operator's bodyweight to generate force through dropping of the knee onto the horse's thorax at a rate of 30 compressions per minute. Monitoring (ECG, RR, SpO_2 and $EtCO_2$) was rapidly re-established and asystole was confirmed on ECG <2 min following diagnosis of asystole by auscultation. Intravenous adrenaline (0.002 mg/kg) was administered 2 min 40 s after initial detection of asystole with a following dose of intratracheal adrenaline (0.01 mg/kg) 1 min 30 s later. Thoracic compressions were continued. Five minutes 50 s following initiation of CPR, electrical activity was detected on the ECG; weak, rhythmic beats were audible on auscultation and thoracic compressions were then discontinued. There was a weak peripheral pulse palpable. An intravenous bolus of 5 L isotonic solution was administered, and a dobutamine constant rate infusion (0.002 mg/kg/min) started once a heartbeat had been detected, to increase myocardial contractility. At this point, the mare was bradycardic (24 beats/min) with a sinus rhythm. Despite return of spontaneous circulation (ROSC), and $EtCO_2$ ranging from 30 to 40 mmHg during IPPV, the mare did not start to breathe spontaneously, and pupils remained centrally fixed and mydriatic. Dexamethasone was administered (0.09 mg/kg, i.v. bwt) in a single dose. Corneal reflexes slowly reappeared within 10–15 min after ROSC and the heart rate gradually increased to 28 beats/min. The exact time when spontaneous breathing resumed was not recorded; it followed the return of corneal reflexes and a reduction in IPPV rate to 4–6 breaths/min. On return of spontaneous respiration, IPPV was ceased. Approximately 50 min after ROSC, the mare had mild nystagmus and showed signs of movement. Dobutamine and IV fluid supplementation were discontinued. After approximately 80 min from ROSC, the mare positioned herself in sternal recumbency. Following 20 min and three failed attempts at standing, a stable stance was achieved.

The following morning the mare was bright, alert and responsive with normal vital parameters and a good appetite. The mare is currently clinically well with no ill effects noted 6 months after discharge from the hospital. The mare has been covered, but has not conceived.

Key points

- The aetiopathogenesis of cardiovascular collapse in anaesthetised equines is complex with many contributing factors. Proper monitoring during general anaesthesia is of utmost importance to detect and prevent cardiopulmonary arrest.
- Ensuring airway patency, adequate ventilation and circulatory support is necessary for successful CPR. Thoracic compressions are effective in maintaining circulation even in adult Thoroughbreds at an optimum rate of 80 compressions per minute (CPM), although a rate of 30 CPM was successful in this case.
- Chronotropic and inotropic drugs are valuable in CPR particularly adrenaline, although the literature recommends varying doses for horses, with no current gold standard.


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Clinical Commentary

REassessment Campaign On VEterinary Resuscitation: Has the time come for horses?

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Keywords: horse; cardiopulmonary arrest; CPR; international guidelines; RECOVER

It is disconcerting that equine anaesthetic-related fatalities for elective procedures are nearly 10- to 20-fold more frequent than their small animal counterparts, and between 100- and 1000-fold more likely than human anaesthesia-associated fatalities (Brodbelt *et al*. 2008; Li *et al*. 2009; Dugdale *et al*. 2016; Laurenza *et al*. 2019). Approximately one-third of these fatalities come from cardiac arrest or post-operative cardiovascular collapse. The lack of a solid understanding of anaesthetic-related outcomes, the unlikely return of spontaneous circulation (ROSC) and the dearth of comprehensive, evidence-based recommendations nourish the dread of perioperative cardiopulmonary arrest (CPA) among equine practitioners (Bidwell *et al*. 2007; Muir and Hubbell 2009).

Given that perioperative CPA in horses is an uncommon but not extraordinarily rare event, practitioners should be prepared to face this emergency. What stands out from the current literature is the substantial variabilities in equine cardiopulmonary resuscitation (CPR) techniques, that often blend practices echoing the Veterinary Emergency and Critical Care Society REassessment Campaign On VEterinary Resuscitation (RECOVER) guidelines (Fletcher *et al*. 2012) with empirical interventions (Conde Ruiz and Junot 2018; Duggan *et al*. 2022).

The RECOVER guidelines, published in the summer of 2012, aimed to systematically review the body of literature on CPR from a veterinary standpoint and to generate practical consensus guidelines to be used in dogs and cats. Before RECOVER, there were no consensus guidelines available in veterinary medicine. While the small animal guidelines have been applied to neonatal foals (Jokisalo and Corley 2014; Hallowell 2016; Hopster *et al*. 2016), direct transposition to adult horses can be challenging. Nevertheless, they represent an excellent starting point, at least for some general concepts.

It is futile to try to ascertain the exact cause of the CPA in the report published by Duggan *et al*. (2022) in this issue. The negligible monitoring during the last 15 min of anaesthesia makes it difficult to determine the precise moment at which the CPA happened. The authors recognised the arrest when the animal was in the recovery stall. Between 30% and 66% of canine and feline perioperative deaths happen in recovery (Brodbelt *et al*. 2008). Instead, in horses, anaesthesia-related cardiovascular collapse was historically reported to occur early in the anaesthetic period (Johnston *et al*. 2002; Dugdale *et al*. 2016; Dugdale and Taylor 2016) and attributed to the adverse cardiovascular and arrhythmogenic effects of halothane (Johnston *et al*. 2002; Bidwell *et al*. 2007). But, adverse intraoperative cardiac events are rare since halogenated ether compounds have been introduced in equine anaesthesia (Johnston *et al*. 2004; Laurenza *et al*. 2019). Both in human and small animal medicine, there is excellent evidence that early recognition of CPA is critical for successful ROSC (White *et al*. 2010; Fletcher *et al*. 2012). As Conde Ruiz and Junot (2018) emphasised, the inevitable lack of accurate monitoring of horses during transportation from the operating room to the recovery stall and during recovery can delay post-operative CPA detection.

When CPA happens in the post-operative period, as in Duggan *et al*. (2022), all the equipment is available, and the horse is likely intubated. However, how many equine practices keep essential emergency drugs readily available? (and no, that one dose of lidocaine or N-butylscopolammonium bromide withdrawn ready for use do not count). How many practices expose cognitive aids, such as checklists, algorithm charts and dosing charts in the operating room or the recovery stall? When was the last time you practised a simulated arrest in an adult horse? It has been demonstrated that adherence to CPR guidelines can only be accomplished with regular didactic and psychomotor skills training. We often disguise our deferment behind the belief that any effort for successful CPR in horses is vain (Muir and Hubbell 2009). The report published by Duggan *et al*. (2022) in this issue proves us wrong.

The goal of CPR is to restore blood flow and blood pressure. It is now recognised that chest compressions should be initiated as soon as possible after recognition of the arrest (Kleinman *et al*. 2015). 'Push hard, push fast', they say. Thoracic compressions delivered at a rate of 80/min to adult horses may reach a cardiac output (CO) as high as 25 mL/kg/min, about 50% of the CO of an anaesthetised horse (Hubbell *et al*. 1993), which may be sufficient to maintain vital organs' perfusion for a brief period. Faster rates may be warranted (Palmer 2007; Fletcher *et al*. 2012; Kleinman *et al*. 2015). As both Duggan *et al*. (2022) and Conde Ruiz and Junot (2018) highlighted, a single operator rapidly thrusting the knee onto the horse chest just behind its elbow is unlikely to reach the frequency of 80 compressions per minute or above, and frequencies closer to 30/min are more commonly obtained. From a feasibility perspective, chest compressions in adult horses may be a two-people job. There are two main theories behind the mechanism by which external compressions lead blood flow during CPR: the cardiac pump theory and the thoracic pump theory. In the thoracic pump mechanism, intrathoracic veins and cardiac chambers fill during chest relaxation following the pressure gradient created. During canine CPR, compressions over the widest portion of the chest are more likely to be effective than direct compressions over the heart in large canine breeds (Fletcher *et al*. 2012; Hopper *et al*. 2012). The same may be true for horses, and compressions over the widest portion of the thorax, instead of the area behind the elbow, may allow for easier, faster, and, in the end, more efficient compressions. In an older study, neither intermittent simultaneous ventilation nor alternating abdominal compression improved CO (Hubbell *et al*. 1993). The other fact to keep in mind is that performing CPR is physically and mentally tiring. The current guidelines recommend doing compressions in 2-min cycles in intubated patients, with several alternating rescuers (Fletcher *et al*. 2012). Personnel shortage may make this guideline challenging in equine anaesthesia practice.

In the report by Duggan *et al*. (2022), a large animal anaesthetic machine readily available allowed starting intermittent positive pressure ventilation (IPPV) with 100% oxygen at a rate of 10 breaths/min immediately after compressions. In horses that cannot be intubated, nasotracheal catheters, a temporary tracheostomy or high-frequency jet ventilation, are valid alternatives to maintain arterial oxygenation. While doxapram hydrochloride appeared in older text as a respiratory stimulant to control ventilation after the horse was haemodynamically stable (Muir and Hubbell 2009), its use is no longer advocated.

Efficacy of CPR and early recognition of ROSC in the face of constant minute ventilation are best assessed through capnography. While capnography was instituted in this case, end-tidal carbon dioxide was not recorded. The ECG can help identify shockable rhythms and guide Advanced Life Support (ALS), but it should not be used to assess haemodynamics or identify ROSC.

When it comes to ALS, there is contrasting and poorly referenced information in the equine literature. Because only a fraction of normal CO can be achieved even with effective compressions, the administration of low doses of epinephrine every 3–5 min early in the CPR is recommended to centralise circulation and to guarantee coronary and cerebral perfusion. The use of epinephrine in CPR is a double-edged sword. It is widely used for its α-1 adrenergic activity. In contrast, its β-adrenergic activity is less crucial and may be detrimental in early CPR because of increased myocardial oxygen demand, predisposing to arrhythmias (Fletcher *et al*. 2012). This effect is exacerbated following blockage of α-adrenergic receptors by a phenothiazine, like in the report by Duggan *et al*. (2022); the so-called 'epinephrine reversal' (Muir 2009). Duggan *et al*. (2022) reported injecting 0.002 mg/kg of epinephrine intravenously (i.v.) almost 3 min after detecting the CPA. They then followed with 0.01 mg/kg intratracheal dose injected shortly after the first dose. As the authors recognised, there is currently no evidence of intratracheal drug administration's effectiveness that should only be considered in animals in which intravenous access is not available. The epinephrine doses reported fall within the historic range suggested for horses (Muir and Hubbell 2009), but they are only 10–20% of the recommended doses for humans, small animals and foals (Fletcher *et al*. 2012; Kleinman *et al*. 2015; Hopster *et al*. 2016). Vasopressin (0.4–0.8 U/kg i.v.), a pure vasoconstrictor acting on V1 receptors, can be used as an alternative or in combination with epinephrine (Muir and Hubbell 2009; Fletcher *et al*. 2012). There is still mixed evidence on vasopressin's efficacy over epinephrine during CPR and none in the horse. Unlike epinephrine, vasopressin lacks inotropic and chronotropic effects that may worsen myocardial ischaemia. There is no evidence that atropine sulphate (or other antimuscarinics) improves ROSC, and it should, therefore, be used only if the CPA is associated with increased vagal tone. The use of dobutamine and other inotropes or vasopressors after ROSC helps patients with cardiovascular instability.

Doses of 2–4 mg/kg of dexamethasone i.v. were historically recommended for treating horses with shock and ischaemia (Muir and Hubbell 2009). However, there is lack of compelling evidence of neuroprotective effects of corticosteroids either in small animals or in human medicine (Paris *et al*. 1984; Fletcher *et al*. 2012), in the face of possible harmful effects in case of low organ perfusion.

Duggan *et al*. (2022) administered a bolus of 5 mL/kg of crystalloid solution immediately after ROSC and another 10 mL/kg bolus after the horse was back in the stall. Older guidelines recommended aggressive fluid therapy during equine resuscitation (Muir and Hubbell 2009), but they referred to CPA following acute hypovolaemia or severe dehydration. There is now compelling evidence that the routine use of large volumes of i.v. fluids during CPR or after ROSC in euvolaemic animals may increase central venous pressure and decrease coronary and cerebral perfusion pressure (Fletcher *et al*. 2012).

In conclusion, the RECOVER guidelines' publication highlighted the knowledge gap that surrounds equine CPR (Jokisalo and Corley 2014). We overlooked the development of a systemic evidence-based approach to equine CPR, thinking that whatever effort we invested was likely to be futile. The case reported by Duggan *et al*. (2022) in this issue demonstrates that resuscitation can be successful in adult horses. While there is contrasting evidence whether implementing RECOVER consensus guidelines improved CPR in hospitals with an already high ROSC's rate (Hoehne *et al*. 2019), their introduction homogenised success rates across small animal hospitals (Kawase *et al*. 2018). Therefore, we urge the development of updated evidence-based clinical guidelines for practising CPR in equine patients.

Author's declarations of interest

The author is an Associate Editor for Veterinary Anaesthesia and Analgesia.

Ethical animal research

Not applicable to this clinical commentary.

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EQUINE VETERINARY EDUCATION
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Case Report

Tracheal trauma and pneumonia secondary to endotracheal intubation in a horse undergoing general anaesthesia, computerised tomography and myelography

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Keywords: horse; orotracheal intubation; pneumonia; myelography; general anaesthesia; computerised tomography

Summary

A 10-year-old Warmblood mare was referred for investigation of poor performance and suspected intermittent hindlimb ataxia. A neurological examination identified mild hypermetria in all four limbs. No ataxia was observed, and orthopaedic examination was unremarkable. Due to concerns over reports of intermittent ataxia and the implications for rider safety, the owner elected for the mare to undergo head and cervical spine computed tomography and myelography under general anaesthesia. Computerised tomography showed bilateral enlargement of the articular process joints of C4-C5, C5-C6 and C6-C7, with mild osteophyte formation and sclerosis of the subchondral bone. Mild enlargement of the articular process joints of C2-C3 and C3-C4 was also noted. There was no evidence of spinal cord compression.

Approximately 24 h after general anaesthesia, a persistent cough was noted, whilst the vital parameters were unremarkable. Thoracic ultrasound identified an increased number of comet tails and mild consolidation in both cranioventral lung fields consistent with pneumonia. Upper airway endoscopy showed laryngitis with moderate to marked inflammation and erosions extending caudally into the trachea for approximately five cartilage rings. The lesions were symmetrical and localised at the 8 o'clock to 10 o'clock and the 3 o'clock to 5 o'clock positions.

The mare was diagnosed with laryngitis and moderative to severe erosive tracheitis with secondary pneumonia. Movement of the cuffed endotracheal tube was considered as the most likely cause of the tracheal damage due to the extension, location and symmetry of the lesions.

Treatment consisted of flunixin meglumine 1.1 mg/kg bwt intravenously every 24 h, doxycycline 10 mg/kg bwt orally every 12 h for 5 days and a single dose of dexamethasone 0.1 mg/kg bwt intravenously. The following day, flunixin meglumine was discontinued and phenylbutazone 2.2 mg/kg bwt orally every 12 h was started.

Three days later, upper airway endoscopy and thoracic ultrasonography showed a marked improvement of the laryngeal and tracheal inflammation with resolution of the previously identified consolidation in the cranioventral lung fields.

Key points

- Tracheal and laryngeal trauma is common after orotracheal intubation, and it may lead to pneumonia.
- Horses should be monitored closely for signs of tracheal and laryngeal trauma after general anaesthesia for myelography.
- Tracheal damage by the movement of the cuffed endotracheal tube could be avoided by disconnecting the horse from the anaesthetic machine and by deflating the cuff for hoisting or neck flexion and extension. During this time, total intravenous anaesthesia could be used to maintain general anaesthesia.

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Case Report

Thrombosis of the median artery and its branches in a gelding: Clinical appearance, diagnosis and surgical management

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Summary

This case report describes the clinical appearance, the diagnosis and surgical management of a thrombosis of the median artery and its branches in a gelding. The median artery is the distal continuation of the brachial artery, which provides the major blood supply in the forelimb. Thrombosis of this artery and its branches with consequent ischaemia in the distal extremity is rare and mostly accompanied by an acute onset of progressive severe lameness, sometimes accompanied by distress and colic symptoms.

A 4-year-old Danish Warmblood presented with acute severe progressive right front leg lameness, not reacting on painkillers. Initial clinical examination, including radiographs, revealed no clear findings, and a scintigraphic examination showed a decreased radiopharmaceutical uptake in the right front toe in comparison to the left limb. The following day, the temperature of the right front leg was significantly decreased, especially in the area distal to the carpus. No pulsation of the digital arteries could be detected. Doppler ultrasonography revealed that the right median and distal radial artery were completely occluded over a distance of 30 cm by an echogenic, intraluminal mass (**Fig 1**). Based on clinical findings, a presumptive diagnosis of peripheral progressive occlusive thrombosis of the median artery and its distal branches was made. Initially, an anticoagulant treatment was initiated, however, without clinical improvement. The ischaemia became even worse, requiring surgical intervention. A similar approach as for the Aorta-iliac thrombosis in the hindlimb, using a Fogarty® thrombectomy catheter for removal of the thrombi, was undertaken in the front limb, which has not been described previously. The median artery was localised as a hard round structure in the region of the midradius underneath the flexor carpi radialis muscle. The skin was incised dorsal to the muscle, and the median artery was mobilised by careful blunt dissection. No pulse was felt. The artery was incised, and with the use of a thrombectomy catheter, thrombi were removed. The gelding recovered initially, and the patient showed no lameness at walk. Unfortunately, restenosis occurred, and the horse became severely lame 6 days after surgery. Due to a poor prognosis for a second surgery, the gelding was euthanised.

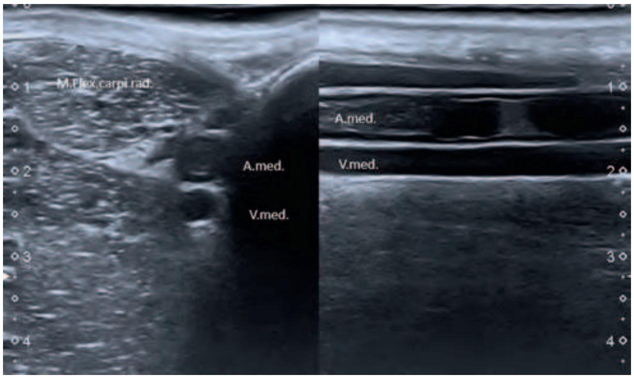

***Fig 1:** Transverse and longitudinal ultrasonographic view of the occluded median artery (A.med.) at the level of the midradius. V.med.: median vein.*

Key points

- Occlusion of the median artery is a sporadic event with impressive clinical signs and might not be directly diagnosed due to it being a rare occurrence.
- The value of Doppler ultrasound for the diagnosis of the presence of the thrombosis is emphasised, which can also help to delineate the extent of the thrombosis.
- Surgical treatment of a patient with acute thrombosis of the median artery and its branches using a thrombectomy catheter might be worthwhile.

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Case Report

First molecular detection of *Babesia gibsoni* in a horse

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Keywords: horse; 18s rRNA; P18; *Babesia gibsoni*; India; polymerase chain reaction

Summary

Equine babesiosis in India has always been a severe and life-threatening disease, attributed to infection with *Theileria equi* and *Babesia caballi*. These organisms are not host-specific as both *T. equi* and *B. caballi* are also reported in dogs. Likewise, *Babesia canis canis* and *Babesia canis rossi*, the common causative agents in canines, were also identified in horses. However, no molecular evidence of *Babesia gibsoni* has been reported in horses in India. This case report describes a 5-year-old Thoroughbred gelding residing in Bengaluru that showed signs of recurrent intermittent fever, inappetence, poor performance, anaemia and depression with abnormal haematological parameters and was suspected to have babesiosis. Generally, *T. equi* and *B. caballi* infect horses, but a study reported the identification of *Babesia canis canis* and *Babesia canis rossi* in horses, suggesting that piroplasms are not host-specific. Therefore, *B. canis canis*, *B. gibsoni*, *B. canis vogeli*, *T. equi*, *B. caballi* and *Anaplasma phagocytophilum* were included in the study. Our study reported a rare case of babesiosis due to *B. gibsoni*. We did not detect *B. canis canis*, *B. canis vogeli*, *T. equi*, *B. caballi* and *A. phagocytophilum*. The unusual result was confirmed by DNA sequencing. A routine complete blood count (CBC) and biochemical profile were performed and were non-responsive to therapeutic interventions. The total leukocyte count was high with thrombocytopenia. The blood smear examination revealed microcytic hypochromic RBCs. The chemistry profile showed elevated blood lactate level and decreased A/G ratio. The blood sample was submitted for screening for equine haemoprotozoans using polymerase chain reaction. The sample was positive for *B. gibsoni* and was confirmed by sequencing. BLAST search against GenBank revealed the highest similarity (95.17%, Accession No. MN385430.1) with *B. gibsoni* 18s rRNA partial sequence. However, this is the first study that provides evidence concerning the occurrence of *B. gibsoni* among equines in Bengaluru, India (**Fig 1**).

Key points

- In India, equine babesiosis has long been a serious and sometimes fatal illness. The horse with aberrant haematological data, was suspected of having babesiosis.
- PCR and sequencing were used to screen *B. canis canis*, *B. gibsoni*, *B. canis vogeli*, *T. equi*, *B. caballi* and *A. phagocytophilum*.
- This is the first research to offer evidence for the presence of *B. gibsoni* amid the horses in Bengaluru, India.

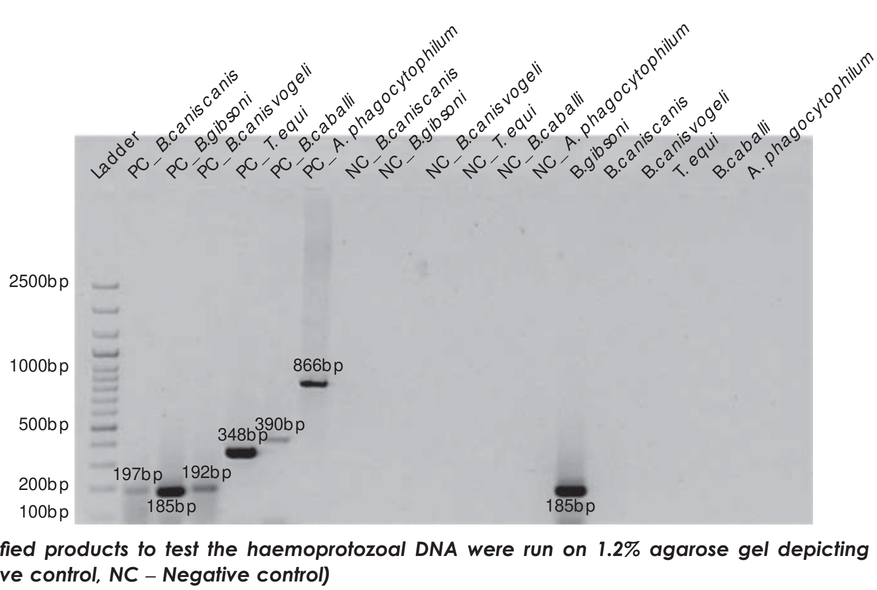

***Fig 1:** The PCR amplified products to test the haemoprotozoal DNA were run on 1.2% agarose gel depicting the sample positive for **B. gibsoni**. (PC – Positive control, NC – Negative control)*

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Case Report

Acute hindlimb paresis caused by extension of a peripheral nerve sheath tumour into the spinal canal of a horse

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Keywords: horse; neoplasia; ataxia; complication; surgery

Summary

A 10-year-old Quarter Horse gelding presented for a large, slowly growing mass of 8-month duration. A firm, nonpainful, immobile subcutaneous mass of approximately 29 × 27 × 13 cm was present dorsally on the right side of the back between the 10th and 16th vertebrae (**Fig 1**). Aside from a marked hyperfibrinogenaemia (9 g/L, normal range:1–4 g/L), physical examination and laboratory parameters were within normal limits.

Histological examination after a biopsy sample of the mass was taken led to the diagnosis of a low-grade soft tissue sarcoma. The mass was surgically removed under general anaesthesia, and the horse recovered uneventfully and returned to normal riding activity half a year later with no signs of external regrowth. Two years after surgery, the horse developed within a 2-week period progressive signs of hindlimb weakness, ataxia and adopting a dog-sitting stance. A neurological examination revealed an asymmetrical weakness and ataxia of the hindlimbs with the right being a grade 3/5 and the left 2/5, as well as hypalgesia and cutaneous trunci reflex deficits caudal to the 12th rib on the right side. Due to the apparent progressive nature of the neurological deficits and consequent poor prognosis, humane euthanasia was recommended. The post-mortem examination revealed that an approximately 3.5 × 2-cm mass was protruding from the right side into the spinal canal at the level of T12, causing compression of the cord (**Fig 2**). A smaller slightly protruding mass of similar gross morphology extended into the spinal canal at the level of T11 (**Fig 2**). A direct connection between the tumours and the previous surgical site was not identified; however, the mass extended from the tissues surrounding the vertebrae through the intervertebral foramen into the spinal canal. No involvement of peripheral nerves or gross metastasis were present. Polymerase chain reaction for detection of bovine papillomavirus type 1 and type 2 was negative and immunohistochemistry revealed a staining pattern consistent with a diagnosis of a peripheral nerve sheath tumour. Given the similar histological appearance of tissues between the original mass and that causing the later neurological signs, regrowth of the initial tumour can be considered most likely in this case.

Fig 1: Initial presentation of a slowly growing mass on the right side of the vertebral column at the level of the 10th – 16th thoracic vertebrae.

