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Lameness Imaging in the Sports Medicine Era: It’s Not Fractures Anymore

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1. Introduction

The use of imaging modalities such as radiographs, ultrasound, nuclear medicine, computed tomography, and magnetic resonance imaging (MRI) have all aided in creating methods to identify abnormalities in the equine patient. Ten years ago, equine patients would have a lameness that was easily identified and imaging yielded a diagnosis. However, as owners and trainers have become more in tune with the equine athlete and the imaging modalities have become more advanced, it is not uncommon to have 6 to 10 imaging abnormalities identified without a clear or single diagnosis as the cause for the lameness. This shift from surgical lameness to sports medicine with the prevalent diagnosis being soft tissue injuries has led to the creation of the American College of Veterinary Sport Medicine and Rehabilitation.

With all of the existing imaging modalities and the increased availability of standing MRI and nuclear medicine to the practitioner, it is rarely the availability of the modality that is the limitation. In certain cases, an accurate or specific diagnosis is still lacking. In the equine realm, most imaging interpretation is done by practitioners or specialists with experience; however, board-certified radiologists have an integrated knowledge of all of the modalities and how they work together to help determine the specific modalities that have the best chance of seeing lesions and can help make a diagnosis. This knowledge allows for understanding the limitations of the modality and furthermore, understanding that a negative study provides both a list of differential diagnoses and excludes many differential diagnoses, which is something that is sometimes overlooked.

The purpose of this review is to discuss the use of radiographs, nuclear medicine, and standing MRI in the equine patient and describe the limitations and methods to overcome these limitations.

2. Radiographs of the Neck: How Good are We at Injections?

Radiographs of the cervical spine are now available to practitioners, thanks to digital radiographic systems. With digital radiography and a small X-ray generator, which used to only be available with larger X-ray tubes, images of the caudal cervical spine to T1 have become part of standard practice. This has led to increased diagnosis and treatment of neck pain in horses. However, have you ever wondered how skilled we are placing a needle in the joint and keeping the material in the joint recess?
At Michigan State University, a resident injected the cervical facet joints of 10 horse from C2–3 to C6–7 using contrast medium and 2 different techniques. The results are what you would expect. The C2–3, C3–4, C4–5, and even C5–6 were repeatedly injected with a majority of contrast material present inside the joint. Injection of C6–7 was much more variable. When the facet joints were missed at C6–7, the contrast material was injected in C7-T1 or just less than 50% of the contrast medium within the C6-C7 joint.

The technique to inject cervical facets with ultrasound guidance will be reviewed but briefly, a curved 8 MHz microconvex or linear >7 MHz ultrasound probe should be used. A 20-gauge needle can be used to inject the joint; however, if hyaluronic acid is being administered, an 18-gauge needle is recommended. The probe should be oriented in a dorsoventral direction and the joint identified as a V-shaped hyperechoic region and the joint capsule can be seen. The needle should be directed into the V-shaped joint space. When injecting, minimal fluid should be seen around the bone and fluid placed in the joint will cause expansion of the joint capsule.

3. Nuclear Medicine: The Underused and Over-Interpreted Modality

Nuclear medicine (also called scintigraphy) is performed using a radiopharmaceutical that binds specifically to hydroxyapatite crystals. Basically, rather than a radiograph that sends radiation through a bone to a detector to see how much can pass through, nuclear medicine provides a radioactive source to the horse and then, with the help of a binding agent, finds areas where osteoblasts are turning over bone. The difficulty with this modality is that bone turnover occurs for numerous reasons. The physis of a foal will normally have a high degree of osteoblast activity and even fractures can continue to heal for up to 3 years after the initial insult. Therefore, the main limitation of nuclear medicine is that it shows bone remodeling, not a source of inflammation or pain. Increased activity can help determine a region of interest for follow-up with radiographs. However, even osteophytes on radiographs do not necessarily correlate to a lameness. The main goal of the nuclear medicine study is to take a complicated multilimb lameness and see if it can be narrowed down to specific regions that cannot be characterized during the physical examination.

Soft tissue can be evaluated by nuclear medicine. This is done based on the premise that increased blood flow will be present when an inflammatory process is present and, therefore, performing the imaging scan at 5 min after injection will show the “soft tissue phase” of imaging. This can also be done using technetium pertechnetate without a binding agent to just see the circulation of the radiopharmaceutical. Imaging immediately after injection can be done to assess blood flow (called the “vascular phase”); if a vascular anomaly is suspected, such as blood clot or vasculitis, unbound technetium can be used to look at the perfusion of the distal limbs. Case examples of this will be provided in the oral presentation.