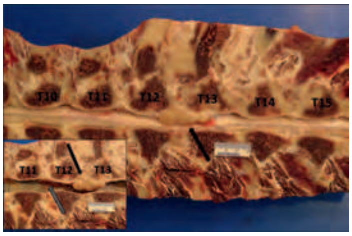

***Fig 2:** Mass invading the spinal canal at the level of the 12th thoracic (T12) vertebrae at post-mortem examination. Larger mass protruding into the spinal canal from the intervertebral space between T12 and T13 (black arrow) and the close-up view after removal of the spinal cord shows the smaller mass (grey arrow) extending into the spinal canal at the level of the 11th thoracic vertebrae (T11). T10–T15: Indicates the bodies of the thoracic vertebrae 10 to 15.*

Key points

- Incomplete tumour resection, local recurrence and extension of a peripheral nerve sheath tumour into the central nervous system can occur even years after initial tumour removal.
- In cases where the tumour location is closely associated with neural structures, further tumour differentiation via immunohistochemistry may prove beneficial to anticipate potential long term complications like spinal cord compression and associated neurological deficits.
- Early removal of a tumour located close to the spinal cord, as well the use of adjunctive therapies, should be considered to minimise the chances of regrowth and its potential complications.

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Case Report

Diffuse osteomyelitis of the fourth metacarpal bone in a horse caused by *Clostridium perfringens*

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Keywords: horse; osteomyelitis; splint bone; clostridial; computed tomography; metacarpal

Summary

A 2-year-old Warmblood mare presented for further investigation of left forelimb swelling and lameness after sustaining a small wound 18 days previously. The referring veterinarian had surgically explored the region anticipating an abscess or a sequestrum, neither of which were identified. On presentation, there was a painful, diffuse swelling of the left distal forelimb. No lameness was observed at walk. A 3-cm vertical skin wound was present on the lateral aspect of the left fore proximal metacarpus (Mc) at the site of surgical exploration. Visible and palpable effusion of the middle carpal joint was noted.

Centesis of the middle carpal joint yielded normal synovial fluid. A deep swab taken from the wound was negative for bacterial culture. Ultrasound and radiography demonstrated multifocal palisading periosteal new bone formation along McIV with the exception of a short segment of McIV at the level of the original wound, and diffuse soft tissue swelling. Computed tomography (CT) under general anaesthesia identified a Y-shaped cortical fracture of the lateral cortex of McIII and diffuse osteomyelitis of McIV Grade 4a (Cierny).

Following CT, the wound edges and subcutaneous pockets were debrided and lavaged. Debridement of infected cortical bone and reaming of the infected medulla, although indicated, were not undertaken due to the risk of destabilising the proximal McIV and breaching the carpometacarpal joint and potential synovial contamination. A sample of new periosteal bone from McIV was submitted for bacterial culture and direct Gram smear, both of which were negative for evidence of bacteria. The wound was partially closed and intravenous regional limb perfusion (IVRP) was carried out with amikacin (500 mg). Due to the fracture in McIII identified by CT, a full limb cast was placed for general anaesthetic recovery. The mare was administered phenylbutazone (2.2 mg/kg bwt q. 12 h) and oxytetracycline (7.5 mg i.v. q. 12 h) and was maintained in a Robert Jones bandage. IVRP (amikacin 500 mg) was repeated on alternate days. After 4 days, the mare was discharged on oral doxycycline (10 mg/kg bwt per os q. 12 h) and phenylbutazone (2.2 mg/kg bwt per os q. 12 h). There was no lameness evident at walk, and the wound was well-apposed with minimal discharge at this time.

Four days following hospital discharge, the mare represented due to the marked increase in lameness, pain and swelling at the surgical site. Purulent material discharged from the wound upon palpation. A sample was taken for bacterial culture, which yielded a heavy growth of *Clostridium perfringens*. Radiographs showed changes compatible with diffuse osteomyelitis affecting most of McIV and the McIII fracture.

All sutures were removed to facilitate drainage, and the wound was lavaged. Once culture results identified *Clostridium perfringens*, the horse was administered enrofloxacin (7.5 mg/kg per os q. 24 h) and metronidazole (15 mg/kg per os q. 8 h). Metronidazole-soaked gauze swabs were placed within the wound pocket and IVRP was carried out daily with ceftiofur (500 mg). The mare was discharged after a further 8 days on enrofloxacin, metronidazole and tapering courses of phenylbutazone and paracetamol.

Ten months following diagnosis some mild swelling of the proximolateral aspect of the metacarpus remained, however, there was no pain on palpation and the horse was sound at walk and trot. Sequential radiographs over this time demonstrated complete focal bone resorption of McIV in the region of McIV that did not demonstrate periosteal new bone formation. This area was subsequently ossified, and McIV underwent substantial remodelling (**Fig 1**).

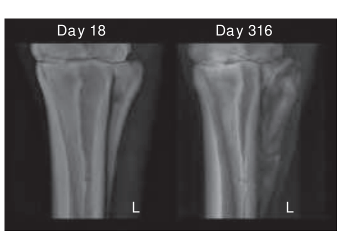

Fig 1: Dorsolateral-palmaromedial oblique radiographs of the proximal metacarpal region were obtained on Days 7 and 316 after the horse's initial injury. Day 7: There is marked soft tissue swelling affecting the lateral aspect of the limb but there are no abnormalities of the bone. Day 316: There is significant distortion of the size and shape of fourth metacarpal bone (McIV). There is partial bridging callus around a transverse radiolucent line extending through McIV 2 cm proximal to the nutrient foramen. A radiolucent area extends from the medulla to the palmaroproximolateral aspect of McIV.

Key points

- Computed tomography was superior to radiography and ultrasonography in the identification of osteomyelitis and unicortical Y-shaped fracture of McIII following a small wound.
- Aggressive medical and surgical debridement of infected bone is recommended for the treatment of diffuse osteomyelitis of long bones. Aggressive surgical debridement of infected bone was not possible in this case resulting in the requirement for protracted and aggressive medical treatment.
- Diffuse osteomyelitis, in this case, resulted in extensive bone remodelling that was still ongoing 10 months following original injury.
- *Clostridium perfringens* is an uncommon bacteria isolate in osteomyelitis in horses.


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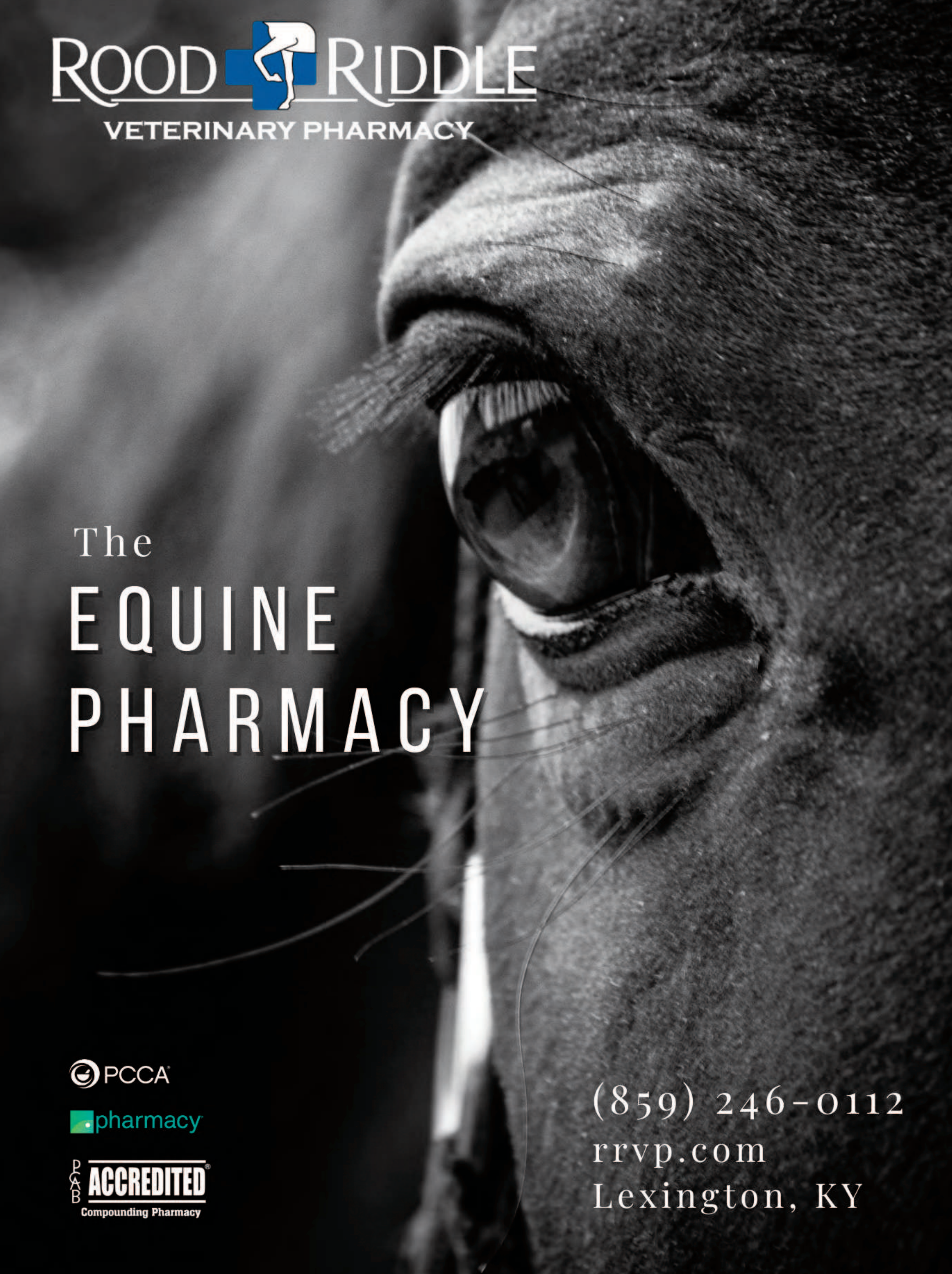
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Case Report

Cystic calculus in a mare due to a misplaced uterine glass marble

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Keywords: horse; bladder; cystic calculus; oestrus suppression; uterine marble

Summary

A 9-year-old Quarter Horse mare was referred with a 3-month history of continuous oestrus, polyuria and suspected pyometra. According to the owner, he had placed a glass marble in the mare's uterus 90 days earlier, and within the next 2 days, the horse began to urinate frequently. On presentation, the patient was bright and alert and showed no signs of pain or discomfort. Upon further examination, off-white sediment was observed on the lower hindlimbs and tail. Transrectal palpation and ultrasonographic examination of the reproductive tract revealed a large amount of sediment within the urine and the presence of a spherical structure consistent with a glass marble; however, it was not possible to distinguish the location of the suspected marble, and due to confirmation bias, the assumption was that it was in the uterus. A hysteroscopy was performed; the endometrium had a pale pink colour, and there was no gross visual evidence of a glass marble nor fluid either in the uterine horn or in the uterine body. After emptying the urinary bladder, an endoscopic examination demonstrated the presence of a spherical calculus with a spiculated surface (**Fig 1**).

The urethra was distended manually, and a specimen retrieval bag was used under endoscopic guidance for calculus removal. The calculus was identified as a spiculated type I urolith of 47 mm by 45 mm, and after the exterior layers were removed, the presence of a glass marble in its nucleus was noted (**Fig 2**).

Urinary bladder endoscopic re-examination 24 hours after the calculus removal showed a subtle decrease in the mucosal irritation. Telephone follow-up with the owner 1 month after the discharge reported that the mare had not shown any sign of discomfort while urinating nor sign of continuous oestrus.

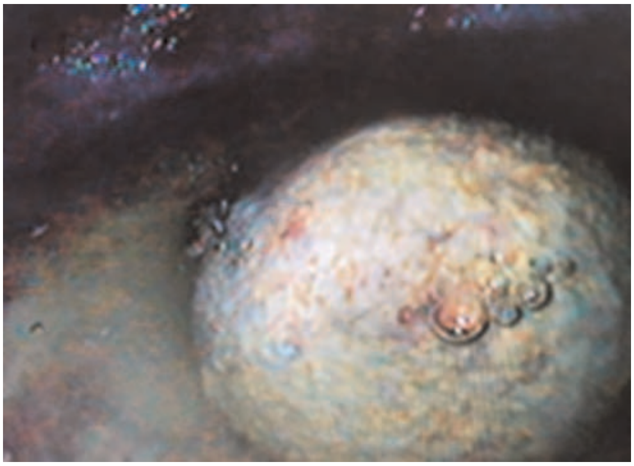

***Fig 1:** Spherical spiculated calculus resting on the bladder floor. The bladder walls present erosive lesions.*

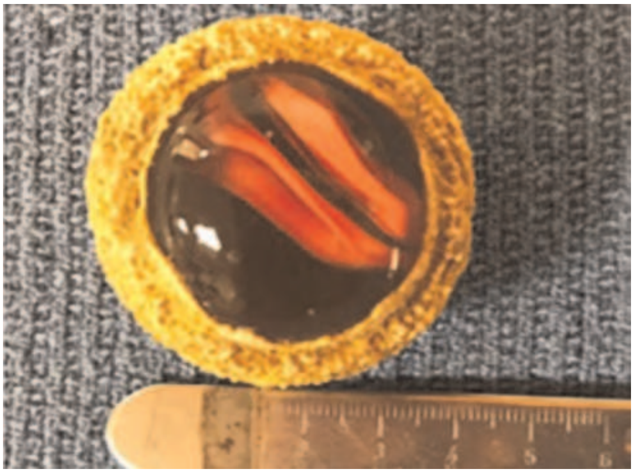

***Fig 2:** Cystic calculus with a 35-mm glass marble core.*

Key points

- Endoscopic examination is a helpful imaging technique in the evaluation of the reproductive and lower urinary tract and the diagnosis of cystic urolithiasis.
- Case examinations must be approached with an open mind, considering the possibility of less common or less likely differential diagnoses if test results are inconclusive.
- If there is a true correlation between a mare's oestrus cycle and behaviour or performance problems, the clinician must counsel the owner of the potential disadvantages or complications of each suppression method, allowing for informed decision-making.

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Original Article

Effect of head and tail rope-assisted recovery of horses after elective and emergency surgery under general anaesthesia

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Keywords: horse; anaesthesia; assisted recovery; head and tail rope; mortality

Summary

The recovery phase is a critical period during equine anaesthesia. In an attempt to reduce the risk of recovery, several recovery systems, including head and tail ropes, have been developed over time. However, the clinical safety and efficacy of these systems have not been compared to a nonassisted group in a larger study. The objective of this comparative, retrospective, nonrandomised single-centre study was to determine whether the risk of developing fatal and nonfatal complications after general anaesthesia is reduced in horses assisted with head and tail ropes during recovery compared with horses recovering unassisted. Included were all horses undergoing general anaesthesia at the Large Animal Hospital, University of Copenhagen, Denmark, from 2010 to 2019. Analysed data included age, body mass, American Society of Anesthesiologists grade of physical status (ASA score), type of surgery and anaesthetic duration. Complications were divided into *none*, *fatal* and *nonfatal*. Logistic regression was performed to analyse the risk and predictors of fatal and nonfatal complications using the built-in R function 'step'. Tukey's honest significance difference test was applied to determine significance, set at P<0.05, within the categorical variables of the reduced models. The study included 1252 horses: 662 recovered with assistance (group A) and 590 without (group NA). Overall recovery-associated mortality was 1.4%: 0.6% in group A and 2.2% in group NA. Both emergency abdominal surgery (P = 0.004) and duration of surgery (P = 0.0001) affected the risk of fatal complications negatively. Assisted recovery (P = 0.02) significantly reduced the risk of fatal complications after emergency abdominal surgery. The limitation of the study was a lack of randomisation and potentially a larger proportion of sedation among assisted horses. It was concluded that emergency abdominal surgery and duration of anaesthesia are significant risk factors for fatal complications during recovery. Head and tail rope-assisted recovery is a significant factor of reducing fatal complications during recovery after emergency abdominal surgery.

Introduction

General anaesthesia of horses is associated with a relatively high mortality rate, and generally, mortality rates around 0.9% have been reported in healthy horses undergoing elective procedures (Young and Taylor 1993; Johnston *et al*. 1995; Johnston *et al*. 2002; Dugdale *et al*. 2016a; Laurenza *et al*. 2020). Much higher mortality rates have been reported in horses undergoing emergency procedures, especially emergency abdominal surgeries with mortality rates as high as 10.4% (Johnston *et al*. 2002). However, the reported equine perioperative mortality rate varies greatly, depending on the study design and the number of post-operative days included (Johnston *et al*. 2002; Bidwell *et al*. 2007; Niimura Del Barrio *et al*. 2018).

A significant reason for the high reported mortality in horses might be the horse's size (body mass and conformation) combined with its inherent flight behaviour and incoordination in the immediate post-anaesthetic period. These factors may lead to premature attempts to stand, and if unsuccessful, over time this may increase the risk of injuries (Hubbell 2004).

A recent study reported the mortality associated with the recovery phase alone, to be 1.1% (Dugdale *et al*. 2016a). The majority (71.4%) of these deaths were related to severe orthopaedic trauma. Other studies have also reported a high proportion of anaesthesia-related fatalities to be caused by orthopaedic trauma (Bidwell *et al*. 2007, 38%). Furthermore, most studies have reported at least half of the anaesthesia-related mortality to be associated with the recovery phase (Young and Taylor 1993; Johnston *et al*. 2002; Bidwell *et al*. 2007; Thelin *et al*. 2015; Dugdale *et al*. 2016a).

Over time, various recovery systems have been described and developed in order to reduce the prevalence and severity of complications during recovery. Techniques include, but are not limited to, manual assistance of the horse, tilt table recovery (Elmas *et al*. 2007), hydropool recovery (Tidwell *et al*. 2002), pool-raft (Sullivan *et al*. 2002), sling recovery (Taylor *et al*. 2005) and head and tail rope assistance (Wilderjans 2008). The head and tail rope recovery system has been advocated as a simple system that is easy and safe to use for both horses and experienced staff (Wilderjans 2008).

Few studies have compared perioperative mortality rate with and without the use of head and tail rope, and it is still debated whether this system improves the recovery quality and reduces the mortality rate (Auer and Huber 2012; Rüegg *et al*. 2016; Arndt *et al*. 2020). At the Large Animal Hospital (LAH), University of Copenhagen, Denmark, all recoveries until 2014 were generally nonassisted with very few manually assisted cases (mainly foals). Since 2014, the head and tail rope technique has been applied for all anaesthetised horses except in cases where contraindications did not allow its application.

The aim of this study was to report the overall safety of head and tail rope-assisted recovery and to determine whether the risk of fatal and nonfatal complications after general anaesthesia is reduced in horses assisted during recovery compared with horses that were not assisted. In addition, other risk factors for recovery-associated complications were included and analysed.

Materials and methods

This study was conducted as a retrospective nonrandomised comparative study approved by the Local Ethical Committee of the Department of Veterinary Clinical Sciences, University of Copenhagen (approval #2019-008).

Inclusion criteria

Anaesthetic records of all horses undergoing general anaesthesia from January 2010 until January 2019 (n = 1491) at the LAH were included in the study, regardless of the surgical procedure. Horses that were euthanised or died during surgery were excluded. Furthermore, horses <1 year of age were excluded, since this age group is generally not subjected to head and tail rope recovery.

Study population

Data collected from the medical records included breed, age, gender (mare, stallion or gelding), data from preanaesthetic examination, anaesthetic protocol, anaesthetic and surgical duration, surgical procedure, length of the recovery period and the clinical status 24 h post-operatively.

Horses experiencing complications during recovery were identified and classified into three categories based on their perianaesthetic outcome: *no complications*, *nonfatal complications* and *fatal complications* (*death*, *including euthanasia*). For statistical comparison, fatal complications where horses were recumbent for an extended period of time, without being able to stand, or stay standing, and without any obvious neurologic deficits were grouped as 'myopathy-like fatalities'. Nonfatal complications included cornea ulceration, skin abrasions, facial paralysis and nonfatal myopathies. For each horse, two of the authors (A.S.K.N. and A.B.N.) retrospectively assigned an ASA score, based on the preanaesthetic examination including complete blood count (CBC), blood lactate, peritoneal fluid analysis in horses subjected to emergency abdominal surgery and other relevant information retrievable from the record (Auer and Stick 2012).

Anaesthesia monitoring

Heart rate, respiratory rate and blood pressure were monitored in all horses. Invasive blood pressure was monitored in the majority horses, although omitted in some horses due to short procedure and/or failure to establish access to an artery. Arterial blood gas analysis (Radiometer ABL 800 FLEX Q®)[1] was performed once during each anaesthetic period unless indicated otherwise. Electrocardiogram, end-tidal CO_2 and isoflurane, as well as pulse oximetry, were monitored continuously during all surgeries (Datex Ohmeda S/5®)[2]. Dobutamine 1–8 μg/kg/min (Dobutrex®)[3] was administered i.v. in horses with a mean arterial blood pressure (MAP) below 60–70 mmHg depending on the preference of the attending anaesthetist.

Premedication included acepromazine (Plegicil®)[4] 0.03 mg/kg bwt i.v., one or two alpha-2 adrenoceptor agonists detomidine (Domosedan®)[5] 0.01 mg/kg bwt i.v. or romifidine (Sedivet®)[6] 0.06 mg/kg bwt i.v. sometimes supplemented with xylazine (Rompun®)[7] 0.15–0.2 mg/kg bwt. All horses also were administered an opioid (butorphanol [Torbugesic®][5] 0.03 mg/kg bwt, morphine [Morfin DAK®][8] 0.1 mg/kg bwt or methadone [Comfortan®][9] 0.06 mg/kg bwt). For some horses, the premedication also included atropine (Atropin [magistrel])[10] 0.005 mg/kg bwt. All horses received a nonsteroidal anti-inflammatory drug (meloxicam [Metacam®][6] 0.5 mg/kg bwt or flunixin [Finadyne®])[11] 1.1 mg/kg bwt and antibiotics (benzylpenicillin sodium [Benzylpenicillin®])[12] 22.000 i.u./kg bwt combined with gentamicin (Genta-Equine®)[9] 6.6 mg/kg bwt in selected cases preoperatively. Anaesthesia was induced with zolazepam–tiletamine mixture (Zoletil®)[13] 1.4–1.8 mg/kg bwt or ketamine (Ketaminol®)[11] 2.2 mg/kg bwt in combination with diazepam (Diazepam DAK®)[8] 0.04 mg/kg bwt or midazolam (Midazolam®)[14] 0.06 mg/kg bwt. Anaesthesia was maintained using isoflurane vaporised in 85–90% oxygen on assisted ventilation (Smith Ventilator L.A. 95®[15] or Smith Ventilator LA-2100+®[16]) in a custom-made closed circle system. If required, local analgesia mepivacaine or supplementary systemic analgesia/anaesthesia (morphine, ketamine, lidocaine, [Lignovet®][17]) was administered at the attending surgeons' discretion.

Recovery procedure

Horses anaesthetised from January 2010 to September 2014 were recovered unassisted (group NA), while horses anaesthetised from October 2014 to January 2019 were recovered using a head and tail rope-assisted system (group A). Sedation prior to recovery was not administered routinely, but approximately one-third of the horses (mainly group A) received a low dose of an alpha-2 adrenoceptor agonist and/or an opioid administered i.v. immediately prior to recovery. The bladder of all horses was catheterised during anaesthesia to enable emptying prior to recovery. At the end of surgery, all horses were transferred to a 3.9 × 3.6-m, fully padded, recovery stall and positioned in lateral recumbency using a hoist. Nasopharyngeal tubes were placed bilaterally and infused with 85–90% oxygen at 10–15 L/min until the connection was lost due to head movement.

For horses in group A, a self-tightening knot was tied around the tail using an inelastic rope and connected to the long tail rope via a carabiner. All horses wore a designated halter with the head rope attached directly to the noseband via a carabiner. Two diagonally oppositely placed metal rings installed at 2.35 m above the floor were used to direct the head and tail ropes outside the recovery stall where these were managed by one or two individuals who adjusted tightening until the horse was standing. The ropes were released after the horse had been standing safely for 5–15 min (tail rope first). A remote-release mechanism is incorporated into the ropes' attachments to the head collar and tail knot to avoid the operators from going inside the recovery stall (**Supplementary item 1**). The recovery area was kept as quiet as possible with the lighting dimmed in order to avoid unnecessary disturbance and excitement of the horses during recovery. The recovery of horses in group A was scored using a descriptive scoring system with a score from 0 to 5, with '0' representing very poor and violent recovery or horse not standing after 2 h and '5' representing perfect recovery in first attempt (Young and Taylor 1993). Recovery was only scored systematically for group A, since it was introduced along with the assisted recovery procedure.

The two groups, A and NA, were compared in terms of their distributions of physical characteristic (body mass, age and gender). In addition, the two groups were compared in terms of the distributions of causes for the recorded complications. The categorical variables, that is gender and cause of complications, were compared by Fisher's exact test using the built-in R function *fisher.test*. The numerical variables, that is body mass and age, could not be assumed to be normally distributed and were therefore compared using a bootstrapping approach, employing the central limit theorem; for each of the two groups, the values of the numerical variables were resampled randomly with replacement 1000 times, and the mean values of each random resampling were calculated and stored. The 1000 sample means from the two groups were then compared by a nonpaired two-sided *t*-test using the built-in R function *t.test*. In all cases, the threshold for significance was set at P<0.05.

Statistical modelling

Logistic regression was performed to analyse the effect of various predictors on the risk of fatal and nonfatal complications during the recovery period. The following variables were included as potential predictors: assistance (yes or no); surgical procedure (elective, emergency abdominal or emergency nonabdominal); anaesthetic duration (min); body mass (kg); and ASA score (1, 2, 3+). The ASA score ranges from 1 to 5, but in our available data only 42 (3.3%) of the observed horses had ASA score of 4, and only one horse (0.08%) had an ASA score of 5. For this reason, ASA scores 3, 4 and 5 were combined into grade 3+.

The logit models for this study were made in R (R Core Team 2017) using the built-in *glm* function with the binomial family. Three separate logit functions were created for describing (1) the overall risk of death; (2) the risk of death after emergency abdominal surgery; and (3) the risk of nonfatal complications. For all three models, all five potential predictors were included as initial independent variables (except surgical procedure in model (2)). These initial models were then reduced using the built-in R function *step* with the direction variable set to 'both'. This function reduces the model to only include variables which contribute a positive predictive value to the model, measured in terms of the Akaike information criterion (AIC).

For reduced models which included categorical variables with more than two categories, Tukey's honest significance difference (HSD) test was applied to determine which specific categories yielded significantly different effects, compared with other specific categories. This was performed using the *glht* function from the *multcomp* package (Bretz *et al*. 2017).

For interpretation and illustrative purposes, the logit values predicted by the reduced models for a range of possible scenarios were converted to probability of event (death and/or complications, depending on the model), using equation 1:

$$\text{probability} = \frac{e^x}{1+e^x} \quad (1)$$

where x is the estimated logit value.

Furthermore, the proportions of fatal complications caused by limb fractures and myopathy, respectively, were compared for assisted versus nonassisted horses. This was performed using Fisher's exact test by calling the R function *fisher.test*. The same test was used to compare the overall incidence rates of the two types of complications in the two groups of horses. Significance was set at P<0.05.

Results

During the 8-year study period, 1491 horses underwent general anaesthesia (**Supplementary item 2**). Ninety-three horses were euthanised during surgery due to inoperable disease, four horses died due to cardiac arrest and 108 horses were excluded from the study because of their young age. This resulted in a total of 1286 that met the inclusion criteria. Of these, 34 horses were excluded from further analysis because of missing data. A total of 1252 horses were included in the statistical analyses, which consisted of 662 horses in group A and 590 horses in group NA. The two groups did not differ significantly with regard to body mass (P = 0.93), age (P = 0.95) and gender (Fisher's test P-value = 0.08).

Complications related to the head and tail rope system, including halter failure where it either fell off or broke and failure of the ropes, that is loosening of the knot when pulling, were reported in 39/677 horses (5.76%). None of these failures resulted in further complications.

Overall, 52 horses (4.1%) experienced recovery-associated complications, leading to death or euthanasia in 17 of these (1.4% of all horses). In group A, the mortality rate was 0.6% (4/662), and in group NA, 2.2% (13/590) (**Table 1**).

Causes of fatal complications

Of the 13 horses in group NA that developed fatal complications during the recovery period, three horses sustained a fracture, one horse developed non-weightbearing lameness of undiagnosed aetiology that could not be managed, one horse developed severe respiratory distress and eight horses developed severe myopathy-like signs. Of the eight horses with myopathy-like signs, five were confirmed as myopathy and three did not receive a final diagnosis. Of the four horses in group A that developed fatal complications during the recovery period, one horse developed vascular collapse, two horses sustained a fracture and one horse died from acute airway obstruction.

The incidence of recovery-associated fractures did not differ significantly between the two groups (NA: 3/590 vs. A: 2/662, P = 0.67).

The incidence of myopathy-associated death was significantly lower in group A (0/662) than in group NA (8/590) (P = 0.0024).

When group A horses were divided into procedural categories, the mortality rate was 0.0% (0/409) for elective procedure cases, 1.3% (2/149) for emergency abdominal surgery cases and 1.9% (2/104) for emergency nonabdominal surgery cases.

When group NA horses were divided into procedural categories, the mortality rate was 0.6% (2/348) for elective procedure cases, 7.9% (11/140) for emergency abdominal surgery cases and 0.0% (0/102) for emergency nonabdominal surgery cases.

TABLE 1: Descriptive statistics of the categorical variables, as they relate to the number of horses who had no complications, had fatal complication or had nonfatal complications during recovery after surgery

Categorical variable	Category	No complications	Death	Other complications
Assistance	Yes	641	4	17
	No	559	13	18
Surgical procedure	Elective procedure	743	3	12
	Emergency abdominal surgery	260	13	15
	Emergency nonabdominal surgery	197	1	8
ASA score	1	793	3	14
	2	205	4	9
	3+	202	10	12

TABLE 2: Parameter estimates for the reduced logistic regression model describing the overall risk of a fatal complication of a horse during recovery after surgery

Variable	Estimate (logit)	s.e.	P-value
Intercept	–8.295	0.984	$3.37 \cdot 10^{-17}$
Assistance			
Yes	0		
No	1.059	0.592	0.07
Surgical procedure			
Elective procedure	0		
Emergency abdominal surgery	1.913	0.662	0.004
Emergency nonabdominal surgery	0.003	1.164	0.998
Anaesthetic duration	0.017	0.004	0.0001

Overall risk of death

When compared to elective and nonemergency abdominal procedures, emergency abdominal surgery was related to a significantly higher risk of death during recovery (P = 0.004) (**Table 2**).

Using the Tukey HSD test, the types of surgical procedures and their relation to the risk of fatal complications during recovery were analysed. The estimates of the differences show that the risk is significantly higher during emergency abdominal procedure compared with elective procedure (P = 0.01). The risk does not differ significantly when comparing emergency nonabdominal procedure and elective procedure (P = 1.00) or emergency nonabdominal procedure and emergency abdominal procedure (P = 0.16).

Increased anaesthetic duration significantly increased the risk of fatal complications (P = 0.0001). The median anaesthetic duration was 105 min for horses with no complications, 170 min for horses which died/were euthanised during recovery and 130 min for horses with other nonfatal complications during recovery (**Fig 1**).

Risk of death after emergency abdominal surgery

After emergency abdominal surgery, group A had a significantly lower risk of fatal complications than group NA (P = 0.02). Body mass did not influence the risk of death significantly (P = 0.11). This factor was, however, found to be predictive in terms of the AIC value during the step-wise reduction in the model (**Table 3** and **Fig 2**).

Risk of nonfatal complications

The reduced logistic regression model describing the risk of nonfatal complications during recovery after surgery confirms that the risk is increased for horses undergoing emergency abdominal surgery (P = 0.04).

Furthermore, the risk of nonfatal complications is increased with longer anaesthetic duration in emergency abdominal surgery (**Fig 3**).

Discussion

This study reports an overall mortality rate of 1.4% during recovery after general anaesthesia. In group A, the overall mortality rate was 0.6%, and in group NA, 2.2%. A recent study (Niimura Del Barrio *et al*. 2018) using head and tail rope during recovery exclusively reported an overall mortality rate of 0.2% including both elective and emergency surgeries (including emergency abdominal surgery). Another study (Bidwell *et al*. 2007) reported an overall mortality rate of 0.12% also including both elective and emergency surgeries (including emergency abdominal surgery) and with all horses, except weanling and yearlings, recovered using head and tail rope assistance. These mortality rates are lower than the ones reported in our population of horses. Direct comparison between studies is, however, difficult due to potential differences in study design, populations and surgical procedures. In the study by Bidwell *et al*. (2007), only 6% of the 17,961 horses underwent emergency abdominal surgery. In the study by Niimura Del Barrio *et al*. (2018), the distribution of surgeries is not described, and although almost half of the complications were encountered in emergency abdominal surgery cases, the reported mean anaesthetic duration of 98 min might suggest that a large percentage of the surgeries were most likely elective. For both studies, the proportion of emergency abdominal surgeries is in stark contrast to the distribution in the present study where 23.0% underwent emergency abdominal surgery, 16.5% underwent other nonabdominal emergency surgical procedures and only 60.5% of the horses underwent an elective surgical procedure. The mortality rate after elective surgery in the present study was 0.0% in group A and 0.6% in group NA. Hence, the high proportion of both abdominal and nonabdominal emergency surgeries in the present study compared with the studies by Bidwell *et al*. (2007) and Niimura Del Barrio *et al*. (2018) can possibly explain the lower mortality rate in comparison with our study.

In the present study, the mortality rate after elective surgeries in both groups A and NA is lower compared with

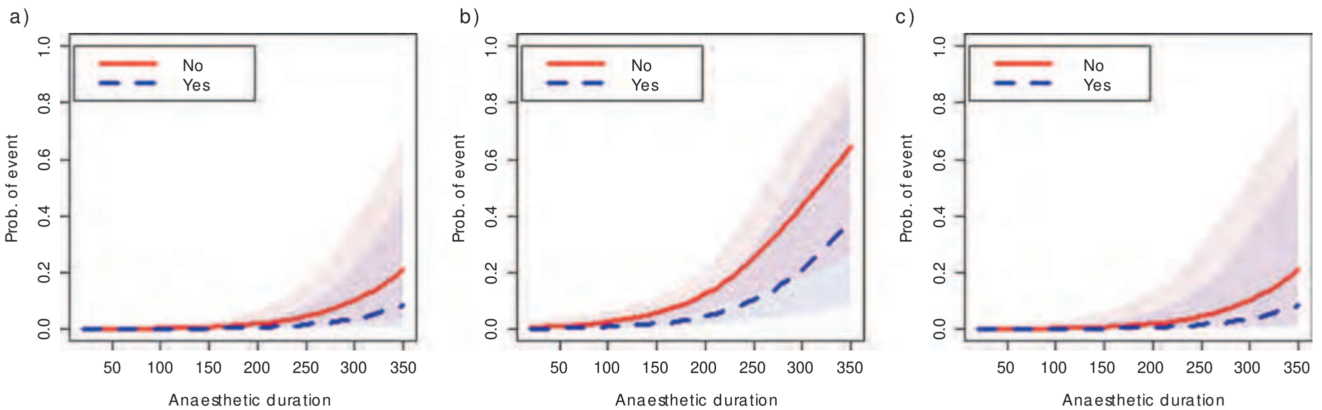

***Fig 1:** The estimated probability (lines) with 95% confidence intervals (CIs) (transparent shades) of the horse developing fatal complication during recovery after surgery, given whether or not the recovery was assisted, the surgical procedure (a: elective; b: emergency abdominal; c: emergency nonabdominal) and the anaesthetic duration, that is the amount of time the horse was anaesthetised. Red transparent shade: 95% CI for nonassisted horses; blue transparent shades: 95% CI for assisted horses; and purple shade: overlap between the two 95% CIs.*

TABLE 3: Parameter estimates for the reduced logistic regression model describing the risk of a fatal complication of a horse during recovery after emergency abdominal surgery

Variable	Estimate (logit)	s.e.	P-value
(Intercept)	−4.54	1.42	0.001
Assistance			
No	0		
Yes	−1.77	0.78	0.02
Weight	0.004	0.0025	0.11

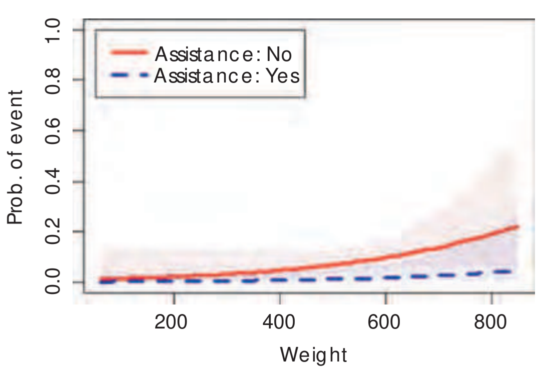

***Fig 2:** The estimated probability (lines) with 95% confidence intervals (CIs) (transparent shades) of a fatal complication during recovery after emergency abdominal surgery as a function of bodyweight, given whether or not the recovery was assisted. Red transparent shade: 95% CI for nonassisted horses; blue transparent shades: 95% CI for assisted horses; and purple shade: overlap between the two 95% CIs.*

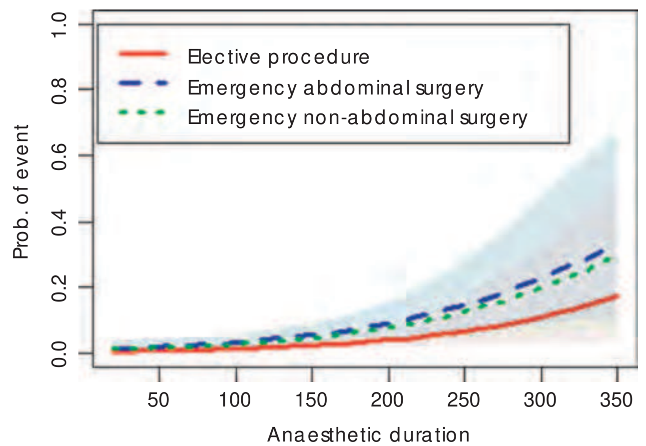

***Fig 3:** The estimated probability (lines) with 95% confidence intervals (CIs) (transparent shades) of any nonfatal complications occurring during recovery given the procedure type and the anaesthetic duration in minutes. Red transparent shade: 95% CI for elective procedure; blue transparent shade: 95% CI for emergency abdominal surgery; green shade: 95% CI for emergency nonabdominal surgery purple shade; and mixed colours: overlap between the three 95% CIs.*

earlier studies reporting a mortality rate between 0.9 and 1.4% of elective cases (Young and Taylor 1993; Johnston *et al*. 1995; Johnston *et al*. 2002; Dugdale *et al*. 2016a). Although not analysed, this difference may at least in part be attributed to improved routines in anaesthetic management and monitoring.

Another factor further complicating direct comparison of mortality rates between studies is the definition of the perioperative period. In different studies, this period varies between only including the recovery phase to including up to 7 days post-operatively or even until the horse was discharged from the hospital. In the present study, the main objective was to analyse the effect of head and tail rope assistance with a secondary objective of identifying other explanatory variables directly affecting the risk of complications in the recovery; hence, we decided to only look at the first 24 h post-operatively.

One of the most frequently reported causes of fatal complications during recovery is unrepairable limb fractures and joint luxations (Hubbell 2004; Rüegg *et al*. 2016; Dugdale *et al*. 2016a; Niimura Del Barrio *et al*. 2018). In the present study, fractures appeared in both group A and group NA and the head and tail rope assistance did not significantly prevent the occurrence of limb fractures. This is in accordance with some other studies that emphasise that the use of head and tail rope assistance does not prevent fractures (Tevik 1983; Auer and Huber 2012; Niimura Del Barrio *et al*. 2018; Arndt *et al*. 2020). However, others have reported very low proportions of severe orthopaedic trauma in studies including only head and tail rope-assisted horses (Wilderjans 2005; Niimura *et al*. 2014). Whether head and tail rope assistance does reduce severe orthopaedic trauma during recovery is therefore still not certain.

Body mass could not be shown to significantly influence the risk of developing a fatal complication during recovery. However, it was still an informative predictive parameter when modelling the risk after emergency abdominal surgery which is in accordance with other studies (Dugdale *et al*. 2016a). The modelling, however, further showed that assisted recovery almost eliminated the effect of body mass. To the authors' knowledge, this effect has not been documented before, although it makes biological/biomechanical sense that assistance might help heavier horses more than lighter horses.

For both the entire population and the subset of horses undergoing emergency abdominal surgery, no association was found between increased ASA score and the risk of fatal complications. This is in contrast to previous studies which have shown a significant increase in mortality with increasing ASA score (Johnston *et al*. 2004; Dugdale and Taylor 2016b). There might be several reasons for this difference; travel to the hospital is relatively short leading to fewer horses with high ASA score or that horses with high ASA scores have an anticipated poor prognosis why they are not operated or are euthanised on the table, hence not included in the study. Alternatively, the difference might simply reflect large interobserver variations reported in ASA grading (McMillan and Brearley 2013).

Although the proportion of myopathy-associated deaths did not differ between groups, the overall incidence was significantly lower in group A (0 horses) than in group NA (8 horses). In the current study, 'myopathy-associated deaths' were horses with normal mentation and with no signs of deficiencies of either the peripheral or the central nervous system, thereby making these horses unable to stand, either because of true postanaesthetic myopathy (PAM) or because of exhaustion myositis. Severe myopathy was mainly seen among horses after abdominal emergency surgery and often associated with exhaustion combined with poor circulation and long duration of surgery. Head and tail rope assistance seem to help otherwise ataxic and/or potentially exhausted horses to stand earlier and with fewer attempts than without assistance (Arndt *et al*. 2020). Although the number of attempts to stand and the overall recovery score were not analysed, it is the authors' impression that this was also true for the horses in the present study. In this way, assistance prevents horses from exhausting themselves during repetitive attempts to stand and thereby reduces the number of horses eventually euthanised because of the inability to stand whether this be due to exhaustion myopathy or weakness. Post-anaesthetic myopathy may be prevented by sufficient tissue perfusion and arterial oxygenation during the anaesthetic period (Grandy *et al*. 1987; Young and Taylor 1993; Duke *et al*. 2006). In the current study, arterial blood pressure was monitored continuously and horses with MAP below 60–70 mmHg were treated with dobutamine, crystalloids and or colloids based on the preferences of the attending surgeon. The practice of this did not change during the study period. To the authors' knowledge, it has not previously been reported whether assistance will influence the incidence of horses not able to stand or the development of post-operative myopathy.

Generally, the choice of predictors to analyse is always a matter of debate. Having too many parameters compared with the number of observed events increases the risk of overfitting, which would mean the model would not generalise to data which are not included in the study. For this reason, variables, which have previously been shown to be relevant and/or which makes most sense in our opinion (body mass, surgical procedure, duration of anaesthesia, disease status of the horse [ASA score]), were included in the data analysis (Young and Taylor 1993; Johnston *et al*. 2002; Dugdale and Taylor 2016b). However, there is always a risk of missing a relevant predictive parameter and this risk might only be overcome in much larger data sets or in a meta-analysis of several studies.

With regard to the nonfatal complications, only the anaesthetic duration and the type of surgical procedure contained predictive information; longer anaesthetic durations correspond to higher risks of complications, and this effect is consistently higher for all emergency procedures compared with elective surgery. Several previous studies have documented an increased risk of mortality with increasing duration of surgery and with specific types of procedures (Tevik 1983; Young and Taylor 1990; Johnston *et al*. 2002). This may correlate well with the increased risk of nonfatal complications documented in the present study. However, the lack of effect of head and tail rope assistance on the risk of nonfatal complications observed in the present study is in contrast to the study by Arndt *et al*. (2020), which found a significant reduction in these complications in the assisted horses.

In the present study, complications related to the assistance system were reported in 5.76% (39/677) of the horses, which compares well to previous studies which have reported failure of the system to be between 0.08% (Niimura Del Barrio *et al*. 2018) and 15% (Rüegg *et al*. 2016). However, in the present study, failure of the assistance system did not lead to any further complications which are in contrast to the study by Rüegg *et al*. (2016), where the high proportion of failures was considered to be responsible for the unexpectedly high number of dangerous and fatal complications encountered.

Limitations of the study

The main limitation of the present study is the lack of randomisation and the fact that almost all NA horses are from one period and A horses from another. In addition, although not always documented, the use of sedation during recovery was increased over time; that is, more group A horses than group NA horses may have received supplemental sedation during recovery which might introduce a bias to the results, since sedation during recovery has been shown to result in improved quality of the recovery which might theoretically also reduce the number of complications (Woodhouse *et al*. 2013).

Furthermore, and due to the retrospective nature of the study, the number of attempts at standing and the duration of recovery were not recorded for all horses and were therefore not included in the analysis.

Conclusion

The application of head and tail rope significantly reduces the risk of fatal complications during recovery after emergency abdominal surgery. Specifically, the incidence of horses not gaining a standing position after surgery (myopathy related complications) is significantly lower in assisted versus nonassisted recoveries, overall making an argument for the use of assisted recovery, particularly after emergency abdominal surgery.

Furthermore, increased body mass of the horse was found to be of positive predictive value in relation to the risk of fatal complications, but this risk appears to be negated when the horse is assisted. Assisted recovery was not found to add any positive predictive value in relation to the risk of nonfatal complications.

Authors' declaration of interests

No conflicts of interest have been declared.

Ethical animal research

This study was approved by the Local Ethical Committee of the Department of Veterinary Clinical Sciences, University of Copenhagen (approval #2019-008).

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Authorship

A. S. K. Nicolaisen contributed to study design, data collection, initial data analysis and preparation of the manuscript. A. B. Nygaard contributed to study design, data collection and initial data analysis. D. B. Jensen conducted the statistical analysis and graphic presentation of the results and contributed to preparation of the manuscript. M. T. Christophersen contributed to the study design and manuscript preparation. C. Lindegaard supervised the study, and contributed to study design, data analysis and manuscript preparation. All authors have reviewed and approved the final version of the manuscript.

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Supporting information

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

Supplementary item 1. The remote release mechanism.

Supplementary item 2. Demographics of the included horses divided into the two groups; assisted and Non-assisted recovery.

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Hypothesis Article

Rethinking equine anaesthetic risk: Development of a novel Combined Horse Anaesthetic Risk Identification and Optimisation tool (CHARIOT)

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Summary

The most widely used method of assessing the physical status of humans presented for anaesthesia is the American Society of Anaesthesiologists Physical Status Classification System (ASA-PS). The ASA-PS has been applied to animals including horses, but its use is problematic. The authors virtually convened a group of internationally recognised equine veterinary anaesthesiologists with the goal of developing a risk assessment tool for the evaluation of healthy and diseased horses presented for anaesthesia. With this survey and analysis, the authors aim to develop a simple rubric system to assess equine anaesthetic risk that augments the ASA-PS system. The goal is to identify both diseased and healthy horses at increased anaesthetic risk prior to induction of anaesthesia so that measures might be implemented to potentially reduce morbidity and mortality.

Introduction

Anaesthesia of the horse is more perilous than anaesthesia for any other common domestic species. Most of the reports on anaesthesia in horses report mortality rates of approximately 1%, whereas reports on humans, dogs and cats indicate rates of 0.02, 0.05 and 0.11%, respectively (Brodbelt et al., 2008; Hackett et al., 2015; Senior, 2015). Horses respond to anaesthesia in a qualitatively similar manner to other species but their temperament, size, weight and anatomy increase the likelihood and magnitude of a number of anaesthetic-associated pathophysiologic, neuromuscular and orthopaedic issues that are atypical for other domestic animals (Hubbell & Muir, 2015; Klineberg & Bagshaw, 1981). Horses exhibit a high level of sensitivity, stress and intense reactions to environmental stimuli (Houpt, 2006; Lansade et al., 2007; Lloyd et al., 2008; Mills et al., 2002). Once anaesthetised and recumbent horses experience greater increases in alveolar dead space, right-to-left intrapulmonary shunting, ventilation-perfusion mismatching and greater decreases in venous return and cardiac output than reported for other commonly anaesthetised species (Dobson et al., 1985; Hopster et al., 2015; Steffey & Howland, 1980). Pulmonary function is further affected by gravity, upper airway resistance, impairment of chest wall expansion, transdiaphragmatic pressure differences and the type and extent of ventilatory assistance applied (Day et al., 1995; Moens et al., 1995; Nyman et al., 1990; Youngblood et al., 2020). These changes and others begin immediately after induction to anaesthesia and recumbency, are progressive and often persist into the recovery period (Mason et al., 1987).

Evidence-based studies examining equine anaesthetic risk (EQAR) are limited and largely dependent on data collected and assembled by the Confidential Enquiry into Perioperative Equine Fatalities (CEPEF 1 and 2) that was conducted between 1991 and 1997. The results were reported in a series of publications extending from 1995 to 2004 (Johnston, 2005; Johnston et al., 1995, 2002, 2004). Data were collected on horses, whilst anaesthetised and for 7 days after anaesthesia and established a mortality rate of 0.9% in 'non-colic' horses anaesthetised for a variety of procedures. Factors associated with an increased risk included age (horses >14 years), the treatment of fractures, out-of-hours anaesthesia and surgery, the use of romifidine, and inhalant anaesthesia without pre-medication. Anaesthetic risk was reduced when acepromazine alone was used as a pre-anaesthetic drug or total intravenous anaesthesia (TIVA) was administered. Cardiac arrest or collapse accounted for 33% of deaths and fractures and myopathy during recovery accounted for 32%. Others have investigated the factors that influence EQAR and reported mortality rates ranging from 0.08 to 1.8% (Bidwell et al., 2007; Dugdale et al., 2016; Laurenza et al., 2020; Mee et al., 1998a, 1998b; Senior et al., 2007). Factors purported to be associated with lower fatality rates include early case referral, standardised anaesthetic protocols, shorter procedure times and appropriately trained veterinarians or veterinary technical assistants performing anaesthesia (Bidwell et al., 2007).

A single-centre retrospective analysis of perioperative mortality from 2016 reported a mortality rate of 0.9% for non-colic cases similar to the CEPEF study conducted some 20 years previously (Dugdale et al., 2016). A striking distinction from the CEPEF study was that all fatalities occurred during recovery or in the post-operative period. The reasons for the shift from intraoperative deaths to fatalities during recovery are not clear but might include changes in the drugs used for induction of anaesthesia and the inhalants used (sevoflurane or isoflurane instead of halothane), and improved monitoring of cardiopulmonary function and anaesthetic depth. Identified risk factors included increased body mass, anaesthetic duration, time of day when the anaesthesia occurred, increasing age, and diminished health status as assessed using the scale developed for humans by the American Society of Anesthesia (ASA). In their summary, the authors questioned whether ‘the flighty nature of the horse, which is often suggested to have the greatest influence on recovery quality, will limit future improvements’.