4. Standing Magnetic Resonance Imaging and Elastography: A Fad or Here to Stay?

There is probably no more widespread expansion of imaging in the last 10 to 15 years that is greater than the use of MRI on the equine athlete. From soft tissue injuries to cartilage damage, MRI has taken the equine market by storm. Also, with the availability of standing MRI, general practitioners and specialists have developed equine imaging facilities to focus on the equine athlete and subtle lameness that is the most common presentation being seen by the equine practitioners.

In addition, a new modality called elastography using ultrasound has recently been reported and shown to be repeatable and easy to use on normal horses to assess tendons and ligaments in horses. A paper from North Carolina State University showed a difference in the elastography or “stiffness” of tendons in weight bearing as well non-weight bearing positions. This program is now available with portable ultrasound units and may become more widespread. More research needs to be done; however, there is a chance this may serve as a method to identify microtears prior to core lesions in horses.

Standing MRI is by far more widespread; however, the limitation of this system is the field strength and patient motion. Since standing units have a small magnetic field, allowing them to be put in any facility and requiring minimal maintenance and power, the resolution is considerably less when compared to high-field systems, especially when smaller structures are being imaged, such as cartilage that is less than 5 mm thick. The level of detail that is discussed by clinicians versus what can be seen in a research environment is quite different. Standing MRI can be used to evaluate tendons and ligaments, bone edema, and even fractures. The size and severity of the lesion must be enough to allow detection using a low-field system. Limitations with magic angle artifacts and simple image noise makes over-interpretation easy, especially when a subtle lameness is present. Also, it is not uncommon to find 8 to 10 subtle lesions in a foot on standing MRI and the question is “which one is causing the problem?”

Ultimately, this one-hour lecture will show several case examples of state-of-the-art imaging available to practitioners and specialists alike. A major limitation in imaging of the equine patient is that currently there seems to be a lack of understanding of some of these modalities and, therefore, they are not used to their full potential. That said, researchers and clinicians are constantly studying...
these modalities and continue to improve our understanding of how best to use and interpret the images. In the realm of noninvasive imaging, the future looks bright and the availability to start critically evaluating treatments is just around the corner.

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Conflict of Interest
The Author declares no conflicts of interest.

References
Comparison of Radiography, Scintigraphy, and Magnetic Resonance Imaging Techniques: How Does One Image Compare to Another?

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Each imaging modality has its own strengths and weaknesses. Knowing the caveats of each will help determine what modalities to use and how to interpret the findings. Author’s address: Alamo Pintado Equine Medical Center, 2501 Santa Barbara Ave., Los Olivos, CA 93441; e-mail: carter@alamopintado.com. © 2014 AAEP.

1. Introduction

Advanced imaging techniques such as magnetic resonance imaging (MRI) and scintigraphy have helped to improve the diagnostic capabilities in the horse. They have allowed a unique perspective into many problems that previously may have been difficult to determine otherwise. With the proliferation of these different imaging modalities, they are being performed much more commonly and, often, in conjunction with each other. The purpose of this presentation is to discuss how MRI, scintigraphy, and radiographic imaging techniques relate to each other and to discuss some of the benefits and pitfalls of each and how over- and under-interpretation of various imaging modalities occur.

2. Scintigraphy and MRI

Nuclear scintigraphy has been used in equine orthopedic imaging to identify physiologic changes in bone and soft tissue metabolism and has been used to identify regions of lameness for decades. While it requires a regulatory license and involves the use of radioactive labeled isotopes, it is still a simple relatively non-invasive diagnostic technique that is performed standing under light sedation. The entire horse can be screened using this technique.

Magnetic resonance imaging (MRI) is the gold standard in imaging human orthopedic conditions and is quickly becoming more commonly available to equine veterinarians. It can be performed in the standing patient using a low field system or in the anesthetized patient using either a low or high field imaging system. The high field systems provide very detailed information about both physiology and anatomy.

Both of these techniques have traditionally been considered in isolation when considering imaging a patient. Scintigraphy is often used when the region of lameness is unknown or indeterminate using routine techniques such as nerve blocks to localize the area of pain. Magnetic resonance imaging is used when the area of pain is known but the cause has not been well established using other techniques. The question that often comes up when using scintigraphy is “what does that scintigraphy
Fig. 1. Plantar scintigraphic projection of the hock region with focal increased uptake of the right hind proximal metatarsus. Transverse T1 image of the proximal metatarsus of the right hind limb in the same region as the scintigraphic uptake showing only suspensory ligament pathology.

Fig. 2. MRI images of the region of increased uptake on the scintigraphy examination. A, Proton density axial, B, T2 short tau inversion recovery (STIR) axial, C, T1 VIBE FS axial, D, proton density FS axial, E, T2 STIR sagittal, and F, T2 STIR dorsal. Note the increased signal (white area in the palmar aspect of MC3) on images B–F and decreased signal on A. This is consistent with bone “edema.” Note the normal appearance to the suspensory ligament, which contains fat and muscle, creating a region of light gray and white within the black ligament fibers.
uptake pattern mean,” and “what might that look like on an MRI?” What the client often asks is “is it necessary to do an MRI?”

The comparison of MRI to scintigraphy has been previously reported and initially showed that the correlation of soft tissue injuries is poor between MRI and scintigraphy while the correlation of bone injuries was high between the two modalities in the foot.¹ This was expanded upon by the evaluation of scintigraphic uptake in the proximal metacarpus (tarsus) and the findings on MRI of the same region in the same horse.² This study showed a trend in the ability to use the relative degree of uptake on the scintigraphic examination to predict the likelihood of a soft tissue-only injury, bone-only injury, or both in the proximal metacarpus (tarsus). While a direct correlation was not possible, it does allow for a relative ability to predict the likelihood of relative involvement of bone, the associated soft tissues such as the suspensory ligament, or both. Interestingly, the more intense the uptake on the scintigraphy exam, the more likely that the lesion is going to involve a majority of bony tissue. Alternatively, if the uptake is relatively faint, it can represent a soft tissue injury. Figures 1 and 2 show examples of these correlations.

There are pathologies that are only evident on MRI and have negative scintigraphic findings. An example of this is the medial collateral ligament injury that does not involve either the origin or insertion. A true soft tissue injury is much less likely to have scintigraphic abnormalities when compared to MRI (Fig. 3). This is likely due to the fact of the relative lack of blood flow to the injury and decreased perfusion of the radioisotope, the specificity of the radionuclide for osteoblasts and bone, and the lack of fidelity of small structures on scintigraphy.

There are situations where the scintigraphic examination proves much more sensitive for a particular problem than the MRI. Certain pathologies involving the coffin bone, navicular bone, and long pastern bone have been identified on scintigraphy with “normal” MRI examinations of these regions. Figure 4 shows an example of severe inflammation of the coffin bone on the scintigraphic exam with a “normal” MRI examination. The reason for studies with discrepancies such as these are unclear. The affinity of the technetium 99m methylene diphosphonate for remodeling bone is extremely high, thus an abnormal bone uptake pattern would be anticipated with a bone type of injury. The MRI signal characteristics usually will show abnormalities in the fat-suppressed (short tau inversion recovery [STIR] of other fat suppression techniques) or T1 weighted images consistent with edema or inflamed tissue. It is possible that the intra-osseous pressure within the bone is too high for the extravasation of fluid that can be detected on MRI, but the cellular activity is great enough to attract the technetium 99m methylene diphosphonate and result in a positive scintigraphic examination and a negative MRI. This type of situation appears to be relatively rare, but does occur, and should be considered when...
a lameness has been precisely localized to a particular region and the MRI is negative.

In summary, MRI and scintigraphy can be thought of as complementary modalities and the use of one should not exclude the use of the other. Scintigraphy is a useful topographical technique to help localize difficult lamenesses and some patterns can infer that certain pathologies are occurring, especially when it relates to a bony issue. However, with soft tissue lesions, the underlying pathology from a positive scintigraphy examination is less clear.

3. Radiographs and MRI

The use of radiographs for the equine patient is paramount for accurate diagnoses and is probably the most commonly used diagnostic modality in the horse. From routine osteochondral fragments in the joints of horses to the most complex fractures, traditional radiography has proven to be essential in equine practice. With the advent of digital imaging modalities and the instant feedback provided by digital radiographic units, the use of radiography has become even more important.

One of the main problems associated with radiography is that it is typically limited in scope to bony problems. While some soft tissue changes can be ascertained, the focus of radiographs is to provide an evaluation of the bony structures of an object. Digital and computerized systems have improved upon the soft tissue evaluation over traditional film based systems. A large change in bone mass or density is required for pathologic changes to be visible to the observer. This change in density is reported to be as great as a 30 to 50% change in density before a pathologic change is identified. This means that a
A large change in bone density is required before the observer can adequately determine it.

Additionally, the traditional radiograph is a two-dimensional representation of a three-dimensional structure. This results in summation of structures, which can obscure lesions and be a significant disadvantage when trying to interpret radiographs. However, in some cases summation can actually serve as an advantage and make the observation of the abnormality more noticeable. For example, osseous proliferation at the margins of joints are most frequently easier to observe on a radiograph than on an MRI. This is due to the fact that the osseous proliferation is summated and combined on the radiograph, whereas on the single-slice MRI it is isolated on each area. This can make radiography easier to interpret peripheral bony changes and osseous proliferation.