Past and more recent reports on EQAR could be used to infer that equine anaesthetic care has not improved in the last 25 years and that future improvements should not be anticipated (Bidwell et al., 2007; Dugdale et al., 2016; Johnston, 2005; Johnston et al., 1995, 2002, 2004; Laurenza et al., 2020; Mee et al., 1998a, 1998b; Senior et al., 2007). Alternatively, the increasing complexity of equine surgical and imaging procedures combined with longer periods of anaesthesia necessitate the need for improved equine peri-anaesthetic care. A large portion of that improvement requires advancing the knowledge of individuals who perform equine anaesthesia through research and education, utilisation of improved monitoring and ventilation techniques and the development of facilities and procedures that are focussed on improving outcomes (Hubbell, 2020). The development of methods for identifying factors associated with EQAR as part of the pre-anaesthetic evaluation could improve outcomes by facilitating discussions leading to the altering of protocols or procedures to reduce risk where possible.

The most widely used method of assessing the physical status of humans presented for anaesthesia is the ASA Physical Status Classification System (ASA-PS). The original ASA-PS was developed in 1941 to record patient preoperative health and described 6 classes of physical status providing examples of diseases in each class (Saklad, 1941). Although the system was not developed to assign anaesthetic risk per se, it is currently considered the standard method for doing so and for determining the fees associated with the anaesthetic procedure. The ASA-PS system has undergone a number of revisions since its origination. Most notably, examples of disease states for each category were included in the original version, then eliminated, and then were added, a step that appears to improve reliability (Hurwitz et al., 2017). Numerous publications in human medicine, however, have questioned the reliability of the ASA-PS system as a risk assessment tool. Most have discovered relatively wide variability in the assignment of status with no consistent pattern (Dripps et al., 1961; Mayhew et al., 2019; Owens et al., 1978; Sankar et al., 2014). A recent informative systematic review on the value of the use of the ASA-PS system in veterinary anaesthesia concluded that dogs, cats and rabbits with ASA-PS scores of 1 or 2 were less likely to die within 24 h (dogs) to 72 h (cats and rabbits) after anaesthesia than animals with ASA-PS scores 3 or greater (Portier & Ida, 2018). Equine anaesthetic risk was not addressed because the reviewed publications did not meet the study’s inclusion criteria; however, the authors commented that other studies have suggested that the ASA-PS classification system could be used to identify poor recovery quality from anaesthesia in horses (Dugdale et al., 2016; Niimura Del Barrio et al., 2018; Portier & Ida, 2018).

A major concern with utilising the ASA-PS system to identify horses with increased risk for anaesthetic-associated complications is that a number of the factors associated with morbidity and mortality in horses are not accounted for. The ASA-PS system can be used to identify and rank systemic illnesses that could affect anaesthesia, but the majority of horses presented for anaesthesia are generally healthy and are assigned ASA-PS scores of 1 (normal) or 2 (mild systemic disease). Given that the approximate 1% mortality rate reported across most studies represents anaesthesia of healthy horses, there is a room for improvement. We developed a simple rubric to assess EQAR that augments the ASA-PS system with the goal of identifying increased risk in healthy horses so that measures to reduce risk and ultimately reduce morbidity and mortality can be implemented.

Materials and methods

The first author (JAEH) initially convened a group of nine equine anaesthesiologists with the goal of developing a risk assessment tool for the evaluation of healthy and diseased horses presented for anaesthesia. The group recognised that the ASA-PS system was inadequate for healthy horses and was inconsistently applied, even among the members of the group. Furthermore, other factors in addition to disease status were identified that can affect anaesthetic risk in horses. Ultimately, a 2-part system was proposed and titled the Combined Horse Anaesthetic Risk Identification and Optimisation Tool (CHARIOT). The first part (ASA-PS-Equine) of CHARIOT was modelled after the 2014 version of the ASA-PS system (Hurwitz et al., 2017). Commonly recognised equine disease states that represented similar degrees of physical compromise to human diseases listed by the ASA-PS system were proposed with the goal of improving anaesthetic risk assessment and consistency of application (**Table 1**).

The second part of CHARIOT was based on a 10-part rubric that utilised the characteristics of individual horses that have been associated with or determined to influence morbidity and mortality in retrospective studies or other scientific reports (Bidwell et al., 2007; Dugdale et al., 2016; Johnston, 2005; Johnston et al., 1995, 2002, 2004; Laurenza et al., 2020; Mee et al., 1998a, 1998b; Senior et al., 2007). The categories included: age, weight, tractability, mobility, pain level, procedure performed, recovery assistance available, anticipated duration of anaesthesia, position during recumbency and abdominal profile. Baseline risk values were assigned a score of 1 in each category as follows: age (1 to 15 years); weight (100 to 700 kg); tractability (easily handled); mobility (normal); pain level (free from pain); procedure (superficial laceration); recovery (personnel available to assist); anticipated duration (30 min); recumbency (lateral) and abdominal profile (flat). A horse with baseline risk would be given a score of 10 points.

Additional items were developed by consensus for each category in order to establish a risk grading system. Items in the age category were as follows: Less than 3 months; 3 months to 1 year; Greater than 15 years. Items in the weight category were as follows: Less than 50 kg; Over 700 kg. Items in the tractability category were as follows: Resistant to handling; Cannot be handled. Items in the mobility category were as follows: Lame on one or more legs; Mild ataxia; Severe ataxia; Recumbent. Items in the pain level category were as follows: Controllable pain; Uncontrollable pain. Items in the procedure category were as follows: Myelography; Arthroscopy; Airway; Fracture Repair; Abdominal exploratory; Ophthalmologic surgery. Items in the recovery category were as follows: Equipment and personnel available to assist; Free recovery. Items in the anticipated duration category were as follows: 30 to 90 min; 90 min to 3 h; greater than 3 h. An additional item in the recumbency category was dorsal (i.e. supine) and an additional item in the abdominal profile category was round-bellied.

TABLE 1: American Society of Anesthesiologists Physical Status Classification System (2014) with examples of equivalent equine conditions

ASA Grade	ASA Definition (Human)	ASA Examples (Human)	Equivalent Equine Conditions (Proposed)
ASA I	A normal healthy patient	Healthy, non-smoking, no or minimal alcohol use	Healthy, afebrile, right or left sided innocent heart murmurs,
ASA II	A patient with mild systemic disease	No functional limitations. Current smoker, alcohol drinker, pregnancy, obesity, well controlled diabetes, mild lung disease	No functional limitations. Right sided systolic heart murmur suggestive of tricuspid valve dysfunction, febrile, laryngeal dysfunction, minimally increased bronchovesicular sounds, mild impaction, non-dehydrating diarrhoea, pregnancy, laminitis, minimal ataxia
ASA III	A patient with severe systemic disease	Substantial functional limitations. One or more moderate to severe diseases. Diabetes, COPD, morbid obesity, pacemaker, on dialysis, moderate reduction of injection fraction	Atrial fibrillation, respiratory crackles and wheezes on auscultation, pleural disease, ruptured bladder, compromised bowel, neonatal isoerythrolysis, Potomac Horse Fever, hyperkalemic periodic paralysis (HYPP), pituitary pars intermedia dysfunction (PPID), equine metabolic syndrome (EMS), recurrent airway obstruction, severe ataxia
ASA IV	A patient with severe systemic disease that is a constant threat to life	Recent myocardial infarction, ongoing cardiac ischaemia, severe valve dysfunction, shock, sepsis	Jugular pulses, fulminant pulmonary oedema, heart failure, rapid ventricular arrhythmias, dehydrating diarrhoea, guttural pouch mycosis, haemorrhage, upper airway obstruction/respiratory distress, severe dehydration or hypovolaemia, endotoxaemia, septicaemia, septic peritonitis, poisoning
ASA V	A moribund patient that is not expected to survive without the procedure	Ruptured abdominal/thoracic aneurysm, massive trauma, intracranial bleed with mass effect, ischaemic bowel in the face of significant cardiac pathology or multiple organ/system dysfunction	Ruptured bowel, guttural pouch mycosis with haemorrhage, complete airway obstruction

A survey was designed to estimate the relative risk of each item within each category. Respondents were asked to assign a score of 1, 2 or 3 to each item to indicate whether an item had the same risk level as the baseline item or represented an elevated risk. A risk score of 1 indicates risk the same as baseline. A risk score of 2 indicates a 2 times greater risk compared to the baseline item. A risk score of 3 indicates a 3 times greater risk compared to the baseline item. The survey along with an electronic message of introduction and intent was sent to a convenience sample of 27 veterinarians (including the authors) with at least 10 years' experience in equine anaesthesia and a record of scientific publication in the field. The electronic message also included a copy of Table 1 for the respondent's reference. Non-responders were prompted on one or two occasions within a 2-week period.

Statistical analysis

All data were analysed using a commercially available software (GraphPad Software LLC). The median and range of the scores were calculated and changes in scoring compared to the set baseline of each parameter using Kruskal-Wallis and Dunn's multiple comparison test. The level of significance was set at 5% ($p < 0.05$).

Results

Twenty-six of the 27 distributed surveys were completed and returned, a response rate of 96.3%. Countries represented were Austria, Australia, Belgium, Brazil, Canada, England, France, Germany, Japan, Scotland, Sweden, Switzerland and the United States of America. The medians and ranges of the scores for each item in each category were calculated and compared to the set baseline. The results are presented with significant differences from baseline for each category indicated (**Table 2**).

Scores significantly different from baseline were identified for items in each of the 10 categories. Significant differences between scores for individual items in eight of the categories were also identified. Based on these data, scores for each item in each category were determined. Horses less than 3 months of age and greater than 15 years of age were assigned scores indicating twice the risk of horses 3 months to 15 years of age. Horses with bodyweights above 700 kg were assigned scores indicating twice the risk of horses with lesser weights. Horses resistant to being managed (i.e. tractable) or unable to be managed were assigned scores indicating twice the risk of easily managed horses. Horses that were mildly ataxic or lame on one or more legs were assigned scores indicating twice the risk of horses with normal mobility. Recumbent horses or horses with severe ataxia were assigned scores indicating three times the risk of horses with normal mobility. Horses that were apparently free from pain or whose pain was controllable (median score 1) were assigned scores indicating less risk than horses with uncontrollable pain (median score 2). Arthroscopy was assigned a procedure score (1) equal to the baseline (superficial laceration repair). Myelography, airway surgery, abdominal exploratory and

TABLE 2: The results of an opinion survey of equine anaesthesiologists on pre-anaesthetic assessment of risk

Category	Baseline Column I	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7
Age	1 to 15 years 1	Less than 3 months 2^{a} (1-3)	3 months to 1 year 1^{b} (1-2)	Greater 15 years $2^{a,c}$ (1-3)			
Weight	100 to 700 kg 1	Less than 50 kg 1^{a} (1-3)	Over 700 kg $2^{a,b}$ (1-3)				
Tractability	Easily handled 1	Resistant to Handling 2^{a} (1-3)	Cannot be handled $2^{a,b}$ (1-3)				
Mobility	Normal 1	Lame on one or more legs 2 (1-2)	Mild ataxia 2 (1-2)	Severe ataxia $3^{a,b,c}$ (1-3)	Recumbent $3^{a,b,c}$ (1-3)		
Pain Level	Free from pain 1	Controllable pain 1 (1-2)	Uncontrollable pain $2^{a,b}$ (1-3)				
Procedure	Superficial laceration 1	Myelography 2^{a} (1-3)	Arthroscopy 1^{b} (1-2)	Airway $2^{a,c}$ (1-3)	Fracture repair $3^{a,c,d}$ (1-3)	Abdominal exploratory $2^{a,c}$ (1-3)	Ophthalmologic surgery $2^{a,e}$ (1-3)
Recovery	Personnel available to assist 1	Equipment available to assist 1 (1-3)	Free recovery $2^{a,b}$ (1-3)				
Duration	30 min 1	30 to 90 min 1 (1-1)	90 min to 3 h $2^{a,b}$ (1-2)	Greater than 3 h $3^{a,b,c}$ (2-3)			
Recumbency	Lateral 1	Dorsal 2^{a} (1-2)					
Abdominal Profile	Flat 1	Round 2^{a} (1-2)					

Data represent median scores and ranges (n = 26). Median and range of 26 scores for each item to indicate relative risk compared to baseline item. (a) Indicates a significant difference of the median score compared to column 1 (baseline) within the same category; (b) Indicates a significant difference of the median score compared to column 2 within the same category; (c) Indicates a significant difference of the median score compared to column 3 within the same category; (d) Indicates a significant difference of the median score compared to column 4 within the same category; (e) Indicates a significant difference of the median score compared to column 5 within the same category.

ophthalmologic surgery were assigned procedure scores indicating twice the baseline risk. Fracture repair surgery was assigned a procedure score indicating three times the baseline risk and significantly greater risk than arthroscopy (score of 1) or airway surgery (score of 2). Recoveries where personnel and equipment were available to assist were assigned baseline risk (score of 1). Free recoveries were assigned scores indicating twice the risk of assisted recoveries. Anaesthetic durations of less than 90 min were assigned baseline median scores (score of 1). Anaesthetic durations of 90 min to 3 h and greater than 3 h were assigned median scores of 2 and 3, respectively. Horses positioned in dorsal recumbency were assigned scores twice that of horses positioned in lateral recumbency. Round-bellied horses were assigned scores indicating twice the risk of horses with flat bellies.

Discussion

The results of this survey suggest that experienced equine anaesthesiologists believe that factors other than health and the presence or absence of metabolic disease affect EQAR. In addition, the responses received in each of the 10 categories suggest that the degree of EQAR should be estimated based on patient factors and factors associated with the intended procedure including positioning, anticipated duration and ability or desire to assist recovery. The levels of EQAR suggested by the results of this survey form the basis of a proposed numerical scale (CHARIOT) that utilises the ten factors identified to affect EQAR in healthy horses in a format that facilitates compilation of information estimating the relative risk of a given horse being anaesthetised for a given procedure prior to induction (**Table 3**). The adoption of such a system in

TABLE 3: Proposed Combined Horse Anaesthetic Risk Identification and Optimisation Tool (CHARIOT)

Category							Score
Age	3 months to 15 years (1)	Less than 3 months (2)	Greater than 15 years (2)				__
Weight	Less than 700 kg (1)	Greater than 700 kg (2)					__
Tractability	Easily handled (1)	Difficult to handle (2)					__
Mobility	Normal (1)	Lame or mildly ataxic (2)	Severely ataxic or recumbent (3)				__
Pain Level	Controllable (1)	Uncontrollable (2)					__
Abdominal profile	Flat bellied (1)	Round bellied (2)					__
Procedure	Laceration (1)	Arthroscopy (1)	Myelography (2)	Airway surgery (2)	Abdominal exploratory (2)	Ophthalmologic surgery (2)	__
Recumbency	Lateral (1)	Dorsal (2)					__
Duration	Less than 90 min (1)	90 min to 3 h (2)	Greater than 3 h (3)				__
Recovery	Assisted recovery (1)	Free recovery (2)					__
							Total score ____

conjunction with ASA-PS-Equine could improve quality of care by increasing the awareness of potential risks and potentially lead veterinarians to modify their procedures, where possible.

Equine anaesthetic risk varies with age (Dugdale et al., 2016; Johnston et al., 2002). Horses aged 1 to 15 years were assigned baseline risk (score of 1) by the authors based on retrospective reports. Respondents indicated that horses 3 months to one year of age were not at increased risk but foals less than 3 months of age and horses greater than 15 years of age had twice the risk compared to baseline. Accordingly, CHARIOT was reduced from 4 to 3 items: Less than 3 months (score of 2); 3 months to 15 years (score of 1); Greater than 15 years (score of 2).

Equine anaesthetic risk varies with the bodyweight of the horse and its abdominal profile (Dugdale et al., 2016; Johnston et al., 2002; Moens et al., 1995). The authors assigned a baseline score of 1 for horses weighing between 100 and 700 kg. Somewhat surprisingly, median score for horses less than 50 kg did not differ from baseline, but horses weighing over 700 kg were scored at a level indicating twice the risk of baseline and horses less than 50 kg. Accordingly, CHARIOT was reduced to two items: Less than 700 kg (score of 1); Greater than 700 kg (score of 2). Abdominal profile has been associated with greater risk of relative hypoxaemia in anaesthetised horses. Respondents indicated that round bellied horses represented twice the EQAR of flat bellied horses resulting in the proposed CHARIOT scores of 1 for flat-bellied horses and 2 for round-bellied horses.

Horses that were resistant to handling or could not be handled were assigned median scores of 2 by the respondents. Accordingly, CHARIOT was reduced to two items: Easily handled horses (score of 1); Horses difficult to be handled (score of 2). Normal mobility was assigned a baseline score by the authors. Respondents assigned horses lame on one or more legs and horses with mild ataxia a median score of 2 but the results were not significantly different from baseline. Respondents assigned horses with severe ataxia and recumbent horses scores of 3, which were significantly different from baseline and the other items. After discussion, the authors proposed reducing CHARIOT to three items: Normal (score of 1); Lame or mildly ataxic (score of 2); Severely ataxic or recumbent (score of 3). Similarly, horses apparently free of pain or whose pain was controllable were not separated by the respondents, but horses with uncontrollable pain were assigned a median score twice that of the other items. Accordingly, CHARIOT was reduced to two items: Controllable pain (score of 1); Uncontrollable pain (score of 2).

The remainder of the identified risk categories relate to the procedure to be performed and factors associated with the facilities available and the attending personnel. Respondents assigned median scores of 2 for the items myelography, airway surgery, abdominal exploratory and ophthalmologic surgery and a median score of 3 for fracture repair. Arthroscopy was assigned a median score of 1. The seven items were maintained in CHARIOT with assigned values based on their median scores.

Increasing duration of anaesthesia has been identified as a source of risk (Bidwell et al., 2007; Dugdale et al., 2016; Johnston, 2005; Johnston et al., 1995, 2002, 2004; Laurenza et al., 2020; Mee et al., 1998a, 1998b; Senior et al., 2007). Respondents indicated that anaesthetic durations less than

90 min represented baseline risk with durations of 90 min to 3 h representing twice the risk of shorter procedures and procedures greater than 3 h representing three times the risk. Accordingly, CHARIOT was proposed with three items in this category: Anticipated duration less than 90 min (score of 1); Anticipated duration 90 min to 3 h (score of 2); Anticipated duration greater than 3 h (score of 3).

Controversy exists with regard to the relative risk of positioning horses in dorsal versus right lateral versus left lateral recumbency for a given procedure (Johnston et al., 2002; Laurenza et al., 2020). Positioning may be determined by the intended procedure but is discretionary in some instances. Regardless, respondents assigned median scores of 2 for dorsal recumbency compared to baseline (non-specified lateral recumbency). Two scores were assigned for CHARIOT: Lateral recumbency (score of 1); Dorsal recumbency (score of 2). Controversy also exists concerning the risk associated with the desire or ability to assist recovery from anaesthesia (Arndt et al., 2019; Kastner, 2010). Respondents scored free recoveries at a risk level twice that of assisted recoveries with or without available equipment so CHARIOT items were reduced to Assisted recovery (score of 1) and Free recovery (score of 2).

The goal of this project is to provide a pathway to identify horses at increased EQAR with the ultimate goal of reducing morbidity and mortality associated with anaesthesia. If validated, CHARIOT could be used to amplify the currently employed, but inadequate, ASA-PS scoring system in recognition that factors in addition to the health of the horse affect EQAR. The baseline CHARIOT score is not proposed at a value of zero because all anaesthetised horses are at risk. The authors postulate that horses with increased CHARIOT scores in multiple categories (Total scores greater than 15) may have pronounced risk compared to horses with scores of 10 (standard risk) and that horses with scores greater than 20 could be at critical risk. If attending personnel recognised an increased EQAR for a given patient, they could potentially modify their procedures (e.g., change recumbency, shorten surgical time, assist recovery) or perhaps refer a patient representing a risk greater than they are prepared to assume. The limitations of this paper include the fact that it is a consensus statement that requires validation and the fact that, whilst numerous factors representing increased EQAR are identified, concrete solutions proven to decrease EQAR are not supplied. In addition, the items within the categories that were rated by the respondents are not nuanced or inclusive and as such do not encompass all conditions, procedures or situations. As a result, utilisation of the tool will require some extrapolation and modification if operationalised. Further, restricting respondent choices to baseline, twice the risk, or three times the risk may have oversimplified this initial version of the rubric, particularly when assessing risk across categories. Categories and the associated scores can be added, modified or eliminated in the future if others find utility in the rubric.

Some researchers have postulated that EQAR may never be reduced from the reported incidence because of the flight or fight nature of the horse (Dugdale et al., 2016). The authors acknowledge these inherent qualities of the horse but postulate that morbidity and mortality can be reduced if risk reduction measures are applied. Some have questioned if establishing ‘standards’ for equine anaesthesia would reduce risk (Senior, 2015). The American College of Veterinary Anesthesia and Analgesia took a step towards improving anaesthetic care in horses by proposing guidelines for equine anaesthesia in 2005 (Martinez et al., 2005). Briefly, the guidelines recognise that horses provide challenges beyond those of the other domestic animals and provide recommendations for evaluation, selection of anaesthetic regimens, monitoring and supportive care, and recovery. Recommendations include the placement of intravenous catheters, supplemental oxygen, monitoring of arterial blood pressure and treatment of hypotension, and provisions for facilitating an uncomplicated return to standing. The authors believe that wider adoption of these guidelines by appropriately trained individuals across equine practice would represent a much needed improvement in the standard of care for the anaesthetic management of horses.

Authors’ declarations of interest

No conflicts of interest have been declared.

Ethical animal research

K. Hopster consulted with Robert A. DeAngelis, PhD, CPIA Assistant Director of IACUC Administration at the University of Pennsylvania and he indicated that the project did not require IACUC approval because it did not involve research or clinical cases or live vertebrate work.

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All authors contributed to study design, study execution, data analysis and interpretation, preparation of the manuscript and gave their final approval of the manuscript.

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Review Article

A review of oestrus suppression techniques in mares

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Keywords: horse; oestrus suppression; oestrus behaviour; ovarian pain; uterine devices

Summary

Many fillies and mares are accused of behaving badly by their owners or trainers, and their reproductive hormones and ovaries are commonly blamed for this. Overt oestrus behaviour, however natural, is undesirable when a horse is being ridden, trained and competed. More subtle behaviours may be attributed to the reproductive cycle and presented as the cause of poor performance in the elite competition mare. Sometimes behaviours are complex, perhaps at odds with what one expects for normal reproductive behaviour and in many cases may not be associated with the reproductive cycle at all, rather associated with pain of musculoskeletal or soft tissue origin. The situation represents a diagnostic dilemma to positively associate undesirable behaviours with the ovarian hormones or ovarian pain, before an attempt can be made to modify the behaviour through the suppression of oestrus. This article will review the reasons for presentation, the behavioural patterns of the reproductive cycle and the diagnosis of reproductive behavioural problems. The range of techniques for oestrus suppression will be reviewed along with their clinical application and any known current regulatory issues associated with their use.

Introduction

In practice, clinicians are commonly presented with mares reportedly behaving ‘badly’ be it either persistently, at regular or irregular intervals. This is often presumed by the owners, trainers and/or riders to be due to their mare being in oestrus or because of her ovaries. Behavioural changes in the mare as a result of the influence of the hormones that govern cyclicity are a normal behavioural expression for the mare and rather than it being considered ‘bad’ behaviour it is better referred to as ‘undesirable’. Such behaviour is variably described including a changing attitude, hyper-excitability, an unwillingness to respond to rider instruction, bucking, rearing, squealing, overt oestrus behaviour, aggression to other horses and/or people, stallion-like behaviour and colic (Jorgensen *et al*. 1996; Kamm and Hendrickson 2007; Christoffersen *et al*. 2007; Hedberg *et al*. 2007a; Crabtree 2011; Roessner *et al*. 2015). When considering these problems, the behaviour in question must first be demonstrated to be associated with the ovaries or oestrus cycle, before it can be attributed to it. Often the cause of the problem is unrelated to ovarian activity or pathology and yet it can vary with normal ovarian function and is therefore misattributed to the ovaries (Pryor and Tibary 2005; McDonnell 2017). Other sources of altered behaviour include pain of musculoskeletal, soft tissue, gastric or dental origin, stress, innate temperamental traits and urinary tract infections. If the undesirable behaviour is confirmed to be associated with the follicular phase of the oestrous cycle then a variety of options are available to suppress oestrus. If behaviour is associated with the luteal phase certain methods may be more appropriate than others.

The oestrous cycle and reproductive behaviour

The equine species has an endogenous circannual reproductive rhythm which is regulated by photoperiod and synchronised to the spring. There are four defined phases of cyclic activity: Winter anoestrus (inactive phase), vernal or ‘spring’ transition (resurging phase), a period of cyclic ‘seasonal’ activity and an autumn transition (receding phase), back to winter anoestrus. Not all mares stop cycling, and those that do, do not start cycling at the same time nor does the same mare necessarily cycle at the same time each season (Ginther 1992b). Variation would appear to be due to inhibitory factors such as latitude, nutrition, body condition, weight loss, social stress, ambient temperature and reproductive status (Ginther 1992b). Cyclic ‘seasonal’ activity is usually from April to September and October to March in the Northern and Southern Hemispheres respectively (Ginther 1992b). The oestrous cycle consists of a follicular phase (oestrus) and a luteal phase (dioestrus) which in horses last a mean of 6.5 and 14.9 days respectively giving an overall cycle length of 21.7 days (Ginther 1992c).