In most situations however, the MRI is more sensitive than radiographs for deciphering the pathology occurring in the area of concern. While the radiographs look at the bony density of a structure and relies on changes in that density to detect pathology, the MRI uses the chemical composition of the tissue to derive its images. This makes physiological changes in the bone more likely to appear on the MRI than on a radiograph. A prime example of that is the identification of bone edema in the absence of radiographic abnormalities (Fig. 2).

Magnetic resonance imaging is also more sensitive at detecting small obscure issues that might be missed using routine radiographic projections. A small osseous “avulsion” fragment of the coffin bone at the palmar insertion of the medial collateral ligament of the coffin joint is very hard to detect on radiographs, but is a relatively simple diagnosis on MRI (Fig. 5).

In summary, radiographs remain a very pertinent diagnostic modality and may be more sensitive for certain bony pathologies such as osteophytes. However, a lame horse with a negative radiograph may have more bony pathology occurring than is present on even the best set of radiographs.
4. Conclusion

Imaging the equine patient can be a complicated process. Negative results on one modality do not preclude the absence of a problem in the patient and an alternative imaging technique may provide more insight into the pathology of a particular patient.

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Conflict of Interest

The Author declares no conflicts of interest.

References


Ultrasound in Equine Practice—Where We’ve Been, Where We Are Now, and Where We Need to Go

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1. Introduction
Ultrasound has been in use in equine veterinary medicine since the early 1980s, steadily gained traction in the late 1980s and early 1990s, and has gradually become widely available for veterinarians to diagnose all types of equine medical and surgical disorders. Ultrasound has been propelled forward by a particularly diverse group of equine veterinarians, ranging from anatomists to internists to surgeons to radiologists and nonboarded specialists. As we look back over the past 35 to 40 years, it is most impressive that ultrasound remains an imaging modality not fully embraced in veterinary education or residency training, despite its widespread use in equine practice. While we have made significant strides, it is curious that exams and indications remain unstandardized, education at the veterinary school level is minimal at best and, with few exceptions, ultrasound is often omitted or minimized within comparative imaging studies. It is important to understand the history of ultrasound in equine veterinary medicine to appreciate the path we have taken to ultrasound in practice today, especially as we plan for the future in this important imaging modality. The purpose of this report is to look back at where we’ve been, how it led us to where we are today, and where we still need to go. It represents the author’s views as a nonboarded specialist in academia combined with historical commentary and viewpoints from several of today’s thought-leaders in equine ultrasound.

2. Where We’ve Been—The Early Years
The roots of ultrasound in equine veterinary medicine can be traced back to the late 1970s. Dr. Virginia Reef, then a veterinary student at the Ohio State University, worked with cardiologist, Dr. Frank Pipers, to perform blind M-mode exams of the equine heart. Meanwhile, Dr. Norm Rantanen, then a radiologist at Washington State University (WSU), became interested in pursuing “alternative” imaging, which, at the time, included ultrasound, nuclear scintigraphy, and computed tomography (CT). Ultrasound ultimately won out due to its relatively low costs, and efforts were put in place at WSU to purchase the first B-mode ultrasound machine for use at a veterinary school. This machine was purchased for $62,500 from Unirad Ultrasound in Denver, Colorado. It was a static (not real-time) B-mode scanner. Image acquisition required that the animals remain completely still. The machine was huge and weighed several hundred pounds (Fig. 1). Images were acquired through the use of a cumbersome reticulated arm, which limited studies to tho-
racic and abdominal exams since the arm could not reach the equine distal limb unless the horse was under general anesthesia. The first real time B-mode scanner was obtained by WSU in 1982 (Fig. 2). This machine expanded the use of ultrasound to many regions, including musculoskeletal exams in the standing horse. This piqued the interest of Michael Hauser, who was then a veterinary student at WSU. Hauser subsequently worked with Dr. Rantanen to publish some of the first works on equine musculoskeletal ultrasound.1–3 Shortly thereafter, Dr. Rantanen relocated to Kentucky, where he then collaborated with internist Dr. Doug Byars to develop techniques to evaluate and characterize many disorders, but especially pneumonia in foals and twin reductions in broodmares.

Meanwhile, on the East Coast, Dr. Virginia Reef had taken over “Heart Station” at the University of Pennsylvania’s New Bolton Center while an internal medicine intern in the early 1980s. Ultrasound equipment at Heart Station was similar to that used by Dr. Rantanen at WSU until the mid-1980s when a more portable real-time system became available. This machine facilitated expansion beyond echocardiographic studies. Although all types of ultrasound exams were, and continue to be, performed by this service, the term “Heart Station” has endured over time. Dr. Reef managed to lead Heart Station through her internal medicine residency and remains in charge to this day. Heart Station is the first known service dedicated to equine/large animal ultrasound at any U.S. veterinary school. The roots of many ultrasonologists, both in the U.S. and abroad, can be traced to Dr. Reef and her team at New Bolton Center. This includes the author and many of today’s ultrasound leaders, including Dr. Johanna Reimer, who became both a boarded internist and cardiologist, published one of the first books on equine ultrasound in 1998,4 and led ultrasound at one of the largest private practices in the country for several years.