Oestrus behaviour is generally thought of as being driven by oestrogens produced from ovarian follicles (follicular phase), whereas dioestrus behaviour is driven by progesterone produced by luteal structures (luteal phase). In oestrus, the mare demonstrates behaviours which are predominantly submissive and accommodating, whereas in dioestrus mares are generally nonreceptive or indifferent through to active avoidance or repulsion of male horses (Ginther 1992a; McDonnell 2017). It is important to note that oestrus behaviour (in response to teasing) is also common in the absence of significant follicular development in the transitional and anoestrus phases of the cycle (Ginther 1974; Asa *et al*. 1980a), when there are low progesterone concentrations. McDonnell (2017) described oestrus behaviour as being characterised by increased social interest, activity and vocalisation towards the stallion with lifting of the tail off the perineum, increased urination, prolonged bouts of clitoral eversion and posturing. Conversely, dioestrus behaviour is characterised by reduced interest and movement away from the stallion with normal tail posture and urination behaviour; if pressured the mare may squeal or grunt and may strike or kick out with clamping or swishing of the tail. Interestingly fear and pain are characterised by a worried facial expression with a clamped or swishing tail and simultaneous squirting urine with squealing and grunting under pressure (McDonnell 2017). In the author's experience, the latter behaviour is commonly displayed by young fillies in training in the spring and is attributed by trainers as being due to them being in season along with a request to modify their behaviour. The demonstration of stallion-like behaviours by mares is rare in the absence of ovarian pathology; however, such behaviours can occur in both the follicular and luteal phases in normal mares (Gastal *et al*. 2007).

Stress and behaviour

Riding and training can be a cause of physiological stress which can have potential effects on performance (Bartolomé and Cockram 2016). It is not unsurprising that a mare's responses to riding and training will vary depending on the stage of the reproductive cycle; however, there is little published information relating to this. Aggressive behaviour is generally associated with testosterone-driven sexual aggression and dominance in males, however, one must acknowledge that stress and testosterone can be physiologically linked. It has been demonstrated that ACTH treatment causes a significant increase in plasma levels of cortisol and testosterone in mares (Hedberg *et al*. 2007a). In addition, Morganti *et al*. (2010) demonstrated that serum cortisol was significantly higher in mares with elevated testosterone suggesting that adrenal cortical activation may result in increases in both serum cortisol and testosterone and that stress in mares may be associated with some aspects of aggressive or stallion-like behaviour. A study by Dalin *et al*. (2002a) noted that the mare which was most nervous during oestrus showed the highest adrenal testosterone response, whereas the calmest mare during oestrus, showed the lowest response. Interestingly mares may have lower cortisol levels in oestrus than in dioestrus (Asa *et al*. 1983).

Ovarian pain

Ovarian pain is not easily defined or quantified in the horse; women commonly experience variable degrees of pelvic pain associated with ovulation (Mittelschmerz pain) and primary dysmenorrhoea (menstrual cramps) as well as the pathological conditions of endometriosis, adenomyosis, fibroids (Won and Abbott 2010) and ovarian cancer (Ebell *et al*. 2016). It is common for horse owners to anthropomorphise, attributing their own experiences of pain and discomfort to their horses. Since mares do not menstruate, they will not encounter menstrual cramps but it is reasonable to suggest that they encounter pain in relation to large follicular structures and/or ovulation (Cox and DeBowes 1987; Pryor and Tibary 2005; Chenier 2009; Vanderwall and Nie 2011; Crabtree 2017). An assessment of pain in the equine patient can be made by transrectal manual palpation of the ovaries (Chenier 2009; Vanderwall and Nie 2011; Crabtree 2017). Pain during palpation of the ovaries is referred to in the literature (Chenier 2009; Vanderwall and Nie 2011) however, there are no guidelines on how to assess or quantify ovarian pain. In the author's experience, the majority of mares will not elicit any significant response to ovarian palpation; a degree of tenderness associated with the pre-ovulatory follicle is normally anticipated (Chenier 2009; Vanderwall and Nie 2011) however, some mares will demonstrate significant discomfort by dropping at the hindquarters, tensing of the abdomen, facial grimaces and turning the head to the side being palpated. Several reports describe colic of ovarian origin (Hooper *et al*. 1993; Hanson and Galuppo 1999; Pryor and Tibary 2005; Roessner *et al*. 2015) and some authors have suggested ovarian pain can lead to sensitivity in the back (Vanderwall and Nie 2011) or hindlimb lameness (Chenier 2009). If these signs are present, repeatable over time and they are associated with pre-ovulatory, large follicular or anovulatory structures, then a 'painful ovary syndrome' could be considered (Crabtree 2017). In addition, one cannot rule out the potential for neoplastic ovaries to be painful as they are in human subjects (Ebell *et al*. 2016; Renaudin *et al*. 2021). Mares suffering from painful ovary syndrome may respond to certain methods of oestrus suppression where follicular development is suppressed, be that in the follicular or luteal phases.

Clinical evaluation

The best way to start to investigate this is to ask the owner and/or rider to keep a diary of when the behaviours are occurring, the nature of the behaviours and under what circumstances they are occurring. It is important to determine if the behaviour is better or worse at different times of year. McDonnell (2017) also suggests asking: What is involved; all her body, ears, tail, limbs, mouth? Can you predict when she is going to do it? Can you provoke the behaviour? Can you interrupt the behaviour? Is there any time when she doesn't exhibit the behaviour? The answers will hopefully allow the clinician to determine if the behaviours are likely associated with oestrus.

A thorough physical examination should be performed to identify sources of pain including a lameness workup with particular attention to bilateral hindlimb or multi limb lameness and back or sacroiliac pain. It is important to also check for muscle pain and stiffness, especially those induced by ill-fitting tack as lumbar sensitivity or discomfort is often interpreted by owners to be associated with the ovaries. In this regard, it is interesting to note that in human patients, musculoskeletal abnormalities may predispose patients to chronic pelvic pain (King *et al*. 1991) and the same could be true for horses. It is also important to screen for sources of dental pain, temporo-mandibular joint sensitivity and gastric ulceration. An analgesic trial is a useful adjunct to the physical examination (Pryor and Tibary 2005). In an attempt to differentiate between behavioural issues and subtle lameness mares can be treated systemically with a nonsteroidal anti-inflammatory drug (NSAID) such as phenylbutazone whilst continuing to be ridden to see if they train better and/or continue to demonstrate undesirable behaviour; an improvement in performance usually indicates a pain-related problem; however, a failure to observe improvement does not preclude pain (Dyson 2016; Pearson 2019).

A complete gynaecological examination should be performed at a time when the undesirable behaviours are occurring and also ideally when they are not. Examination would include a transrectal palpation and ultrasound of the ovaries and uterus with particular attention paid to the detection of luteal structures, uterine tone and echo-texture. Uterine tone is higher under the influence of progesterone and lower in its absence (Ginther 1992a). The presence of oedema in the uterus reflects circulating progesterone levels of <1 ng/mL and the greater the degree of follicular development, the greater oestrogen concentrations are and the greater the degree of uterine oedema (Loy and Swan 1966; Pycock *et al*. 1995). Typically oedema peaks 1–2 days prior to ovulation and decreases immediately prior to ovulation (McCue *et al*. 2011). Mares can however present with an inappropriate level of oedema, where the oedema is greater than would be expected for the degree of follicular development; this is often seen during the spring transition and may also occur in the face of uterine inflammation (McCue *et al*. 2011). A visual examination of the cervix with a speculum and/or a manual palpation of the cervix should be performed paying particular attention to the degree of cervical relaxation. In simple terms, a mare in the luteal phase of the cycle will have a pale, dry, firm and closed cervix and a mare in the follicular phase will have a reddening, moist, relaxed and open cervix. The cervix gradually relaxes from the beginning of the follicular phase and is maximally relaxed as ovulation approaches (Ginther 1992c). The degree of cervical relaxation can however be variable and the older maiden mare may have a cervix that fails to relax (Pycock 1993). The 'teasing' of a mare, by bringing her into contact with a stallion, can aid in determination of the phase of the mare's oestrus cycle however, this is often not logistically possible or is unsafe in the non-stud setting. Expression of oestrus by teasing does not necessarily indicate that the mare is in the follicular phase of the oestrous cycle as anoestrus (inactive phase), ovariectomised and pregnant mares may show signs of oestrus upon teasing (Asa *et al*. 1980a; Asa *et al*. 1983a; Dalin *et al*. 2002b; Imboden *et al*. 2006). If one was in any doubt regarding the phase of the oestrous cycle a progesterone assay can be performed with levels of <1 ng/mL indicating that the mare is in the follicular or the inactive phase and levels of >2 ng/mL indicate a patent luteal structure. A mare behaving badly when she is in the follicular phase of the oestrous cycle and behaving well when she is in the luteal phase increases the likelihood that the behaviour is driven, or exaggerated by oestrogen, in the absence of progesterone. If there are any doubts over the presence of ovarian pathology such as granulosa cell tumour (GCT), then diagnostic endocrinology is indicated.

Diagnostic endocrinology

The GCT panel should include progesterone, testosterone and anti-Müllerian hormone (AMH) to allow differentiation of ovarian enlargement due to large and/or irregular luteal tissue, anovulatory structures, haemorrhagic anovulatory follicles, and those due to GCT (Almeida *et al*. 2011; Crabtree 2011). Due to the variation in levels of inhibin during the oestrus cycle and the difficulties encountered in interpreting GCTs in pregnant mares, serum anti-Müllerian hormone (AMH) has in many cases replaced inhibin in the diagnosis of GCT. Unlike inhibin, there are no significant variations in serum AMH concentrations during either the oestrous cycle or pregnancy (Ball *et al*. 2013; Crabtree *et al*. 2013), and AMH appears to have a greater sensitivity than inhibin, testosterone, or the combination of inhibin and testosterone for the diagnosis of GCT (Ball *et al*. 2014). Elevations in serum AMH concentrations >4 ng/mL seem to be diagnostic for equine GCTs when compared to normal mare ovaries (Ball *et al*. 2013; Ball *et al*. 2014), however recent work has suggested that when comparing mares with GCT to mares with abnormal ovaries the cutoff values may be in the region of 4.7 ng/mL (Murase *et al*. 2018). Despite these values, mares with established and histologically confirmed GCTs will likely have significantly higher AMH levels (Almeida *et al*. 2011) and the concentration of AMH will likely be positively correlated to tumour weight as it is for Inhibin (Cook 2008; Almeida *et al*. 2011). Testosterone remains a useful aid in the GCT panel and is elevated in approximately 50% of cases (McCue *et al*. 2006). It has been suggested previously that mares expressing stallion-like behaviours have testosterone concentrations above 100 pg/mL (0.35 nmol/L; Stabenfeldt *et al*. 1979) however, this is not absolute, as mares with levels >100 pg/mL may not demonstrate this kind of behaviour (Crabtree 2011) and mares with levels <100 pg/mL may (Bailey *et al*. 2002).

Strategic avoidance

Rather than suppressing oestrus, it may be possible in certain scenarios to strategically avoid being in oestrus. For mares which have regular and predictable periods of oestrus, clinicians may be able to induce oestrus with the use of prostaglandin and then induce ovulation, and a subsequent luteal phase, with an ovulation induction agent, prior to competition. Generally, the *corpus luteum* (CL) is responsive (by means of complete luteolysis) to 'standard' doses of prostaglandins from 4 to 5 days post-ovulation. On average a mare will return to oestrus 3–4 days after treatment and ovulate within 8–10 days. The mare's 'response' to prostaglandin administration is governed by the concurrent follicular activity present at the time of administration (Crabtree 2009). For instance, a mare with no significant follicular activity at the time of prostaglandin administration is going to be slower to 'respond' than a mare which concurrently has a CL and a 35 mm follicle. As a general rule, a mare with a growing follicle of 35 mm or greater in diameter combined with a maximal endometrial oedema pattern and a relaxing cervix should respond to an ovulation induction agent.

Oestrus suppression methods

Therapies to suppress oestrus can be divided into five categories depending on the mode of action. Methods can either mimic a state of dioestrus, by supplementing progesterone or a synthetic analogue, cause a prolongation of the natural luteal phase, suppress ovarian activity through suppression of GnRH or by induction of anti-GnRH antibodies or remove the ovarian influence totally via ovariectomy.

Methods to mimic a state of dioestrus

Progesterone supplementation

Supplementation of progesterone or the synthetic analogue altrenogest (allyltrenbolone) can be used as a diagnostic trial and as a therapy. If a horse has a behavioural improvement whilst on altrenogest, it could be assumed that the oestrogen-dependant behaviour has been 'neutralised' as progesterone can be considered 'dominant' over oestrogen. Administration of oral altrenogest (Regumate[1]) will suppress behavioural oestrus in mares within 2–3 days by creating an artificial luteal phase for as long as it is administered. When prescribing such treatment, one should be aware of the potential for cross contamination of other horses and human subjects administering the product. In addition, mares being administered altrenogest for long periods may be outside of the product data sheet recommendations and consideration should be given to periodic screening of the reproductive tract for uterine infection. It should be noted that some mares which are unresponsive to the 'standard' dose of 0.044 mg/kg may be increased to a 'double dose' of 0.088 mg/kg. In considering this a direct 'calming' affect at a higher (CNS) level should be acknowledged (Roberts and Beaver 1987), which is supported by the fact that progestagens are also often effective at curbing unwanted sexual or aggressive behaviour in geldings (McDonnell 2000). It is important to recognise that follicular development and ovulation is not reliably suppressed by altrenogest at the standard dose and therefore mares that have painful ovary syndrome may continue to show discomfort even though other behavioural signs of oestrus have been suppressed (Lofstedt and Patel 1989; Pryor and Tibary 2005; Crabtree 2017).

In addition to oral altrenogest, long-acting injectable formulations of progesterone or altrenogest are available from compounding pharmacies in different parts of the world. Such preparations have been demonstrated to 'suppress' oestrus behaviour for a period of 7 days (Vanderwall *et al*. 2003; McConaghy *et al*. 2016). Anecdotal reports of injection site reactions and the subsequent potential for coat colour changes should be considered when prescribing such medications. Progesterone releasing intra-vaginal devices could be considered for the use of oestrus suppression however their side effects may be undesirable in the competition mare compared to the broodmare (Crabtree *et al*. 2018). Other 'off-label' animal and human products such as progesterone and oestradiol implants (Synovex-S[2]), delmadinone acetate (Tardak[3]), proligestone (Delvosteron[1]), medroxy-progesterone acetate (Depo-Provera[4]), chlormadinone acetate (Lutoral[5]), 17-alpha hydroxy-progesterone and Etonogestrel (Nexplanon[6]) have been used anecdotally; some have been investigated experimentally and shown to demonstrate limited or no clinical effect (McCue *et al*. 1997; McKinnon *et al*. 2000; Gee *et al*. 2009; Hazan 2011). It is important to note that such compounds are considered 'prohibited' or 'banned' under many codes.

In late 2018 it was reported in international racing jurisdictions that trace levels of the anabolic steroids trenbolone and/or trendione had been detected in products which contain altrenogest. Anabolic steroids are 'prohibited at all times' under the British Horseracing Authority (BHA) rules of racing in the United Kingdom and their investigations revealed the oral altrenogest (Regumate[1]) and injectable altrenogest (Altrenogest injection[7]) contained traces of trendione. Subsequent to this, the BHA advised owners and trainers not to administer any product containing altrenogest to a Thoroughbred from birth until permanent retirement from racing and that detection of trenbolone/trendione in a sample from a horse may result in a 14-month suspension from racing, in essence the use of altrenogest was 'banned'. Altrenogest is a synthetic 17-alkylated form of nandrolone (19-nortestosterone); trenbolone is an estrane derivative of nandrolone and synthetic alkylation of trenbolone results in allyltrenbolone (altrenogest). It would appear that the anabolic androgenic steroids (AAS) trenbolone and trendione are present as impurities in altrenogest containing products through incomplete alkylation of trenbolone to altrenogest and oxidation of trenbolone to trendione. Concerns that altrenogest itself acts as an AAS exist but remain unproven. Hodgson *et al*. (2005), administered altrenogest at 0.044 mg/kg for 8 weeks to sedentary mares and reported no demonstrable effect on dominance hierarchies, body mass or body condition score. They concluded that altrenogest had no obvious anabolic effects that may affect the performance of a competition mare. Regumate[1] is currently allowed in mares under Fédération Equestre Internationale (FEI) rules without any additional certification.

Methods to prolong the natural luteal phase

Occasionally a primary CL will fail to regress during the expected time of luteolysis. Such persistent CLs occur in 8–10% of oestrous cycles during the peak of the ovulatory season and about 25% during the autumn months (King *et al*. 2010). Such idiopathic or spontaneous luteal persistence will result in a luteal phase that can persist for up to 90 days before natural regression of the CL (Stabenfeldt *et al*. 1974). Methods to prevent luteolysis will therefore result in suppression of oestrus by continued endogenous progesterone production from the persistent CL.

The 'anti-luteolytic' effect of oxytocin

When the peptide hormone oxytocin is administered in the mid-luteal phase before Day 10 after ovulation it often disrupts luteolysis, causing prolonged CL function (Goff *et al*. 1987). Vanderwall *et al*. (2007) demonstrated that the intramuscular administration of 60 IU of oxytocin (Oxytocin-s[1]) twice daily on Days 7–14 after ovulation was an efficacious method of inhibiting luteolysis and extending CL function. Subsequently, it was demonstrated that 60 IU oxytocin once daily was equally efficacious with 63% of mares experiencing prolonged luteal function compared to 71% in twice daily treated mares (Vanderwall *et al*. 2012), and this has become the 'standard' treatment. Such protocols rely on the day of ovulation being known. If this is unknown, 60 IU oxytocin can be administered for 29 consecutive days which will, in the majority of mares, encompass the crucial period 7–14 days after ovulation, with an anticipated response of over 70% (Parkinson *et al*. 2015). As an alternative, Sarnecky *et al*. (2019) evaluated a proprietary slow-release oxytocin formulation. Mares received 1.0 mL of slow-release oxytocin containing 2400 IU oxytocin intramuscularly once on Day 7 and again on Day 10 after ovulation. Luteal persistence characterised by progesterone concentrations remaining >1.0 ng/mL continuously for at least 30 days was demonstrated in 75% of treated mares. This is potentially a more practical treatment protocol with only two injections compared to eight using the standard treatment protocol. Theoretically, if the date of ovulation was unknown, 10 injections of a long-acting preparation, every 3 days may prove potentially efficacious. Oxytocin is 'allowed' under the BHA rules and is a 'controlled medication' under FEI rules. The short half-life of oxytocin of 6.8 min (Paccamonti *et al*. 1999) would suggest that a relatively short withholding period could be applied for competition and the Nordic Equine Medication and Anti-doping Committee (NEMAC) currently publishes a withhold period of 96 h.

Intrauterine devices (IUDs)

Glass, copper, silver and water-filled plastic balls have been studied, with efficacy varying from 0 to 75% of mares experiencing prolonged luteal phases (Nie *et al*. 2001; Nie *et al*. 2003; Meyer 2003; Rivera del Alamo *et al*. 2008; Argo and Turnbull 2010). The first study by Nie *et al*. (2001) reported 41.7% (n = 12) of mares experienced prolonged luteal function which lasted a mean of 88.8 days when a 35mm glass ball was inserted within 24 h of ovulation. In a later publication, the same team reported 39% (n = 18) mares experienced prolonged luteal function; this was made up of mares experiencing extended phases immediately after ball placement and after the second and third ovulatory cycles (Nie *et al*. 2003). Interestingly the 61% of mares which did not experience prolonged luteal function continued to cycle normally for four cycles after which the ball was removed. It should be noted that in both reports, mares received a 250 μg dose of cloprostenol at ball insertion which was also post-ovulation and may have interfered with luteal development (Mocklin *et al*. 2006). Rivera del Alamo *et al*. (2008) placed 20 mm water-filled plastic spheres (estimated to be approximately 7.8 g) into the uterus 2–4 days post-ovulation and induced a prolonged luteal phase in 75% (n = 12) of the mares with a mean luteal phase of 57.0 days. Argo and Turnbull (2010) however, demonstrated no extended luteal phases in 12 cycles for each of 4 Pony mares when 35 mm glass balls were inserted. Did these mares not respond because of their breed, because they were all members of a subset of 'nonresponders', or due to a difference in IUD or insertion technique? The answer is not clear but the authors introduced the idea that clinical or owner impression was a manifestation of 'placebo by proxy'.

A mechanism for luteal persistence in the presence of an IUD is as yet undetermined. No significant differences have been demonstrated between endometrial biopsy samples prior to placement and post-removal of the devices (Nie *et al*. 2001; Nie *et al*. 2003; Rivera del Alamo *et al*. 2008; Argo and Turnbull 2010). Rivera del Alamo *et al*. (2008) proposed that close contact of the IUD with the endometrium may prevent the endometrial cells from releasing PGF 2-alpha since their responder mares showed baseline PG metabolite levels from Day 14 post-ovulation, whilst the control and nonresponder mares showed increased levels. Klein *et al*. (2016) used the same IUD and insertion technique to further elucidate the mode of action of IUDs. They encountered luteal persistence in 46.7% (n = 15) mares but were however unable to demonstrate the mechanism for it. They suggested that the variable efficacy of IUDs in mares may possibly be influenced by mare age and the presence of endometrial angiopathies.

The relatively widespread use of glass marbles for this purpose has led to cases of whole or fractured marbles acting as foreign bodies with or without associated uterine infection (Klabnik-Bradford *et al*. 2013; Turner *et al*. 2015; Diel de Amorim *et al*. 2016; Morris *et al*. 2017) and the concurrent presence of two glass marbles have been associated with urogenital discomfort and recurrent colic (Vanderwall 2013; Freeman and Lyle 2015). In addition, they have developed a reputation for being difficult to remove, which is likely due to the glass surface being damaged, making it porous and allowing fibrovascular ingrowth. As a result, glass marbles are not recommended for this purpose (Vanderwall 2015) and sterile water-filled or solid plastic spheres are a suggested alternative. Regardless of this, some feel that devices left in situ, perhaps accidentally, for long periods of time represent a risk to uterine health, especially if they result in a prolonged luteal state. The author is aware of anecdotal reports of a range of inappropriate devices either being placed, or found, in the uterus and this practice is perhaps giving the use of all IUDs a bad reputation. The use of sterile medical grade 35 mm polymethyl-methacrylate (PMMA) spheres weighing approximately 26 g has been described and client satisfaction appears to be good (Crabtree 2019), consistent with field observations of others (Burger *et al*. 2008). The PMMA spheres, like glass balls, are readily detectable by transrectal palpation and they cast a similar characteristic acoustic shadow to glass upon ultrasound (Diel de Amorim *et al*. 2017). In the author's clinical experience, they are most likely found at the base of a uterine horn however occasionally they can go undetected if they occupy a ventral position in a pendulous uterus (Diel de Amorim *et al*. 2017). It should be noted that there are no published studies into the long-term presence of any of these devices in the uterus of mares and, therefore, if they are to be used, it is recommended that they are removed at the end of the physiological breeding season. In comparison to glass balls, the author has removed a limited number of the PMMA devices after being in situ for more than 12 months without damage to the sphere, nor any notable adverse effects on uterine health and future pregnancy, supported by limited pregnancy data in experimental mares post IUD removal (Nie *et al*. 2003; Gradil *et al*. 2019).

More recently a self-assembling device consisting of three polymer-coated magnets has been described to successfully prolong luteal function and suppress oestrus (Gradil *et al*. 2019). The devices consist of three 12 × 26 mm polymer-coated elliptical elements with a magnetic core which results in the elements self-assembling into a 'ring'. This arrangement has the advantage of being able to be placed into the uterus and retrieved via an applicator and magnetic retriever, in addition their metal core allows their presence to be detected using an external metal detector. Gradil *et al*. (2019) reported 85.7% (n = 12) mares experienced extended luteal function and the average luteal phase was 74.1 ± 11.1 days. Further study is necessary but this particular form of IUD shows promise as an effective method of oestrus suppression. Currently, to the author's knowledge, there appears to be no published regulatory opinion on the use of IUDs other than NEMAC who state 'no withdrawal time' for 'intrauterine implants for delaying oestrus'.

Intrauterine coconut oil

A report by Wilsher and Allen (2011a) reported an inadvertent finding of an experimental study into the maternal recognition of pregnancy. Oestradiol in fractionated coconut oil was infused into the uterus of mares at Day 10 post-ovulation and in 92% (n = 12) of mares, luteolysis was blocked. Controls demonstrated that oestradiol was not necessary to block luteolysis and coconut or peanut oils alone induced 92% (n = 12) luteal persistence. The ability of the treatment to block luteolysis was not significantly different when administered on Day 8 (9/12; 75%), 12 (10/12; 83%) or 14 (6/12; 50%) of dioestrus but declined significantly when given before Day 8. Despite this initial report other researchers have failed to repeat these results with 0% (n = 5; Diel de Amorim *et al*. 2016b) to 33% (n = 6; Campbell *et al*. 2017) of mares demonstrating prolonged luteal phases with coconut and peanut oils respectively. Campbell *et al*. (2017) demonstrated superficial erosion of the endometrial surface epithelium in all mares and significantly increased eosinophil numbers in the endometrium of mares, postinfusion of peanut oil. They also demonstrated, in at least one mare, that the infusion resulted in a significant uterine reaction with the formation of fluid. Campbell's and Diel de Amorim's groups either tested or filtered their oils for bacterial contamination however it raises the question if there could have been other contaminants such as endotoxins in the oils used? If Campbell *et al*. (2017) findings are consistent then mares may have a hypersensitivity type reaction to the infusion of oil. The technique has been used clinically with success in low numbers (Crabtree 2019). The author described the clinical use of 1.0 mL of pharmaceutical-grade fractionated coconut oil which was passed through a 22 micron filter and infused into the uterus using a Minitüb insemination pipette[8] with an inner catheter in a clean fashion on Day 9–11 post-ovulation. Some effort was placed into determining the exact day of ovulation and often an ovulation induction agent was used to provide some accuracy into the detection of day of ovulation. Client feedback was positive (Crabtree 2019); however, one cannot rule out the placebo by proxy effect. Campbell *et al*. (2017) suggested that 'oils' may be considered 'medicines' by the regulatory authorities. To the author's knowledge, there is no current published regulatory opinion on the use of intrauterine oil(s) however, substances 'not-approved' by medicines agencies are considered 'prohibited' under many codes.