The history of ultrasound in equine practice would not be complete without mention of Dr. Ron Genovese, owner of Randall Veterinary Hospital near Cleveland, OH (currently at Cleveland Equine Clinic). Dr. Genovese is considered one of the early pioneers and visionaries of equine ultrasound. With a busy racetrack practice, Dr. Genovese had become frustrated with the limitations of radiography and the number of racehorse breakdown injuries. He was looking for alternative means to detect injuries that could potentially predispose horses to breakdown. Dr. Genovese found it in a hotel room at the 1982 AAEP meeting. Without a trade show, vendors hosted sessions in hotel suites to show their wares. Steve Dumond, later the owner of Classic Ultrasound, hosted a session with Dr. Norm Rantanen to show ultrasound images he had been acquiring at Washington State University. Dr. Genovese was immediately intrigued, purchased a machine (Fig. 3), and invited Dr. Rantanen to Cleveland to learn techniques for distal limb ultrasound (Fig. 4). Within a few years, these efforts were presented at the first in depth session on ultrasound at the 1985 AAEP Convention in Toronto, Canada5–7 and also within the first major work on equine ultrasound, the April 1986 edition of Veterinary Clinics in North America.8 Soon after, Dr. Genovese became host to veterinarians from all over the world who wanted to learn more about this new imaging modality. Drs. Genovese and Rantanen also began teaching short courses to disseminate their knowledge. Such wet labs eventually became part of AAEP meetings.

![Fig. 1. Abdominal ultrasound on a horse using a static B-mode scanner (Unirad Ultrasound) at Washington State University with technician, Bob Ewing. Notice the extremely large size of the machine and the reticulated arm that prevented imaging of distal limbs in the standing horse. Image provided courtesy of Dr. Norm Rantanen, circa 1980.](image1)

![Fig. 2. Dr. Norm Rantanen, then faculty radiologist at Washington State University, performs a renal ultrasound exam on a horse using a real-time B-mode scanner (MK100 Ultrasound System, Advanced Technology Laboratories, Inc). Image provided courtesy of Dr. Rantanen, circa 1982.](image2)
Back on the west coast, University of California (UC) Davis was incubating its own large animal ultrasound service. In the late 1980s, Dr. Carol Gillis began performing musculoskeletal ultrasound exams during her equine surgery residency to resolve a client service problem. At the time, horses were being kept overnight until a radiologist became available to perform an ultrasound exam. Similar to many institutions, it was difficult for the radiologists to prioritize equine ultrasound exams over their busy small animal imaging caseload. Because Dr. Gillis had already developed a reputation for ultrasound as a private practitioner in the Northern California Bay Area, she was the ideal solution to this problem. Dr. Gillis had been inspired by Dr. Genovese’s presentations on distal limb ultrasound at the 1985 AAEP Convention in Toronto, Canada. Dr. Gillis eventually staffed the Large Animal Ultrasound Service full time after her residency until she left for private practice in 1999. Although the Large Animal Ultrasound Service at UC Davis was modeled after New Bolton Center’s Heart Station, the two services have retained somewhat distinct personalities, traceable to their surgical and internal medicine origins, respectively.

Publications
A PubMed search for “ultrasound and horse” reveals one of the earliest publications to be authored by Dr. Frank Pipers in 1977 on the topic of equine echocardiography.9 Dr. Pipers authored several ultrasound publications in the early 1980s, primarily on echocardiography but also on the use of ultrasound for pregnancy diagnosis and monitoring with transrectal and transabdominal approaches.10–14 The use of ultrasound to diagnose early single and twin pregnancies had also been described by a group from Newmarket in 1982.15 Other early publications included the use of ultrasound to diagnose one of 4 horses with cholelithiasis in a 1982 Journal of the American Veterinary Medical Association (JAVMA) article16 and to detect fistulous tracts and foreign

Fig. 3. One of the first portable ultrasound machines (ATL) in equine practice purchased in 1983 by Dr. Ron Genovese (Randall Veterinary Hospital, Warrensville Heights, OH). Images were “captured” with the Polaroid camera mounted on the left side of the machine. Once an image was frozen and labeled, the camera was swung over the screen and a photo taken of the image for documentation of the exam. Image provided courtesy of Dr. Genovese, Cleveland Equine Clinic, Ravenna, OH.

Fig. 4. Metacarpal ultrasound (1984–85). A, Placement of a mechanical sector transducer to obtain transverse metacarpal images. B, Transverse ultrasound image of a large tear of the suspensory ligament body. C, Longitudinal image showing fiber disruption in a similar injury in another horse. Images provided courtesy of Dr. Ron Genovese, Cleveland Equine Clinic, Ravenna, OH.
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bodies in horses in 1984.\textsuperscript{17} Ultrasound for musculoskeletal imaging was first embraced by the Journal of Equine Veterinary Science.\textsuperscript{1,3,18,19} The first substantial works on ultrasound were published in two editions of Veterinary Clinics of North America dedicated to cardiology (1985) and ultrasound (1986).\textsuperscript{8,20}

Equine ultrasound steadily gained traction throughout the 1980s, and the early- to mid-1990s represented the culmination of many groups’ efforts. By this time, ultrasound visionaries had sufficient time to accumulate cases to publish both retrospective and prospective studies. Many studies focused on the use of abdominal ultrasound, but several reported on musculoskeletal ultrasound. Much of the latter described the normal and abnormal appearance of the superficial digital flexor tendon, especially in racehorses.\textsuperscript{21–27} While such intense focus on the superficial digital flexor tendon (SDFT) provided tremendous information on tendon injuries and healing, it may be argued that this information has hindered our knowledge of musculoskeletal soft tissue injuries. Unfortunately, and sometimes erroneously, this information continues to be extrapolated to other tendon or ligament injuries, especially as it relates to injury staging and ultrasonographic monitoring of healing. While the SDFT garnered most of the attention, publications on other distal limb injuries also began to emerge, including studies on injury distribution\textsuperscript{28–33} and individual structures such as the suspensory ligament, inferior check ligament, and deep digital flexor tendon.\textsuperscript{33–40} Veterinary Clinics of North America published a pair of editions in 1994 and 1995 on the topic of tendon and ligament injuries with Dr. Sue Dyson as the guest editor.\textsuperscript{41,42} This era also featured early descriptions of ultrasound to evaluate bone, specifically to diagnose pelvic fractures in racehorses.\textsuperscript{43–44}

In terms of abdominal ultrasound, multiple descriptions of renal, hepatic, and splenic abnormalities were published in the early 1990s, including the use of ultrasound to diagnose cholelithiasis, urolithiasis, and lymphosarcoma in horses.\textsuperscript{45–48} Ultrasound to evaluate the gastrointestinal tract also began to take hold as authors published techniques to diagnose left dorsal displacements, right dorsal colitis, and intussusceptions in foals, among others.\textsuperscript{49–54} Of these, a 1996 prospective study out of Chino Valley Equine Hospital in Southern California was one of the most influential publications on the use of ultrasound in the acute abdomen. The authors reported findings from 226 horses with colic and found ultrasound to be highly reliable to detect small intestinal strangulating obstructions.\textsuperscript{52}

Surprisingly, it wasn’t until the late 1990s that textbooks dedicated to equine ultrasound were finally published. These included Equine Diagnostic Ultrasonography, edited by Drs. Norm Rantanen and Angus McKinnon.\textsuperscript{55} Equine Diagnostic Ultrasound by Dr. Virginia Reef,\textsuperscript{56} and the Atlas of Equine Ultrasonography by Dr. Johanna Reimer.\textsuperscript{4} All were published in 1998 and have remained the primary resources available to equine veterinarians for more than 15 years.

Equipment

The evolution of ultrasound equipment has been impressive. The articulated arms of the 1970s and 1980s were gradually replaced by sector and then linear array transducers in the mid-1980s and 1990s. Whereas the size and expense of the original ultrasound machines limited their use to academic institutions, ultrasound gradually migrated into equine private practice in the mid to late 1980s when somewhat portable machines capable of real-time B-mode imaging became available. Early transrectal exams for reproductive imaging were often performed with large sector transducers with an offset beam. Reproductive ultrasound with linear transducers was initially problematic because of their poor lateral resolution and lack of focal zones. This significantly affected the examiners’ ability to distinguish between pregnancies and uterine cysts or ovarian follicles or between twin and singleton pregnancies. Sector transducers were the norm until the mid- to late 1990s when linear transducers became more widely available for musculoskeletal and rectal imaging. Linear transducers of this decade provided improved resolution compared to their sector counterparts but, more importantly, allowed evaluation of fiber pattern across the entire image when performing longitudinal views of tendons and ligaments (Fig. 5). Low frequency (2–5 MHz) curvilinear array transducers became available in the mid-1990s, but their value was initially limited by poor penetration relative to sector transducers. Over time, curvilinear transducers improved in terms of penetration, resolution, and detail and have now replaced sector transducers for equine abdominal work (Fig. 6).