Inducing dioestrus ovulation

A study by Hedberg *et al*. (2006) looked at induction of dioestrus ovulation to induce a prolonged luteal phase. It appeared to be possible to induce ovulation of a dioestrus follicle ≥30 mm using 3000 IU human chorionic gonadotropin (hCG; Chorulon[1]). Three of four hCG-treated mares ovulated within 72 h after treatment and developed prolonged luteal phases of 58, 68 and 82 days respectively (Hedberg *et al*. 2006). Theoretically one could use a GnRH analogue for the same purpose. Human CG is allowed under many codes however an appropriate withhold period may need to be applied.

Termination of early pregnancy

Lefranc and Allen (2003), reported the results of a study in Welsh pony and Cob-type mares whereby concepti were manually ruptured between Days 16 and 22. The CL persisted morphologically in all the mares and serum progesterone concentrations remained >1 ng/mL for a mean of 82 ± 13 days (range 64–109 days). Theoretically if pregnancy termination was delayed to after the establishment of the endometrial cups, between 36 and 38 days of gestation (Allen *et al*. 1973), then the continued secretion of equine Chorionic Gonadotropin (eCG) would prolong the luteal phase even further, until the degeneration of the endometrial cups between 105 and 150 days (Wilsher and Allen 2011b). However, there would be potential complications associated with a later termination and there are obvious ethical considerations to the termination of pregnancy for this purpose and concerns of how this would be perceived by the public and subsequently sport regulatory authorities. Another option would be to leave the mare pregnant; a number of fillies in training will be put in foal and continue to compete whilst they are pregnant due to a perceived increase in performance (British Horseracing Authority 2008; Blake 2017) and the BHA allows fillies/mares to run until 120 days of gestation.

Suppression of ovarian activity through suppression of GnRH

It has been noted in some mares that the use of Ovuplant implants[9] (2.1 mg deslorelin acetate) cause a prolongation of the subsequent inter-ovulatory interval if they did not become pregnant (Johnson *et al*. 2000; Morehead and Blanchard 2000), due to a negative feedback on the hypothalamic-pituitary axis. This mechanism has been adapted for oestrus suppression. An experiment by Johnson *et al*. (2003), demonstrated that mares receiving three implants had prolonged luteal phases with a mean of 36.8 days, compared with mares receiving a single implant (22.5 days). Clinically one can appreciate mixed results depending on the degree of the individual mare's sensitivity to down-regulation (Crabtree 2019). Ovuplant is an effective ovulation induction agent so if administered to a mare with a responsive follicle it will be effective at 'ending' the follicular phase. In practice, the author starts with two implants and if repeat treatment is necessary considers increasing the dose to three implants (Crabtree 2019). Anecdotally the more concentrated form, marketed for dogs and ferrets as Suprelorin[10] (4.7 mg deslorelin acetate), has been used clinically off-licence. Recently Kaps *et al*. (2021) published a study looking at down-regulation of pituitary GnRH receptors and subsequent inhibition of ovulation and oestrus behaviour in Shetland mares using one or two 4.7 mg Suprelorin[10] implants. There was a transient inhibition of ovulation which was approximately equivalent to one and two oestrous cycles for the 4.7 mg (one implant) and 9.5 mg (two implant) groups, respectively. The mean number of days with oestrus behaviour was significantly less in treated mares when compared to controls; however, there were considerable differences in response between individuals in agreement with the author's field observations.

Deslorelin is not listed as a prohibited substance with the FEI; the BHA rules of racing state 'a horse must not have any implant, unless the implant is pharmacologically inactive' and as such should be free from deslorelin on raceday. It is difficult to compose an appropriate withdrawal period when multiple implants are used. GnRH antagonists such as antarelix and cetrorelix are not really a practical therapy for oestrus suppression in the mare, despite being reversible, as daily therapy of large doses (relative to human patients) are required making them relatively expensive (Evans *et al*. 2002; Briant *et al*. 2003).

Suppression of ovarian activity through induction of anti-GnRH antibodies

GnRH vaccination has become popular in competition horses for suppression of oestrus. A GnRH vaccine is commercially available in Australasia (Equity oestrus control vaccine[11]) for the control of oestrus and oestrus-related behaviour in mares, not intended for breeding. In addition, the vaccine GonaCon-Equine[12] is approved by the United States Environmental Protection Agency, for contraception of feral horses and burros (Killian *et al*. 2008; Baker *et al*. 2018). Vaccines are also commercially available for pigs and are being used clinically 'off-label' in mares (Crabtree 2019;


Demands of exercise are a stressor for the performance horse. Reactive oxygen species (ROS) such as free radicals are produced in the muscles during exercise. Heavy work can overwhelm the body's natural ability to deal with ROS resulting in oxidative stress which can damage muscle proteins, lipids, and DNA, release pro-inflammatory cytokines leading to muscle pain, and damage the mitochondrial membrane thus decreasing energy production.
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Burger 2020). Mares cease all ovarian activity within approximately 4 weeks of the second injection of a primary course and remain suppressed for a variable amount of time (Imboden *et al*. 2006; Elhay *et al*. 2007; Schulman *et al*. 2013). The younger the mare is when vaccinated the longer the return to cyclicity is likely to be (Schulman *et al*. 2013). In a study by Imboden *et al*. (2006) of nine mares vaccinated twice, five returned to ovulatory activity from 28 to 100 weeks, three resumed follicular activity without ovulating and one remained inactive over the 100 weeks observation period. They concluded that the duration of the inhibitory effect is highly variable, not clearly related to GnRH antibody titres and resumption of ovulatory activity may require more than 100 weeks. Mares vaccinated against GnRH can however also demonstrate oestrus behaviour after ovarian inactivation (Dalin *et al*. 2002b; Imboden *et al*. 2006), which is not unsurprising as the prevailing hormone pattern is that of an anoestrus mare. Given the suppression of folliculogenesis it is likely that a mare with ovarian pain syndrome will respond to this therapy.

There is great variation in an individuals' response to vaccination (Stout and Colenbrander 2004; Schulman *et al*. 2013) and it is not known how long mares that receive repeated doses of vaccine (boosters) will remain inactive for. The author's clinical experience suggests there is potential for the effect to be longstanding or potentially permanent which is consistent with the observations of others (Burger *et al*. 2008; Burger 2020). In the study by Imboden *et al*. (2006) 1 of 9 vaccinated mares did not remain completely suppressed for the entire duration of 60 months of the study. Schulman *et al*. (2013) reported that 7.8% of mares did not resume cyclicity within 2 years after only receiving two doses of vaccine. For this reason, vaccination is not recommended in mares intended for future breeding and the author recommends that clients sign an 'off-label' authorisation form, stating that they understand that the mare may not be able to breed in the future. The porcine vaccine (Improvac[3]) is associated with variable but significant injection site reactions (Imboden *et al*. 2006; Botha *et al*. 2008). Approximately 90% of horses vaccinated into the neck develop pyrexia after initial vaccination and approximately 30% develop painful and swollen necks. On boosting, approximately 80% of horses react with painful, swollen and stiff necks, necessitating concurrent nonsteroidal anti-inflammatories at vaccination; additionally, two deaths have been encountered presumably due to anaphylactic shock representing an estimated 0.2% risk (Imboden *et al*. 2006; Burger 2020). Vaccination into the gluteal muscle may reduce the occurrence of vaccine reaction (Botha *et al*. 2008). The equine licensed vaccine Equity[11] on the other hand, has been demonstrated to be safe when administered intramuscularly in the neck (Elhay *et al*. 2007; Janett *et al*. 2009) and for this reason its use is recommended over the porcine licensed Improvac[3] in competition horses (Burger *et al*. 2008; Crabtree 2019; Burger 2020). Equity[11] can be imported to the UK under a special import licence given appropriate justification.

According to European Union regulations, all vaccines administered by a veterinary surgeon must be recorded in the horse's passport regardless of whether or not the horse is intended for human consumption (Commission Regulation 2008). Therefore, administration of a GnRH vaccine should be recorded, but in reality, this is suspected not to be always happening and mares which have received one or more doses of the vaccine are being sold and presented by a new owner for breeding. To the author's knowledge, there is no published study looking at subsequent reproductive performance in vaccinated mares however, doubts exist over future reproductive potential (Imboden *et al*. 2006; Crabtree 2019; Burger 2020). In the author's clinical experience, resumption of follicular development in vaccinated mares is not necessarily accompanied by normal cyclicity. Not unlike the transitional phase, follicular activity can develop, but they do not necessarily progress through to ovulation (Imboden *et al*. 2006). If an ovulation is detected it is not necessarily followed by a resumption to normal cyclic pattern. Screening for anti-GnRH antibodies is possible (Bailly-Chouriberry *et al*. 2017) but commercially in Europe this service is currently only available for sport horses and limited availability in Thoroughbreds (Bailly-Chouriberry 2020, personal communication). As previously stated, the inhibitory effect is not clearly related to GnRH antibody titres (Imboden *et al*. 2006) however, antibodies are long-lasting (Burger 2020) and so antibody screening will likely give an indication if any vaccinations have historically taken place.

The FEI does not list GnRH vaccination in the equine-prohibited substances list and although it was previously advised that GnRH vaccination usage should be recorded in the horse's FEI passport this advice has now been withdrawn. The BHA Veterinary Committee advises 'Immuno-sterilisation should not be permitted in horses intended for racing in the UK' and the rules state that 'only vaccines licensed against infectious agents are permitted' therefore, the use of a GnRH vaccine is excluded under this rule. NEMAC lists GnRH vaccination under 'other prohibited treatments and substances.'

Suppression of oestrus by ovariectomy

The author has reviewed the published evidence for ovariectomy in the management of undesirable behaviours elsewhere (Crabtree 2016; Crabtree 2017). Three studies of bilateral ovariectomy for behavioural reasons have been published to date (Hooper *et al*. 1993; Kamm and Hendrickson 2007; Roessner *et al*. 2015). Hooper *et al*. (1993) reported that 35% of mares ovariectomised demonstrated continued oestrus behaviour and in 9% of cases this was judged to be 'objectionable' by the owners. Kamm and Hendrickson (2007) reported that 22% of owners were either impartial or dissatisfied; mainly due to a failure of behavioural change following surgery. In the study by Roessner *et al*. (2015) bilateral ovariectomy was associated with a better outcome than that of altrenogest therapy however the dose of altrenogest received by mares was highly variable and no endocrinological screening nor histopathological analysis of removed ovaries was performed. Recent work published by Melgaard *et al*. (2020), reported a series of 10 mares with histopathologically normal ovaries that underwent ovariectomy for behavioural reasons. Post ovariectomy an 80% improvement in 'rideability' and 40% improvement in behaviour towards people and/or other horses was reported from an owner's perspective. Inclusion criteria required there to be no extra-ovarian primary pathology and included trial therapy with NSAIDs and altrenogest. No response to NSAID or altrenogest made the mare a candidate for surgery. It is not clear what subset of mares these criteria selected however, questions were related to, flank sensitivity, kicking, biting, bucking and rearing.

In summary, if the undesirable behaviour which prompts ovariectomy is normal sexual (oestrus) behaviour then the likelihood is that surgery will not correct the problem. In fact, ovariectomy may make the situation worse as oestrus behaviour may become irregular and/or persistent post-surgery (Asa *et al*. 1980a; Hedberg *et al*. 2007b). Why is this? It was suggested by Asa *et al*. (1980a) that the luteal ovary plays a controlling role in the inhibition of oestrus behaviour, with progesterone providing the mechanism for periodic inhibition of sexual behaviour during dioestrus, that is the mares 'default' position is one of receptivity. Given peri-ovulatory oestrus is more vigorous than that observed in ovariectomised or anovulatory mares, it was hypothesised that additional steroidal stimulation is supplied by the ovarian follicles in the days just prior to ovulation. Alternatively, if we assume that the mares' default setting is one of neutral behaviour then additional oestrogens are acting to stimulate this behaviour with the adrenal gland being the most likely source; phytoestrogens of dietary origin are also a potential source (Asa *et al*. 1980a; Asa *et al*. 1980b; Weng *et al*. 2007). If the behaviour that prompts ovariectomy is aggressive in character then ovariectomy is more likely to be a successful therapy, but the evidence for this is weak (Crabtree 2017; Melgaard *et al*. 2020). Ovariectomy may well be indicated and curative for ovarian pain syndrome however, inducing ovarian inactivity via the use of a GnRH vaccine may also be a viable option that does not require surgery.

In order to predict the mares' response to ovariectomy, Roessner *et al*. (2015) compared ovariectomy to previous response to therapy with altrenogest. As discussed by Crabtree (2017), this is a potentially flawed approach as altrenogest therapy, mimics the luteal phase whereas ovariectomy more closely resembles the inactive anoestrus phase, therefore observing the mare's behaviour in anoestrus would be a more appropriate predictor of response to surgery. Regardless of the reason for performing ovariectomy, it would be prudent to warn an owner of the possibility of intermittent or persistent signs of oestrus behaviour post-surgery. From a regulatory perspective the BHA rules that as a 'requirement of running' a mare or filly must not have undergone laparoscopic sterilisation, unless she has undergone the procedure for therapeutic reasons. It is assumed that ovariectomy for oestrus suppression is not a therapeutic reason? The author is not aware of any other ruling regarding ovariectomy and subsequent competition.

Caslick's procedure

A study by Christoffersen *et al*. (2007) reported on the use of a Caslick's procedure in the management of referred vaginal pain as a cause of behavioural problems in mares. Fourteen mares exhibiting performance problems such as kicking against the rider's legs, bolting, or refusing to move forward were selected for this study. Performance problems or stereotypic behaviour were observed either permanently or intermittently during oestrus. In 86% (n = 14) of mares, the performance problems were totally eliminated or diminished within 6 months after a Caslick's operation (Christoffersen *et al*. 2007). As a result of this study, all mares undergoing oestrus suppression therapy should be critically appraised for vulval conformation and pneumovagina and have a Caslick's procedure performed if appropriate.

Conclusions

In conclusion, evaluation of mares for undesirable behaviour is a complex and in-depth process to determine if the undesirable behavioural patterns being experienced are caused by the reproductive cycle and the prevailing hormone balance or not. It may take time and a number of examinations to come to a conclusion and one needs to get to grips with the sometimes complex relationship between owner, trainer, rider and mare. Mares may demonstrate undesirable behavioural traits in the follicular or the luteal phase or both. If the behaviours are not caused directly by the reproductive cycle, the mare may simply cope better with training or competition stresses when she is in, or out of season. The choice of appropriate oestrus suppression technique will vary on many factors including the phase of the cycle one is trying to mimic, response to trial therapy with altrenogest, patient compliance, future breeding potential of the mare, cost, competition schedule and regulatory considerations. Some suppression techniques are reversible whereas other solutions may have a longstanding or permanent effect.

Author's declaration of interests

No conflicts of interest have been declared.

Ethical animal research

Methods referred to in this manuscript were subject to internal ethical review and approved.

Manufacturers' addresses

[1]MSD Animal Health, Milton Keynes, Buckinghamshire, UK.
[2]Zoetis USA, Charles City, Iowa, USA.
[3]Zoetis UK, Leatherhead, Surrey, UK.
[4]Pfizer Limited, Sandwich, Kent, UK.
[5]Teva Pharmaceuticals USA, Sellersville, Pennsylvania, USA.
[6]Merck Sharpe & Dohme Limited, Hoddesdon, Hertfordshire, UK.
[7]Bova Specials UK Limited, London, UK.
[8]Minitüb GmbH, Tiefenbach, Germany.
[9]Dechra Veterinary Products, Shrewsbury, Shropshire, UK.
[10]Virbac limited, Carros Cedex, France.
[11]Zoetis Australia, Rhodes, New South Wales, Australia.
[12]National Wildlife Research Centre, Fort Collins, Colorado, USA.

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Review Article

Mortality and morbidity in equine anaesthesia

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Keywords: horse; mortality; morbidity; anaesthesia; complications

Summary

Equine peri-anaesthetic mortality and morbidity are of interest to anaesthetists, practitioners, horse owners and insurance companies. The largest prospective study, 'The Confidential Enquiry into Perioperative Equine Fatalities' (CEPEF) was conducted more than 20 years ago. It included over 40,000 horses from multiple centres and reported mortality to be 1.9% that decreased to 0.9% when only elective cases were considered. This is in stark contrast to mortality rates in small animal (dogs: 0.17%, cats: 0.24%) and human anaesthesia (0.04–7/10,000). In spite of developments in understanding the pathophysiology of equine anaesthesia mortality has not decreased in the intervening years. The main contributors to peri-anaesthetic equine mortality are cardiac arrest, fractures and myopathy or neuropathy. Spinal cord myelopathy and cerebral necrosis are less common. Malignant hyperthermia and hyperkalaemic periodic paralysis are diseases associated with genetic mutations that can be triggered during general anaesthesia and may be fatal if not recognised and treated immediately. Morbidities are reported less frequently, presumably because often they do not cause permanent harm and may resolve within a short period of time. Complications in equine anaesthesia are numerous and include injuries at induction and recovery, damage to the airway associated with orotracheal or nasotracheal intubation, post-anaesthetic myopathy or neuropathy, regurgitation and aspiration of stomach contents, ocular injuries and complications associated with intravascular cannulation. Hypotension, hypoventilation, hypoxaemia, hypothermia and dysrhythmias may occur both during the maintenance phase of anaesthesia but also in recovery. Airway obstruction during recovery has repeatedly been reported over the years as causing pulmonary oedema, which is often fatal if the airway is not restored extremely quickly. This review summarises the literature on the risk of mortality and morbidity. Information has been gathered from single case reports as well as larger research studies.

Introduction

Equine general anaesthesia is associated with a high incidence of mortality compared with dogs and cats (Johnston *et al*. 1995; Johnston *et al*. 2002; Brodbelt *et al*. 2008) and humans (Haller *et al*. 2011). In dogs, the mortality rate has been reported to be one in 601 and in cats one in 419 (Brodbelt *et al*. 2008), whereas in humans it ranges between 0.04 and 7 per 10,000 anaesthetics (Haller *et al*. 2011). The 'Confidential Enquiry into Peri-anaesthetic Equine Fatalities' (CEPEF), a large multi-centre prospective study, described an overall peri-anaesthetic mortality rate of around one in 100 (one in nearer 50 if emergencies were included) (Johnston *et al*. 2002). Other smaller single-centre studies reported overall mortality ranging from at one in 150 to one in 830 (Young and Taylor 1993; Mee *et al*. 1998a; Bidwell *et al*. 2007), but more recently mortality is still reported as around one in 100 (Jago *et al*. 2015; Dugdale *et al*. 2016; Laurenza *et al*. 2020). This is in contrast to human medicine where mortality rates are continuously decreasing (Haller *et al*. 2011). As in human medicine however, the range of mortality rates may be explained by the lack of standardised definition of anaesthesia related mortality, the chosen duration of the peri-anaesthetic period, the variety of the case load, and in horses, the inclusion criteria for cases that were subjected to euthanasia (Haller *et al*. 2011).

In CEPEF, for elective cases, the most common causes of peri-operative death were cardiac arrest (33%), catastrophic fractures in recovery resulting in euthanasia (26%) and unspecified abdominal causes (13%). Post-anaesthetic myopathy (PAM) accounted for 7% of fatalities, and spinal cord myelopathy (SCM) or central nervous system complications for 6% (Johnston *et al*. 2002). Similarly, Bidwell *et al*. (2007) reported fractures and cardiac arrest as the main causes of mortality, followed by PAM. Fatalities predominantly occurred during the recovery period (Johnston *et al*. 2002; Dugdale *et al*. 2016; Laurenza *et al*. 2020).

For horses undergoing abdominal surgery, a range of mortality rates has been reported, ranging from around 2 to 30% (Mee *et al*. 1998b; Johnston *et al*. 2002; Proudman *et al*. 2002; Johnston *et al*. 2004; Mair and Smith 2005a; Proudman *et al*. 2006; Dugdale *et al*. 2016; Adami *et al*. 2020; Laurenza *et al*. 2020). Horses presented for caesarean section were also shown to have increased mortality risk (Johnston *et al*. 1995). Small retrospective studies reported a mortality rate of around 10 to 20% for this patient group (Juzwiak *et al*. 1990; Freeman *et al*. 1999; Byron *et al*. 2003; Abernathy-Young *et al*. 2012; Rioja *et al*. 2012). Causes included fractures, myopathy/neuropathy, haemoabdomen, cardiovascular collapse associated with sepsis, vaginal/uterine tears; euthanasia or death related to the surgery were also included contributing to the high mortality rate (Juzwiak *et al*. 1990; Freeman *et al*. 1999; Abernathy-Young *et al*. 2012; Rioja *et al*. 2012).

Factors increasing the risk of mortality have been identified as increasing age (Johnston *et al*. 2002; Dugdale *et al*. 2016), out of hours surgery (Johnston *et al*. 2002), higher American Society of Anesthesia (ASA) physical status grade and longer duration of anaesthesia (Johnston *et al*. 1995; Dugdale *et al*. 2016; Laurenza *et al*. 2020). Total intravenous anaesthesia (TIVA) and acepromazine reduced the risk of mortality, whilst lack of premedication, romifidine alone and use of volatile agents as a sole anaesthetic agent increased the risk (Johnston *et al*. 2002). In horses undergoing abdominal surgery, increased body mass, intra-operative tachycardia (Proudman *et al*. 2006; Adami *et al*. 2020), nasogastric reflux, acidosis and duration of anaesthesia were identified as risk factors for mortality (Adami *et al*. 2020).

Patient harm and associated costs include not only patient mortality but also anaesthesia related morbidity. Mortality and morbidity are tightly enmeshed and are best investigated together to assess patient safety (Haller *et al*. 2011). While considerable effort has been spent identifying risk factors for the high risk of equine anaesthetic death, morbidity is often neglected although reported to be between 1 and 18% (Young and Taylor 1993; Johnston *et al*. 2004; Senior *et al*. 2007; Jago *et al*. 2015; Dugdale *et al*. 2016; Laurenza *et al*. 2020). This is comparable to incidences of minor morbidity in humans where numbers reach 18–22% (Bothner *et al*. 2000; Fasting and Gisvold 2003) and include post-operative nausea and vomiting, dental damage, trauma to the pharynx, drug administration error and problems with anaesthetic equipment (Haller *et al*. 2011). However, intermediate and major morbidities, such as neuropathies (3%) and paraplegia after spinal or epidural anaesthesia (0.6–0.9/10,000) or brain injury (0.9/10,000) and cardiac arrest (3.3/10,000), respectively, are less common (Haller *et al*. 2011). In comparison, morbidities in small animal anaesthesia are described in 2% to 50% of cases (Dyson *et al*. 1998; Redondo *et al*. 2007; Gruenheid *et al*. 2018). The recognised problems associated with data collection regarding mortality in humans are likely to be similar in other species and may apply to morbidity as well (Haller *et al*. 2011).

Morbidity may increase the duration of hospitalisation, costs, affect the future performance of the horse and, in worst case scenarios, lead to euthanasia. In equine anaesthesia, few studies have investigated morbidity, but numerous case reports describe complications occurring in the peri-anaesthetic period.

Hence, this review summarises information obtained not only from larger prospective and retrospective studies but also from case reports. Complications not specifically addressed but described include electrolyte abnormalities, specifically hypocalcaemia and hypokalaemia, inappetence, colitis, diarrhoea, pyrexia and pain (Proudman *et al*. 2002; Mair and Smith 2005b; Senior *et al*. 2007; Haupt *et al*. 2008; Jago *et al*. 2015; Adami *et al*. 2020; Laurenza *et al*. 2020).

Injuries to humans

Injuries to the anaesthetist, surgeon or support staff are recognised, but rarely reported formally if minor. However, certain major injuries or death must be reported legally although regulations may vary depending on the country. Injuries may occur because of inadequate precautions or staff inexperience but also due to the unpredictability of equine behaviour, the simple fact of its large body mass, particularly when in a confined space. Safety of staff is of high priority; induction and recovery represent the greatest risk periods, when the horse loses or regains consciousness. During maintenance, sudden awareness and arousal leading to movement can injure both staff and horse. Ocular surgery has been associated with increased incidence of movement during anaesthesia (Parviainen and Trim 2000). More than half of the horses undergoing enucleation moved during surgery, whereas only a quarter moved during splint bone excision. Reduced access to the head for anaesthetic depth assessment is a possible explanation; monitoring the end-expiratory inhalant concentration reduced the number of horses that moved by over 50% (Parviainen and Trim 2000). Inhalant concentration differences between the large animal circle and the vaporiser setting (Steffey and Howland 1977), combined with reduced access to the head for assessing the depth of anaesthesia suggest that end-expiratory inhalant concentration monitoring would be beneficial.