The Ausonics Opus and its next generation, the Ausonics Impact, became the machine to own in equine hospitals in the mid- to late 1990s. While this machine could be taken “mobile,” ambulatory practitioners bought more portable machines from Aloka, Pie Data, and Medison. These machines were primarily geared for reproductive use but could also be used for musculoskeletal imaging. Driven by advances in medical ultrasound, image quality steadily improved, especially in larger clinic based equipment. Linear rectal transducers were available for most machines marketed to equine veterinarians. With frequencies of 5 to 7 MHz, these transducers could also be used for basic tendon and ligament ultrasound and were certainly adequate to diagnose acute SDFT or suspensory ligament injuries. In the late 1990s and early millennium, linear transducers designed for musculoskeletal use became increasingly available for portable machines. These “tendon probes” were more ergonomic for musculoskeletal imaging than rectal transducers and offered higher frequencies (10–13 MHz) to im-
prove resolution of tendons and ligaments (Fig. 7). This began the rapid expansion of equine musculoskeletal ultrasound, both in terms of diversity and quantity.

Specialists and Education

The 1990s and new millennium began to see veterinarians emerge from the fellowship program at New Bolton Center. Fellows received extensive training for 1 to 2 years, during which time they learned systematic techniques to evaluate a busy and diverse caseload from the surrounding Chester County horse country. UC Davis followed with its own fellowship program in 2001. Several graduates of these fellowships have gone on to academic positions and some have developed their own programs. Others have set up their own ultrasound consulting services in private practice.

The AAEP began holding annual ultrasound wet labs in association with its annual convention and then in Lexington at the Kentucky Horse Park.

Fig. 5. Comparison between sector (A) and linear (B) transducers to evaluate fiber pattern. Both longitudinal images were obtained at the proximal metacarpus. Image A was obtained with the 7.5 MHz fluid-offset sector transducer shown below the ultrasound image. Note that the fiber pattern can only be evaluated in the central part of the image with this type of transducer. Image B was obtained using the 7 to 10 MHz linear array transducer with a standoff shown below the image. Note the superior evaluation of fiber pattern across the width of the ultrasound image with linear transducers compared to sector transducers. Linear transducers became available in the mid-1990s and have replaced sector transducers for musculoskeletal imaging.

Fig. 6. Abdominal ultrasound images of the spleen and left kidney from 1999 through 2014 with the transducers shown above each image. A, A 2.5 MHz sector transducer from 1999 produces an image of the spleen and left kidney but does not provide substantial detail of the kidney compared with that seen in images B to D. B, A 2 to 5 MHz curvilinear transducer from 2001 shows improved detail of the left kidney. C, A 2 to 5 MHz curvilinear transducer from 2007 produces a softer image with improved resolution compared to the previous images. D, A 2 to 5 MHz curvilinear transducer from 2012 shows an even softer image. Note that image quality has improved (more detail and less coarseness), despite the fact that the frequency range of these transducers has remained essentially unchanged.
Ultrasound short courses and wet labs began to proliferate throughout the country, usually headlined by ultrasound specialists and supported partially or wholly by ultrasound vendors. This was also a time where Dr. Jean-Marie Denoix emerged onto the American ultrasound scene. As an anatomist and imager, Dr. Denoix can be credited for the widespread acknowledgement that ultrasound really is about anatomy. Although others had been emphasizing this relationship for years, Dr. Denoix’s in-depth lecture on joint ultrasound at the 2001 AAEP convention caused practitioners to stand up, take notice, and revisit their understanding of anatomy. The subsequent formation of ISELP (International Society for Equine Locomotor Pathology) has continued to emphasize this crucial relationship between anatomical knowledge and imaging. Dr. Denoix’s book on the equine distal limb was published in 2000 and continues to be the “go-to” resource on anatomy and imaging of this important region in the horse.

The Imaging Wars

The early millennium marked the emergence of magnetic resonance imaging (MRI) onto the imaging scene. With it, came the beginning of the imaging “wars” between MRI and ultrasound. Some early adopters could even be heard to proclaim that MRI would spell the end for ultrasound. Obviously, this has not been the case. Ultrasound remains in heavy use today for the same reasons that CT has not spelled the end for radiography. There is no doubt that MRI offers significant advantages over ultrasound from a diagnostic standpoint, but it remains out of reach for many horse owners (and veterinary clinics), primarily because of affordability issues. Early authors often seemed heavily biased to prove that MRI was superior to ultrasound to visualize soft tissue injuries. In many of these studies, ultrasound had either not been performed, was performed in an inconsistent manner prior to referral, or techniques were not defined within the body of the report. Unfortunately, these studies seemed to create an unprecedented rift between imaging modalities which did little to drive us forward from an ultrasound standpoint. To date, only a few comparative imaging studies have been published in a fair, unbiased, and comparative manner. Ultrasound and MRI are complementary and there is much to be learned from both imaging modalities.