Induction of anaesthesia

Severe adverse events were less commonly reported at induction than during maintenance or recovery of anaesthesia (Johnston *et al*. 2002). Subluxation of the elbow joint was reported in a pony due to severe abduction of the limb during induction of anaesthesia using the free fall technique (Senior *et al*. 2002). Monitoring physiological function is difficult and unexpected cardiac arrest during induction in healthy horses scheduled for elective surgery is recognised (Johnston *et al*. 2002; Bidwell *et al*. 2007).

Endotracheal intubation

Complications associated with intubation are rarely severe, but mild to moderate damage to the oral or nasal mucosa, larynx and trachea can be expected in almost all intubated horses and may go unnoticed (Holland *et al*. 1986; Heath *et al*. 1989; Touzot-Jourde *et al*. 2005). Tissue trauma may occur during insertion, overzealous cuff inflation or when moving the tube without deflating the cuff. Nasotracheal intubation can cause haemorrhage in the ventral or middle meatus, with the potential for airway obstruction by blood clots as well as aspiration.

Minor laryngeal trauma from intubation such as oedema, ecchymosis and haematomas is common (Trim 1984; Holland *et al*. 1986; Heath *et al*. 1989; Bradbury *et al*. 2008). Lesions have been observed even after uneventful intubation (Holland *et al*. 1986; Heath *et al*. 1989). In one study including 20 horses, minor laryngeal trauma was not associated with decreased laryngeal function after anaesthesia (Bradbury *et al*. 2008). A single case was described where laryngeal paresis developed one day after anaesthesia and did not resolve within the 7 days observation period (Holland *et al*. 1986). Bilateral laryngeal paralysis is rare without any pre-existing clinical signs (Abrahamsen *et al*. 1990; Dixon *et al*. 1993; Bidwell *et al*. 2007); this may be associated with neck extension and ischaemia of the recurrent laryngeal nerve (Abrahamsen *et al*. 1990). In one horse, pharyngeal trauma was described after intubation using an uncuffed tapered tube (Cole tube) despite no recognition of difficult placement or airway obstruction; this ultimately led to ventral neck necrosis and euthanasia (Brock 1985).

Tracheal damage is pressure dependent and may occur within 15 min of pressure application when the cuff to tracheal wall pressure exceeds the mucosal perfusion pressure (Nordin 1977). In horses in which cuffs were inflated to prevent leaks (pressure 59–73 mmHg; 80–10 cmH_2O), gross lesions were reported in two out of five horses, but microscopic lesions were found in all horses. At cuff pressures of 88 mmHg (120 cmH_2O) gross lesions were observed in four out of five horses, and all horses in this group showed histological damage to the mucosa. The gross lesions consisted of hyperaemia and focal haemorrhage and where the cuff compressed the mucosa epithelial attenuation and erosion were detected histologically (Touzot-Jourde *et al*. 2005). Others have observed mucosal damage at the site of the cuff lasting between 24 and 48 h with complete healing only evident after 7 days (Holland *et al*. 1986; Heath *et al*. 1989). It could be inferred from these reports that the cuff should be inflated until no leak is discernible and the cuff pressure checked using a pressure gauge to minimise tracheal epithelial damage.

Overinflation of the cuff may cause tracheal mucosal sloughing (Jago *et al*. 2015) or a tracheal tear (Little 2015). Secondary bacterial infection causing tracheal necrosis (Wylie *et al*. 2015) and pleuropneumonia (Rainger *et al*. 2006) may be fatal. Tracheal tears and perforation were assumed to be associated with movement of the tube and extensive extension and flexion of the neck after cuff inflation (Heath *et al*. 1989; Rainger *et al*. 2006; Saulez *et al*. 2009). The site of perforation matched the location of the cuff (Saulez *et al*. 2009). Clinical signs may take up to 2 days to develop (Saulez *et al*. 2009), presenting as subcutaneous emphysema spreading from the neck to front limbs and thorax, and pneumomediastinum in severe cases (Caron and Townsend 1984). Although lesions often resolve without intervention (Fubini *et al*. 1985; Saulez *et al*. 2009), supportive therapy or surgical repair may be indicated.

Tracheal necrosis has been described after contact with ethylene oxide used to clean endotracheal tubes (Schatzmann *et al*. 1981).

Cardiovascular complications

Cardiovascular collapse represented a quarter to a third of all fatalities encountered in horses undergoing elective procedures (Johnston *et al*. 2002; Johnston *et al*. 2004; Bidwell *et al*. 2007), while a decade later a retrospective study did not reveal any intraoperative cardiac arrests (Dugdale *et al*. 2016). In the last 10 years, isoflurane and sevoflurane have replaced halothane for maintenance of anaesthesia. Halothane causes greater myocardial depression compared with isoflurane (Raisis *et al*. 2000) and predisposes the myocardium to catecholamine-induced dysrhythmias (Lees and Tavernor 1970). It is tempting to speculate that a lower incidence of dysrhythmias and better cardiac function may be associated with the increasing use of isoflurane and sevoflurane (Johnston *et al*. 2004). However, mortality with isoflurane was similar to the mortality experienced with halothane except in horses aged 2–5 years. It is of note that cardiac arrest was less common with isoflurane in high-risk cases (Johnston *et al*. 2004).

Dysrhythmias associated with cardiac arrest included second-degree atrioventricular block unresponsive to atropine (Bidwell *et al*. 2007; Marolf *et al*. 2018), ventricular tachycardia in a horse in recovery (Bidwell *et al*. 2007) and in a foal leading to ventricular fibrillation (Coudry *et al*. 2007). Vasovagal reflex in association with manipulation of the eye or structures near the vagal trunk itself may cause bradycardia or cardiac arrest (Short and Rebhun 1980; Raffe *et al*. 1986; Parviainen and Trim 2000; Taylor and Clarke 2007). Bradycardia followed by asystole attributed to a Cushing-type reflex was described in a foal after cerebrospinal fluid collection (Bennell and Bardell 2021). Dysrhythmias are reported to occur in 5.3% of cases (Parviainen and Trim 2000) but often are self-limiting and therefore seldomly reported. Occasional reports describe, mainly with halothane, ventricular dysrhythmias (Cornick *et al*. 1990; Bright 1994), second- or third-degree atrioventricular block (Whitton and Trim 1985; Marolf *et al*. 2018) and accelerated idioventricular rhythm during dobutamine blood pressure support (Karrasch *et al*. 2013).

Post-anaesthetic dysrhythmias within the first 24 h of abdominal and nonabdominal surgery have been noted and include supraventricular and ventricular premature complexes as well as atrioventricular blockade (Garber *et al*. 1992; Morgan *et al*. 2011).

In horses undergoing abdominal surgery, intraoperative tachycardia has been identified as a risk factor for mortality (Proudman *et al*. 2006; Adami *et al*. 2020). Tachycardia may be associated with nociception, hypovolaemia, endotoxaemia or vigorous dobutamine use.

Monitoring is difficult during transport of horses to and from the operating table via hoist when cardiovascular function may be compromised due to redistribution of blood volume. Incidents appear rare but cardiac arrest was reported in a foal (Hopster *et al*. 2016) and a mare (Conde Ruiz and Junot 2018). The mare was successfully resuscitated (Conde Ruiz and Junot 2018). Although cardiopulmonary resuscitation in horses is challenging, successful attempts are reported in foals and mature horses (Kellagher and Watney 1986; McGoldrick *et al*. 1998; Vieitez *et al*. 2017; Niimura del Barrio *et al*. 2018; Marolf *et al*. 2018; Conde Ruiz and Junot 2018).

Hypotension is encountered in 42% and 88% of horses undergoing anaesthesia for elective and abdominal surgery, respectively (Parviainen and Trim 2000; Adami *et al*. 2020). In general, anaesthetic drugs, mechanical ventilation and position of the horse contribute to hypotension. Dorsal compared with lateral recumbency causes more pronounced hypotension (Blissit *et al*. 2008). Hypotension contributes to a prolonged recovery (Lindsay *et al*. 1989; Voulgaris and Hofmeister 2009) as well as other peri-anaesthetic complications, which are discussed below.

Hypothermia

Hypothermia occurs frequently but may go unnoticed, especially in the mature adult horse if not specifically monitored, with temperatures of 34–35°C, contributing to prolonged recovery (Voulgaris and Hofmeister 2009).

Hypercarbia and hypoxaemia

Ventilation associated complications are encountered in the majority of cases undergoing general anaesthesia and the reader is referred to recently published extensive reviews (Hubbell and Muir 2015; Auckburally and Nyman 2017; Mosing and Senior 2018).

During recovery, anaesthesia-induced hypoventilation causes hypoxaemia, which can be improved by increasing the inspired oxygen fraction and supplementing inspiration with a demand valve (Mason *et al*. 1987). In horses breathing adequately, 15 L/min oxygen supplementation increased oxygenation (McMurphy and Cribb 1989). Changing lateral recumbency should be avoided as it will worsen hypoxaemia (Mason *et al*. 1987). Controlled ventilation during general anaesthesia resulted in better oxygenation in early recovery but was associated with a period of apnoea (Bardell *et al*. 2020). Permissive hypercapnia reduced the time to spontaneous ventilation during recovery (Thompson and Bardell 2016) and standing (Brosnan *et al*. 2012). Hypoxaemia (less than 60 mmHg PaO_2) was identified as a risk factor for complications in recovery (Rüegg *et al*. 2016) although no association with reduced survival was shown in horses undergoing colic surgery (Trim and Wan 1990). In a single report, hypoxaemia was associated with a prolonged recovery in a draught horse (Dupont *et al*. 2018).

Recovery

Mortality and morbidity occur predominantly during recovery (fracture, joint dislocation, upper airway obstruction [UAO]) or become evident at that point (PAM, neuropathy, SCM; Johnston *et al*. 2004; Bidwell *et al*. 2007; Jago *et al*. 2015; Dugdale *et al*. 2016; Laurenza *et al*. 2020). However, in a retrospective study, the majority of horses (95%) recovered without complication (Dugdale *et al*. 2016).

Fractures in recovery were the second most common cause of mortality reported in CEPEF, accounting for a quarter of the deaths (Johnston *et al*. 2002) and for one fifth of the deaths in a retrospective study (Bidwell *et al*. 2007). Fractures occurred mainly in older Thoroughbred mares (9–18 years old) presented for emergency abdominal surgery (colic, dystocia, caesarean section), but this was also reported in a yearling undergoing osteotomy (Bidwell *et al*. 2007). Fracture sites included tibia, carpus and radius. Reduced bone density in post-parturient mares (Glade 1993), reduced limb strength after fracture repair and fatigue in severely ill horses may increase the risk of fracture. Fracture of the contralateral limb after fracture repair has been reported once (Dzikiti *et al*. 2008). Scapulohumeral joint luxation occurred in two horses without obvious cause (Zilberstein *et al*. 2005; Hahn *et al*. 2011) and carpal dislocation in one (Dugdale *et al*. 2016). Coxofemoral joint luxation is described in one horse previously diagnosed with equine motor neuron disease (Portier and Walsh 2006).

Various techniques are employed to recover horses from anaesthesia, and none is without complication. While two retrospective studies showed no difference in complications between unassisted and rope-assisted recoveries in the general horse population (Auer and Huber 2012) and in horses undergoing abdominal surgery (Rüegg *et al*. 2016), another prospective study claimed fewer attempts to stand and better recovery quality with less injuries with rope-assisted recovery in healthy horses (Arndt *et al*. 2020). However, 8% of horses did not tolerate ropes (Arndt *et al*. 2020). Complications with rope-assisted recovery range from 0.5 to 3% (Rüegg *et al*. 2016; Niimura del Barrio *et al*. 2018; Arndt *et al*. 2020). Technical difficulties and human error have been described in 0.08–10% of rope-assisted recoveries. These included unexpected release of the head rope, loss of the head collar, wrapping around legs and tangling of the ropes, tail hair breakage and slipped knots (Rüegg *et al*. 2016; Niimura del Barrio *et al*. 2018; Arndt *et al*. 2020).

Hydro-pool recovery can be used to facilitate recovery in high-risk cases. Complications were reported in one third of these cases, including pulmonary oedema (17%; 10 out of 60 horses), multiple skin abrasions, facial oedema, septic arthritis and incisional infections (Tidwell *et al*. 2002). The pool-raft recovery had a complication rate of 7%, but another 13% had subsequent complications once returned to the recovery box (Sullivan *et al*. 2002). In contrast, the Anderson Sling appeared to enable smooth and successful recovery although one horse would not accept its support (Taylor *et al*. 2005; Steffey *et al*. 2009). Tilt-table recovery systems have been reported to fail in six out of 54 cases, eight cases had minor complications including skin abrasions and cast failures, and one horse was subjected to euthanasia due to cast failure (Elmas *et al*. 2007).

Minor complications in recovery such as abrasions, lacerations of the tongue, lip or eye, mild epistaxis, contusions or haematomas are seldom reported and difficult to quantify (Tidwell *et al*. 2002; Ray-Miller *et al*. 2006; Senior *et al*. 2007; Jago *et al*. 2015; Arndt *et al*. 2020). Delayed awakening and prolonged duration of lateral recumbency may be predispose to PAM and respiratory complications. Prolonged recovery is described in a horse with pre-existing vestibular disease due to loss of orientation relation to gravity (Lord *et al*. 2019).

One report describes the unexpected occurrence of focal seizures and permanent central blindness in an adult horse after abdominal surgery without any complications noticed during anaesthesia maintenance (Rovel *et al*. 2015).

Post-anaesthetic myopathy

Post-anaesthetic myopathy and/or neuropathy is reported in 0.02% to 0.9% of cases (Johnston *et al*. 2002; Johnston *et al*. 2004; Bidwell *et al*. 2007; Jago *et al*. 2015; Dugdale *et al*. 2016; Laurenza *et al*. 2020). Older studies report a higher incidence of up to 6%, but better understanding of the aetiology, enabling specific prevention, may have decreased the incidence (Young and Taylor 1993; Duke *et al*. 2006).

Post-anaesthetic myopathy has been associated with decreased muscle perfusion related to hypotension, defined as mean arterial pressure (MAP) less than 65 mmHg (Grandy *et al*. 1987; Lindsay *et al*. 1989) or 70 mmHg (Dodman *et al*. 1988; Richey *et al*. 1990), prolonged duration of general anaesthesia (Richey *et al*. 1990; Johnston *et al*. 2004), lateral recumbency (Johnston *et al*. 2004) and larger body mass (Franci *et al*. 2006). However, myositis may also occur in foals (Manning *et al*. 1995). Intracompartmental muscle pressure is elevated in the dependent muscle groups in anaesthetised horses, and significantly more in hypotensive horses (Lindsay *et al*. 1989). However, brachial triceps muscle necrosis was reported after an uncomplicated anaesthetic (halothane maintenance) and MAP ranging above 70 mmHg (Ayala *et al*. 2009), suggestive of inadequate intracompartmental perfusion. Intraoperative prevention of hypotension may not always prevent PAM but may reduce its severity (Young and Taylor 1993; Duke *et al*. 2006). While halothane and isoflurane carry similar risks of peri-anaesthetic complications (Johnston *et al*. 2004), the favourable cardiovascular properties of isoflurane and probably also sevoflurane facilitate muscle perfusion. In contrast to halothane, isoflurane leads to better left ventricular systolic function and vasodilation resulting in increased femoral blood flow (Raisis *et al*. 2000). Although it prevents local high-pressure points, protective padding alone does not prevent PAM in hypotensive horses (Lindsay *et al*. 1989). However, triceps muscle intracompartmental pressure was reduced by adequate positioning (pulling dependent forelimb cranially while supporting the nondependent limb horizontally) and significantly decreased further by adding padding (White and Suarez 1986). Post-anaesthetic myopathy usually occurs in muscles of the trunk or legs but smaller muscles such as the masseter may be affected (Clark-Price *et al*. 2012).

Horses undergoing magnetic resonance imaging (MRI) might incur an increased risk of PAM due to limited space and difficult positioning (Franci *et al*. 2006). However, this has not been clearly substantiated: eight out of 350 MRI horses and two out of 229 undergoing nonabdominal surgery developed PAM in a study too small to detect significant differences (Franci *et al*. 2006). Further, no complications were reported in 77 horses recovering from anaesthesia after MRI (Leece *et al*. 2008).

Clinical signs of PAM are first seen in the recovery period and include pain or discomfort resulting in box walking and sweating. The affected muscle groups are hard and swollen and the horse may be unable to stand if several muscle groups are affected (Lindsay *et al*. 1989; Young and Taylor 1993). Isolated raised plaques may develop over bony prominences at table contact points (Grandy *et al*. 1987). Delayed onset (30 min) and worsening symptoms may occur after successful recovery (Trim and Mason 1973). Muscle enzymes increase in horses undergoing general anaesthesia but are significantly elevated in horses suffering from hypotensive episodes (Trim and Mason 1973; Grandy *et al*. 1987; Lindsay *et al*. 1989; Duke *et al*. 2006). Creatine kinase increased tenfold compared with normotensive horses 48 h after anaesthesia and aspartate transaminase remained elevated for up to 7 days (Grandy *et al*. 1987; Lindsay *et al*. 1989). Treatment includes analgesia and nursing care. Differential diagnosis of post-anaesthetic lameness should include compartment syndrome, which can present similarly (Norman *et al*. 1989; Louro *et al*. 2020).

Horses undergoing transvenous electrical cardioversion of atrial fibrillation may have a higher risk of mild PAM (8%; six out of 62 horses). However, no definite diagnostics were attempted, and recovery scores were good to excellent for the majority of horses (Bellei *et al*. 2007). In a few single cases, PAM was associated with equine polysaccharide storage myopathy, primarily but not exclusively in draught horses (Valentine *et al*. 1997; Bloom *et al*. 1999; Valentine 2003).

Neuropathy

Neuropathy and PAM are often not distinguished, so the incidence of neuropathy is unclear, but appears low, reported in <0.1% of anaesthetised horses (Young and Taylor 1993). Underreporting of neuropathy seems likely, especially when mild neurological deficits resolve within a short period of time. A recent retrospective study reported an incidence of 1.6% (Laurenza *et al*. 2020).

Post-anaesthetic neuropathy of the femoral (Dyson *et al*. 1988; Young and Taylor 1993; Franci *et al*. 2006), radial (Lindsay *et al*. 1989; Jago *et al*. 2015; Dupont *et al*. 2018), obturator after parturition (Bidwell *et al*. 2007), peroneal (Moreno *et al*. 2020) and the facial nerves (Grandy *et al*. 1987; Bellei *et al*. 2007; Niimura del Barrio *et al*. 2018; Bird *et al*. 2019) have all been reported. Femoral nerve paralysis has been described in eleven warmblood horses and four ponies undergoing surgery or MRI in lateral recumbency (Dyson *et al*. 1988; Franci *et al*. 2006; Mirra *et al*. 2018; Moreno *et al*. 2020) and in one horse positioned in dorsal recumbency (Young and Taylor 1993). Clinical signs may be delayed (Dyson *et al*. 1988; Young and Taylor 1993; Moreno *et al*. 2020) and resemble those of PAM but are usually associated with pain unresponsive to various classes of analgesics (Lindsay *et al*. 1989). While mild or unilateral nerve damage may have a favourable outcome (Dyson *et al*. 1988; Young and Taylor 1993; Franci *et al*. 2006; Oosterlinck *et al*. 2013; Moreno *et al*. 2020), bilateral femoral nerve paralysis has a guarded prognosis due to the inability of the horse to stand and subsequent challenges of managing a recumbent horse (Dyson *et al*. 1988; Winfield *et al*. 2014). The nondependent fore- or hindlimb may also be affected (Grandy *et al*. 1987; Oosterlinck *et al*. 2013; Mirra *et al*. 2018; Moreno *et al*. 2020) due to decreased perfusion (Branson *et al*. 1992; Raisis *et al*. 2000), but the mechanism is less well understood. Pulling the forelimb caudally may obstruct venous outflow (Taylor and Young 1990).

The aetiology of post-anaesthetic neuropathy is not certain, but factors similar to the causes of PAM may play a role. Inadequate padding or direct pressure on the nerve may damage it. However, femoral nerve paralysis has been associated with hyperextension of the pelvic limbs in dorsal (Young and Taylor 1993) and lateral recumbency (Dyson *et al*. 1998; Franci *et al*. 2006). Examination of carcasses showed that extension of pelvic limbs stretches the psoas minor tendon and femoral nerve (Dyson *et al*. 1988).

Spinal cord myelopathy

Spinal cord myelopathy has been reported in 33 cases since 1979 (Schatzmann *et al*. 1979; Blakemore *et al*. 1984; Zink 1985; Brearley *et al*. 1986; Yovich *et al*. 1986; Stolk *et al*. 1991; Lerche *et al*. 1993; Wan *et al*. 1994; Lam *et al*. 1995; Raidal *et al*. 1997; Joubert *et al*. 2005; van Loon *et al*. 2010; Ragle *et al*. 2011; Patschova *et al*. 2014; Küls and Rocchi 2017; Hughes *et al*. 2019) and has occasionally been recorded in equine mortality investigations (Johnston *et al*. 2002; Jago *et al*. 2015; Dugdale *et al*. 2016). The aetiology of SCM remains unknown; reduced perfusion and ischaemia of the spinal cord in dorsal recumbency (Schatzmann *et al*. 1979), reduced venous return due to compression of the vena cava by abdominal contents (Blakemore *et al*. 1984; Yovich *et al*. 1986; Wan *et al*. 1994), vitamin E deficiency destabilising spinal cord membranes (Stolk *et al*. 1991), stretch ischaemia of the spinal cord, verminous arteritis and embolism (Dugdale and Taylor 2016) have all been suggested.

Most cases of SCM are young male horses (<2 years old) undergoing anaesthesia of less than 1.5 h duration. However, SCM also has been described in mares (Schatzmann *et al*. 1979; Blakemore *et al*. 1984; Brearley *et al*. 1986; Ragle *et al*. 2011; Küls and Rocchi 2017). Positioning in dorsal recumbency and heavier breeds were associated with SCM, but cases are also reported after lateral recumbency (Raidal *et al*. 1997; Ragle *et al*. 2011), in lighter horses (Zink 1985; Yovich *et al*. 1986; Wan *et al*. 1994; Lam *et al*. 1995) and in a pony (Hughes *et al*. 2019). Various anaesthetic protocols were used, including halothane, isoflurane and sevoflurane as well as TIVA (Raidal *et al*. 1997). Arterial blood pressure was reported only occasionally but when stated was within an acceptable range in the majority (Wan *et al*. 1994; van Loon *et al*. 2010; Ragle et al. 2011). In recovery, horses struggle to stand up or are able to stand but develop progressive paraparesis or paraplegia of the hindlimbs. With time clinical signs progress, potentially including forelimbs, requiring euthanasia in all cases. Histopathological findings depended on the duration and severity of clinical signs. Venous congestion, oedema and haemorrhage into the grey matter have been reported affecting thoracic and lumbosacral spinal cord segments (Schatzmann *et al*. 1979; Blakemore *et al*. 1984; Zink 1985; Brearley *et al*. 1986; Yovich *et al*. 1986; Lerche *et al*. 1993; Wan *et al*. 1994; Raidal *et al*. 1997; Joubert *et al*. 2005; Ragle *et al*. 2011; Hughes *et al*. 2019).

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Malignant hyperthermia

Malignant hyperthermia (MH) has been described in Quarter Horses, Thoroughbreds, Appaloosa, Arabs and ponies undergoing general anaesthesia (Waldron-Mease *et al*. 1981; Hildebrand and Howitt 1983; Manley *et al*. 1983; Riedesel and Hildebrand 1985; Klein *et al*. 1989; Aleman *et al*. 2005; Aleman *et al*. 2009). It is associated with a mutation in the ryanodine receptor gene (RyR1) causing increased myoplasmic calcium (Aleman *et al*. 2004). Clinical signs include hypercapnia, respiratory acidosis, hyperthermia, tachycardia, hypertension, electrolyte derangements and sometimes muscle rigidity due to a hypermetabolic response (Waldron-Mease *et al*. 1981; Hildebrand and Howitt 1983; Manley *et al*. 1983; Riedesel and Hildebrand 1985; Klein *et al*. 1989; Aleman *et al*. 2005; Aleman *et al*. 2009). Halothane or isoflurane was used for maintenance in all equine cases of MH; however, other inhalant agents and succinylcholine have been linked to its development in other species (Rosenberg *et al*. 2015). Halothane maintenance in combination with succinylcholine triggered MH (Hildebrand and Howitt 1983; Manley *et al*. 1983). Most horses were treated symptomatically and recovered from anaesthesia with a few exceptions; one horse died from cardiac arrest in recovery and three were subjected to euthanasia due to complications in recovery (Manley *et al*. 1983; Aleman *et al*. 2005, 2009). Post-anaesthetic myopathy may be encountered after recovery (Manley *et al*. 1983; Klein *et al*. 1989).

Hyperkalaemic periodic paralysis

Hyperkalaemic periodic paralysis (HPP) is an autosomal dominant hereditary disease in Quarter Horses descended from the stallion *Impressive*. The mutation causes failure of sodium channel inactivation after depolarisation resulting in a reduced resting membrane potential, increased efflux of potassium and subsequently hyperkalaemia (Meyer *et al*. 1999). A few horses have developed HPP episodes during anaesthesia (Cox 1985; Robertson *et al*. 1992; Traub-Dargatz *et al*. 1992; Cornick *et al*. 1994; Moody *et al*. 1995; Bailey *et al*. 1996; Carpenter and Evans 2005; Baetge 2007; Pang *et al*. 2011) and successful management is reported (Cornick *et al*. 1994; Moody *et al*. 1995; Carpenter and Evans 2005; Baetge 2007; Pang *et al*. 2011). Episodes of HPP are triggered by stress, anaesthesia, diets high in potassium, transport and concurrent disease. During anaesthesia, HPP causes hypercapnia, muscle fasciculations and hyperkalaemia leading to bradycardia-associated changes in the electrocardiogram (Robertson *et al*. 1992; Traub-Dargatz *et al*. 1992; Cornick *et al*. 1994; Moody *et al*. 1995; Bailey *et al*. 1996; Baetge 2007; Pang *et al*. 2011). Occasionally, paradoxical tachycardia is reported (Cornick *et al*. 1994; Bailey *et al*. 1996; Pang *et al*. 2011). Horses may undergo one uneventful general anaesthetic, but stress-related incidents may cause an episode during a second (Cornick *et al*. 1994; Pang *et al*. 2011). Hypercarbia and hyperkalaemia should be treated immediately. Genetic testing of Quarter Horses and related breeds descending from *Impressive* are recommended.

Regurgitation and aspiration

Regurgitation has been reported only once, in a horse undergoing orthopaedic surgery without any subsequent sequelae (Carpenter and Hall 1981). However, it is encountered in approximately one in ten horses presented with colic (Bennell and Senior 2019).

In horses undergoing abdominal surgery, nasogastric reflux was not associated with increased mortality (Proudman *et al*. 2006), but aspiration of gastric contents may have severe consequences, although only three cases have been reported (Anderson *et al*. 2017; Monticelli and Adami 2019). Two horses presented with gastric impaction, abdominal distension and had a nasogastric tube in place during induction and maintenance. It was hypothesised that aspiration occurred during induction (Monticelli and Adami 2019). Gastric contents were seen in the orotracheal tube once mechanical ventilation was started. Reverse Trendelenburg position, suctioning the airway, ventilation strategies and salbutamol to treat hypoxaemia were applied successfully in one horse (Monticelli and Adami 2019). The anatomy of the equine cardiac sphincter makes regurgitation or reflux rare (Budras and Henschel 2008) but pathological changes or placement of a nasogastric tube might change this. Intubation and securing the airway in sternal may be considered for prevention (Monticelli and Adami 2019).

The third reported case experienced nasogastric reflux during recovery after undergoing sham ventral coeliotomy for a research project, with minimal manipulation. Treatment was withheld due to the experimental procedure, resulting in pneumonia, systemic inflammatory response syndrome and euthanasia within 18 h (Anderson *et al*. 2017). Nasogastric sphincter incompetence was the speculated cause.

Other complications associated with nasogastric tube placement include UAO during recovery in a horse with laryngeal hemiparesis when the nasogastric tube was left in place (Veres-Nyéki *et al*. 2011), sinusitis in three horses (Nieto *et al*. 2014) and usually mild and self-limiting epistaxis. However, severe nasal haemorrhage in a horse caused the loss of 24 litres of blood, requiring blood transfusion (Trim *et al*. 1997).

Cerebral necrosis

Post-anaesthetic cerebral necrosis, confirmed by histopathology, has been described in six horses (Spadavecchia *et al*. 2001; McKay *et al*. 2002). Neurological signs developed either during recovery, including galloping, nystagmus and myoclonic movement of the tongue (Spadavecchia *et al*. 2001) or up to 7 days later, including bilateral blindness, propulsive pacing, head pressing, lethargy and generalised seizures (McKay *et al*. 2002). All horses were adult, anaesthetised with halothane or isoflurane and undergoing abdominal or orthopaedic surgery. Periods of hypercapnia and hypoxaemia occurred, which could have influenced cerebral autoregulation, but the cause of the cerebral necrosis remains unknown.

Pulmonary oedema and upper airway obstruction

Reports of pulmonary oedema are accumulating (Jones *et al*. 1988; Abrahamsen *et al*. 1990; Dixon *et al*. 1993; Kollias-Baker *et al*. 1993; Shaw *et al*. 1995; Ball and Trim 1996; Tute *et al*. 1996; Tidwell *et al*. 2002; Borer 2005; Senior 2005; Holbrook *et al*. 2007; Pellegrini-Masini *et al*. 2009; Kaartinen *et al*. 2010; Veres-Nyéki *et al*. 2011; Melis *et al*. 2014; Merlin *et al*. 2019). Respiratory complications are described in CEPEF as fatal in 12 out of 35,978 horses; some 4% of the fatalities, and presumably included pulmonary oedema, but not exclusively. Dugdale *et al*. (2016) reported four cases of respiratory obstruction in 1268 cases; two of these died with pulmonary oedema.

Pulmonary oedema develops for a number of reasons, including UAO (Abrahamsen *et al*. 1990; Dixon *et al*. 1993; Kollias-Baker *et al*. 1993; Ball and Trim 1996; Tute *et al*. 1996; Borer 2005; Senior 2005; Kaartinen *et al*. 2010; Merlin *et al*. 2019), microembolism (Jones *et al*. 1988), drug-associated capillary leakage (Shaw *et al*. 1995), venous air embolism (Holbrook *et al*. 2007; Pellegrini-Masini *et al*. 2009) and mechanical causes (Tidwell *et al*. 2002). Re-expansion injury and anaphylaxis, which increases vascular permeability (Ball and Trim 1996; Kaartinen *et al*. 2010), have been considered likely to contribute.

'Negative pressure pulmonary oedema' develops almost instantly after one or two attempts to inspire against the increased resistance of an obstructed airway due to the large negative pressures generated (Senior 2005). Immediate establishment of an airway followed by symptomatic treatment is crucial: oxygen supplementation, anxiolysis, furosemide diuresis, bronchodilation and nonsteroidal anti-inflammatory drug administration have all been described (Senior 2005). Clinical signs of pulmonary oedema include respiratory distress and (blood stained) foam from the lungs pouring out of the nostrils and mouth. Deterioration with hypoxaemia, collapse and cardiac arrest may be rapid.

Upper airway obstruction may be proximal or distal to the larynx or associated with the larynx itself. Congestion and oedema of the nasal passages from increased hydrostatic pressure when the head is positioned below the level of the heart may hinder airflow (Ball and Trim 1996; Borer 2005). Avoiding UAO has been attempted by instillation of phenylephrine into the ventral meatus at the end of anaesthesia to reduce congestion and obstruction without major side effects (Lukasik *et al*. 1997). Alternatively, an orotracheal tube left in situ or a nasal tube placed for recovery may bridge the gap until the nasal passages return to normal function (Thomas *et al*. 1987). However, obstruction from a kinked tube may occur (Kaartinen *et al*. 2010). Deflating the cuff may ensure some airflow around the tube. Orotracheal tubes left in situ may be bitten off or break. One report described successful removal of a nasotracheal tube the next day using endoscopy (Potter *et al*. 2015).

Upper airway obstruction due to bilateral laryngeal paralysis after extubation in horses without pre-existing signs (Abrahamsen *et al*. 1990; Dixon *et al*. 1993; Bidwell *et al*. 2007) were associated with nerve damage due to neck extension, laryngeal nerve ischaemia (Abrahamsen *et al*. 1990), tissue oedema due to surgical manipulation, laryngeal oedema and spasm or functional airway collapse (Dixon *et al*. 1993; Tute *et al*. 1996; Merlin *et al*. 2019). Pre-existing left laryngeal hemiplegia, large body mass, prolonged anaesthesia, hyperextension of the neck, hypotension, hypoventilation and hypoxaemia were named as risk factors for UAO (Southwood *et al*. 2003). Airway surgery may be a predisposing factor but only one case report described UAO after ventriculocordectomy (Tute *et al*. 1996). In horses with unilateral laryngeal paralysis, dorsal displacement of the soft palate (Kollias-Baker *et al*. 1993) and a nasogastric tube left in situ for recovery (Veres-Nyéki *et al*. 2011) caused UAO.

One case report described fatal pulmonary haemorrhage in a horse with pre-existing exercise-induced pulmonary haemorrhage, after partial UAO in recovery and speculates that beside UAO, catecholamine release, hypoxic pulmonary vasoconstriction, the use of alpha-2 adrenergic agonists or blunt trauma may have played a role (Boustead *et al*. 2020).

Pulmonary oedema may be drug associated and is reported after the use of carfentanil and xylazine in horses (Shaw *et al*. 1995). The proposed mechanism may be similar to pulmonary oedema caused by alpha-2 adrenergic agonists in sheep where alpha-2 adrenergic agonist-induced bronchoconstriction and pulmonary vasospasm probably result from direct stimulation of peripheral alpha-2 adrenoceptors (Kästner 2006).

Mechanical causes of increased airway pressure, such as the extrathoracic hydrostatic effects of immersion in a recovery pool, plus associated cardiopulmonary changes, have been described leading to pulmonary oedema (Richter *et al*. 2001; Tidwell *et al*. 2002). Ten out of 60 horses developed pulmonary oedema of which three ended fatally (Tidwell *et al*. 2002). Unsuitable or misused equipment may also lead to pulmonary oedema: demand valves that require high inspiratory pressures may increase airway pressure and the risk of pulmonary oedema (Watney *et al*. 1985; Johnson *et al*. 1994).

Post-anaesthetic colic

Post-anaesthetic colic (PAC) is the most commonly described peri-anaesthetic complication (Proudman *et al*. 2002; Senior *et al*. 2007; Jago *et al*. 2015). In nonabdominal surgery, the incidence of PAC ranges from around one in 33 to one in ten horses (Senior *et al*. 2004; Andersen *et al*. 2006; Senior *et al*. 2006; Jago *et al*. 2015; Bailey *et al*. 2016). Different study designs and the definition of colic may contribute to the variation. The risk of PAC was much higher, one in two to seven, in horses undergoing abdominal surgery (Proudman *et al*. 2002; Mair and Smith 2005b; Brown *et al*. 2015).

Clinical signs developed between 4 h and 5 days after abdominal surgery (French *et al*. 2002; Senior *et al*. 2004; Nelson *et al*. 2013; Jago *et al*. 2015). Most commonly, PAC developed within the first day (Jago *et al*. 2015) or 12–72 h after surgery (Senior *et al*. 2004). A specific diagnosis was often not made, but large intestinal impaction, including caecal impaction, has been implicated (Senior *et al*. 2004, 2006; Jago *et al*. 2015). In most cases, medical treatment was sufficient to abolish PAC (Senior *et al*. 2004, 2006; Andersen *et al*. 2006; Nelson *et al*. 2013; Jago *et al*. 2015). Duration of

PAC lasted from one (Senior *et al*. 2006) to two days (Jago *et al*. 2015).

Horses undergoing orthopaedic surgery are at an increased risk of developing PAC compared with horses undergoing nonorthopaedic surgery (Senior *et al*. 2006) or MRI (Andersen *et al*. 2006). PAC developed in only 1.5% of horses undergoing MRI compared with 7.1% of horses undergoing orthopaedic surgery (Andersen *et al*. 2006).

Morphine appeared to increase the risk of PAC fourfold in horses undergoing elective, nonabdominal procedures (Senior *et al*. 2004). Butorphanol decreased the incidence (Jago *et al*. 2015). However, morphine was not associated with PAC in other studies (Mircica *et al*. 2003; Andersen *et al*. 2006) and may be a confounding factor when the type of surgery is taken into account. Other factors associated with an increased incidence of PAC were sodium benzylpenicillin or ceftiofur administration (Andersen *et al*. 2006; Jago *et al*. 2015), out of hours surgery (Senior *et al*. 2004) and Thoroughbred breeds (Jago *et al*. 2015). Longer duration of general anaesthesia decreased the risk (Andersen *et al*. 2006).

In horses undergoing abdominal surgery, PAC was associated with jugular thrombosis possibly related to endotoxaemia, a high-packed cell volume (PCV) on presentation, colon torsion and re-coeliotomy (French *et al*. 2002).

The above factors have been shown to play a role in the development of PAC; however, the aetiology of colic is multifactorial; changes in management including diet and housing, behaviour, age and parasite infection have been identified as risk factors for development of colic in non-hospitalised horses (Curtis *et al*. 2019). In the hospitalised horse, pain, starvation and anaesthetic drugs are likely also to contribute to PAC.

Post-anaesthetic ileus

Post-anaesthetic ileus (POI) is a specific cause of PAC and is described in 6–40% of horses after abdominal surgery with varying mortality from 14 up to 66% (Mee *et al*. 1998b; Freeman *et al*. 2000; Morton and Blikslager 2002; Proudman *et al*. 2002; Cohen *et al*. 2004; Mair and Smith 2005a,b; Holcombe *et al*. 2009; Torfs *et al*. 2009, 2015; Jacobs *et al*. 2019). The diagnosis is based on small intestinal dysmotility and/or distension with reflux of large volumes of intestinal content, tachycardia, abdominal discomfort, reduced faecal output or absent borborygmy (Lefebvre *et al*. 2016). Re-laparotomy may be required in 8–19% of cases (Parker *et al*. 1989; Proudman *et al*. 2002; Mair and Smith 2005c; Gorvy *et al*. 2008; Brown *et al*. 2015; Findley *et al*. 2017). While the incidence of functional ileus and obstruction appears similar (Mair and Smith 2005c), successful outcome after re-laparotomy varies between 24 and 81% (Parker *et al*. 1989; Mair and Smith 2005c; Dunkel *et al*. 2015; Bauck *et al*. 2017; Findley *et al*. 2017). The incidence of POI may be as high as 62% following re-laparotomy (Mair and Smith 2005c).

Risk factors for POI include duration of anaesthesia and surgery (Roussel *et al*. 2001; Cohen *et al*. 2004) and type of surgery (Roussel *et al*. 2001). The risk of developing POI increased twofold with each hour of surgery. Small intestinal surgery (Roussel *et al*. 2001; Cohen *et al*. 2004; Torfs *et al*. 2009), resection or anastomosis of the intestine (Roussel *et al*. 2001), length of resection (Holcombe *et al*. 2009) and pedunculated lipoma removal (French *et al*. 2002) were associated with an increased risk of developing POI. Other related factors were increased PCV at induction (Blikslager *et al*. 1994; Roussel *et al*. 2001; French *et al*. 2002; Cohen *et al*. 2004; Holcombe *et al*. 2009), increased total protein (Roussel *et al*. 2001; Cohen *et al*. 2004), Arabian breed (Roussel *et al*. 2001; Nelson *et al*. 2013) and increasing age (Holcombe *et al*. 2009; Brown *et al*. 2015). POI was also associated with developing wound discharge, diarrhoea and laminitis (Cohen *et al*. 2004), longer duration of hospitalisation and death or euthanasia (Roussel *et al*. 2001). A recent review article considers this in detail (Lisowski *et al*. 2018).

Complications with arterial and venous cannulation

Arterial cannulation for direct arterial blood pressure monitoring and arterial blood gas analysis is essential for monitoring anaesthetised horses. Associated risks in humans include haemorrhage, thrombosis, sepsis, temporary occlusion, permanent ischaemic damage, haematoma formation and infection (Scheer *et al*. 2002). Destruction of the proximal sesamoid bones has been described in three horses after metatarsal artery cannulation resulting in lameness and subsequent euthanasia in two of these cases (Barr *et al*. 2005).

Venous thrombophlebitis occurs in about one in a hundred horses undergoing nonabdominal procedures (Senior *et al*. 2007) but nearer one in 13 undergoing coeliotomy (Proudman *et al*. 2002; Mair and Smith 2005b). Endotoxaemia increases the risk of developing thrombophlebitis 20-fold, hypoproteinaemia and intestinal disease four- to fivefold (Dolente *et al*. 2005). Other associated factors are increased PCV in horses with colic (French *et al*. 2002), long duration of cannulation (Lankveld *et al*. 2001), increased temperature (Traub-Dargatz and Dargatz 1994; Geraghty *et al*. 2009) and diarrhoea (Traub-Dargatz and Dargatz 1994).

Transient Horner's syndrome after routine jugular venipuncture was reported in two horses (Sweeny and Sweeny 1984). Extravascular thiopentone causes the skin to slough (Jones 1968); confirmation of correct placement of the venous cannula should be vigilantly confirmed prior to using thiopentone.

Inadvertent placement of the venous cannula into the carotid artery is a potential hazard, which should be recognised to avoid inadvertent intracarotid injection. Blood clots can occlude the catheter (Gulick and Meagher 1981) and should not be flushed into the systemic circulation.

Exsanguination and air embolism are potential risks if a cannula cap is dislodged or if the cannula inadvertently disconnects from a fluid line, depending on the direction of the venous cannula placement and position of the horse (Caporelli *et al*. 2009; Parkinson *et al*. 2018; Makra *et al*. 2019). Normal coagulation usually prevents exsanguination from a venous cannula. Clinical signs of venous air embolism range from decreased end-expiratory carbon dioxide, tachycardia and hypotension during general anaesthesia to mild pruritus, agitation and neurological signs including vestibular signs and central blindness to pulmonary oedema and cardiovascular collapse in the awake horse (Bradbury *et al*. 2005; Holbrook *et al*. 2007; Sams and Hofmeister 2008; Caporelli *et al*. 2009; Pellegrini-Masini *et al*. 2009; Sacks and Mosing 2017; Parkinson *et al*. 2018; Makra *et al*. 2019). In 75% of cases in a small retrospective study, resolution of clinical signs occurred within 6 h (Parkinson *et al*. 2018).

Accidental breaking, cutting of the cannula or loss of a guidewire may result in a foreign body in the vascular system, which can lodge in the heart, pulmonary artery or lungs. Penetration of the right ventricle from a cannula tip was reported in a foal (Lees *et al*. 1989). Remnants have been successfully removed from foals and adult horses (Lees *et al*. 1989; Ames *et al*. 1991; Hoskinson *et al*. 1991; Scarratt *et al*. 1997; Little *et al*. 2002; Culp *et al*. 2008; Nannarone *et al*. 2013). Removing the cannula embolus in adult horses is more difficult; appropriately long equipment is needed, and imaging the foreign body clearly is difficult even if a radiopaque cannula is used (Scarratt *et al*. 1997; Nannarone *et al*. 2013).

Complications with myelography

Cervical myelography can cause multiple adverse effects related to idiosyncratic reactions to the contrast agent and alterations in craniospinal volume or pressure. Adverse reactions occurred in a third of horses undergoing cervical myelography with iohexol, including hypotension during general anaesthesia, hyperaesthesia, focal or generalised seizures, peripheral neuropathy, myopathy, blindness, ataxia and reduced mentation (Mullen *et al*. 2015). Longer anaesthesia and higher volume of contrast increase the likelihood of adverse reactions (Mullen *et al*. 2015). Manipulation of the head and neck during myelography may result in tracheal lesions causing (pleuro)pneumonia (Rainger *et al*. 2006; Mullen *et al*. 2015). Worsening of the neurological signs can be expected in 25% of horses (Hubbell *et al*. 1988; Mullen *et al*. 2015).

Adverse drug reactions

Adverse drug reactions are well recognised in human medicine and can be classified as augmented (dose-dependent and predictable) or bizarre (dose-independent and unpredictable; Patton and Borshoff 2018). Either the active compound, the preservative or additives may contribute to the reaction and affect organ systems or receptors directly, cause allergic or anaphylactoid reactions or lead to acute toxicity.

Examples of 'augmented' adverse drug reactions in equine anaesthesia include haemodynamic effects of drug administration but may also focus on decreased gastrointestinal motility after administration of opioids (Boscan *et al*. 2006; Figueiredo *et al*. 2012), alpha-2 adrenergic agonists (Merritt *et al*. 1998; Elfenbein *et al*. 2009; Mama *et al*. 2009) or anticholinergic drugs (Roberts and Argenzio 1986).

In the horse, anecdotal 'bizarre' reactions to various drugs are recognised in practice but the literature is sparse. Sodium penicillin administration causes a transient (10 min) decrease in arterial blood pressure by 8–15 mmHg in anaesthetised horses but the cause remains undetermined (Hubbell *et al*. 1987). Dysrhythmias and hypotension, followed by cardiac arrest in few cases, have been reported after intravenous administration of trimethoprim/sulphonamide in horses when combined with detomidine (Dick and White 1987; Taylor *et al*. 1988; Parson 1989).

Seizure-like activity has been reported in a foal after gadolinium administration for magnetic resonance imaging and after treatment the foal recovered uneventfully (Argano *et al*. 2018).

Pruritus after extradural administration of morphine in horses was described (Haitjema and Gibson 2001; Burford and Corley 2006) and while histamine release is speculated to be causative, the molecular mechanism has not yet been determined.

Priapism that required medical management was reported in a gelding after premedication with acepromazine (Taylor and Bolt 2011). However, the prevalence of penis prolapse after acepromazine administration was encountered in less than one in 10,000 cases and described to be transient with less than 1–6 h of duration and not requiring intervention in majority of cases (Driessen *et al*. 2011).

Human error and equipment failure

There is, as yet, little documentation on the effects of human error in equine anaesthesia. This includes, for example, inadvertent arterial injection of a drug, injection of the wrong drug, dosing errors and failure to check equipment.

Human error contributes to 51–77% of human anaesthesia related mortality and has been associated with lack of experience or competence in the vast majority and errors of judgment in a few cases (Lienhart *et al*. 2006). Teamwork and communication were identified as contributing factors (Lienhart et al. 2006; Haller *et al*. 2011). The risk of mortality was reduced if a senior anaesthetist was available (Arbous *et al*. 2005). In human medicine, it is recognised that 'the presence of an appropriately trained and experienced anaesthetist is important for the safety during anaesthesia' (Checketts *et al*. 2016). Anaesthetist competence includes not only practical skills and theoretical knowledge but also non-technical skills, understanding of work and intuitive expert knowing (Larsson 2017). It seems likely that anaesthetist skill and experience has a similar effect in equine anaesthesia, and it is to be hoped that the fourth Confidential Enquiry into Perioperative Equine Fatalities (CEPEF-4; Gozalo-Marcilla *et al*. 2020) will elucidate this.

Few reports acknowledge human error in equine anaesthesia. Detomidine overdose resulted in prolonged recovery; this was successfully rectified with an antagonist once the cause had been recognised (Di Concetto *et al*. 2007). Accidental overdose of lidocaine in a foal caused cardiac arrest but treatment with intralipid and cardiopulmonary resuscitation was successful (Vieitez *et al*. 2017). Accidental administration of unfractioned heparin resulted in cancellation of surgery and prolonged clotting times (Pekkola *et al*. 2018). Inadvertent mixing of drugs, for example thiopentone and ketamine, which are both used to deepen anaesthesia, may lead to undesirable adverse effects as they form a glue-like plaque when combined.

Interventions associated with surgery may influence physiological function. Hypertension and tachycardia have been reported after application of a tourniquet; these resolved after tourniquet removal (Abrahamsen *et al*. 1989).

Failure to check or identify malfunctioning anaesthetic equipment prior to use may lead to complications: malfunction of the oxygen concentrator and the auxiliary oxygen supply causing hypoxaemia (Kropf and Hughes 2018); malfunction of the inspiratory valve resulting in hypercapnia (Baxter *et al*. 1991) or inability to mechanically ventilate the patient (Pleyers *et al*. 2020); ventilator bellows leaking into the breathing system causing increased airway pressure and decreasing depth of anaesthesia (Klein and Wilson 1989); rebreathing due to an incompetent expiratory valve leading to severe hypercapnia (Thompson 2014); positive-end-expiratory pressure and increased airway pressure caused by slipping of leucoplast tape that was applied to prevent a leak between endotracheal tube and connector (Gregson and Clutton 2012) or by a dysfunctional expiratory flow regulator (Cruz-Benedetti *et al*. 2017); unrecognised wear of the endotracheal tube cuff leading to overinflation, herniation of the cuff and airway obstruction (Richardson and McMillan 2017); underestimation of arterial blood pressure due to a broken pressure transducer interface (Le Chevallier and Van Oostrom 2020). Failure of the equipment or to secure it adequately and interference by the person operating the ropes have resulted in complications during rope-assisted recovery (Rüegg *et al*. 2016; Bird *et al*. 2019; Arndt *et al*. 2020).

Demand valves must be used carefully to avoid increased dangerously high airway pressure. If oxygen is supplied via a nasal, nasotracheal or orotracheal tube, it must not impede expiration or baro- or volutrauma may occur, especially in smaller horses.

Ocular damage

Corneal erosions or ulcers can develop during general anaesthesia due to reduced tear production, abrasion or scratching during positioning (Hubbell *et al*. 1988; Jago *et al*. 2015; Mullen *et al*. 2015). Clinically asymptomatic corneal erosions have been reported in almost 20% of anaesthetised horses despite routine use of eye lubrication and were associated with duration of anaesthesia and lateral recumbency (Scarabelli *et al*. 2018). Cautious preparation for surgery or arterial cannulisation to avoid contamination of the eye with cleaning fluids and tissue glue, as well as careful identification of eye lubricant to prevent inadvertent use of the wrong, possibly irritant materials are recommended.

Conclusion

Equine anaesthesia harbours a variety of risks for the patient, the anaesthetist and the other staff involved. Causes and risk factors for peri-anaesthetic mortality have been identified and continue to be the focus of current research although most still depends on retrospective evaluations. The unchanged mortality rate over the last decades is disappointing and invites further large prospective research studies. Hopefully CEPEF-4 (Gozalo-Marcilla *et al*. 2020) will provide some answers for both mortality and morbidity.

This narrative review summarises the current literature, including case reports, with the aim of providing a complete overview of equine peri-anaesthetic mortality and morbidity and raising awareness of the large variety of complications.

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J. Deutsch prepared the manuscript. J. Deutsch and P. Taylor contributed to design, interpretation and critical revision of the article. All authors gave the final approval of the manuscript.

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