3. Where We are Today

What We are Scanning

The last 10 years have brought about tremendous change in the world of equine ultrasound. Ultrasound has become accepted to diagnose all types of musculoskeletal injuries, from cartilage lesions (Fig. 8), to pelvic disorders (Fig. 9), meniscal tears (Fig. 10), to cranial nuchal bursitis. Ultrasound is now in widespread use in academic institutions and by private practitioners, both in the hospital and ambulatory setting. Continuing education (CE) courses have proliferated across the country. Motivated practitioners have sought out CE to learn ultrasound of “basic” regions such as the metacarpus, metatarsus, and pastern as well as more advanced regions such as the shoulder, tarsus,
We have also capitalized upon ultrasound's advantages to diagnose osseous abnormalities of the cervical, lumbosacral, and sacroiliac regions; regions where radiography is often limited in terms of viability and availability. Such widespread use of ultrasound underscores the importance of machine buttonology to prevent misdiagnoses. Even with today's sophisticated machines, there is no substitute for a working knowledge of frequency, scanning depth, focal zones, time-gain-compensation (TGC), and overall gain; the same controls emphasized nearly 30 years ago at the 1985 Toronto AAEP Convention.

Whereas ultrasound-guided procedures had previously been performed by specialists to biopsy or aspirate abdominal organs, the value of ultrasound-guidance to access many synovial structures has become well-documented. Ultrasound has significant advantages over blind techniques to inject such structures as the navicular bursa, bicipital bursa, shoulder joint, cervical and lumbar articular facet joints, femorotibial joints, coxofemoral joint, and sacroiliac joint. Additionally, the burgeoning use of regenerative therapies for tendon and ligament injuries has pushed many practitioners to learn ultrasound-guided techniques for intralesional injection. The entry of these products into the market, including platelet-rich plasma, stem cells, bone marrow concentrate, etc., coincided somewhat with the 2008 economic downtown and created somewhat of a perfect storm. Despite conclusive evidence of long-term efficacy, these therapies have been so rapidly embraced by horse owners that nearly any hypoechoic area could become a potential recipient of...
some type of regenerative medicine product. This subject was frequently voiced as a major concern among ultrasonographers interviewed for this presentation. It was generally felt that the efficacy of these products must be evaluated for longer time periods (i.e., throughout rehabilitation) and compared with controlled exercise and rehabilitation programs. Unfortunately, few studies have been performed in this manner.113,114

Another current and emerging trend is the practice of imaging prior to lameness localization. This issue is an area of concern for many interviewed and must be addressed. In the absence of swelling, ultrasound should be performed after sequential distal-to-proximal blocking of the limb, even when veterinarians (or the trainer or owner) are “sure” it’s the suspensory ligament, the stifle, shoulder, or sacroiliac region. While this is understandable in a fractious patient, it should be otherwise discouraged. The excuse that owners won’t approve of blocking is not acceptable. It is up to us as a profession to educate owners of the value of lameness localization. It is a short-term investment that could prevent them from spending thousands of dollars for treatment and rehabilitation for an injury that does not exist or is clinically insignificant. Additionally, it often prevents the discovery of the actual source of lameness.

Abdominal ultrasound has become routine upon referral of a colic patient to a surgical facility and is gradually making headway into the ambulatory setting. Whereas ultrasound was primarily used to detect evidence of strangulating small intestinal lesions, left dorsal displacement, and right dorsal colitis, we now look for evidence of right dorsal displacements (Fig. 12),115–116 colon torsions,117 and cecal lymphadenopathy (Fig. 13).118 The recently described fast localized abdominal sonography of horses (FLASH) technique has prompted veterinarians to scan beyond the left kidney and inguinal regions.119 Abdominal ultrasound has also become more accepted to evaluate horses for fever of unknown origin, weight loss, and suspect neoplasia (Fig. 14)120–124 and even to perform transrectal evaluation of the equine ureters (Fig. 15).125 Thoracic ultrasound is used routinely in academic settings and private clinics with foals as a large percentage of their patient population. In other settings, thoracic ultra-
Sound is often underutilized to evaluate horses in the field with suspect pulmonary or pleural disease, despite being relatively straightforward to perform and interpret. Echocardiography remains in the hands of a few specialists, usually in academic settings. Its use is most limited by the lack of available specialists. The demand for echocardiography is anticipated to rise as our horse population ages and more owners become aware of its value.

Equipment

It is fair to say that the majority of today’s veterinarians own at least one ultrasound machine, although actual numbers are not known. Many practitioners have retained their first portable machine for reproductive use and subsequently purchased a higher quality machine for musculoskeletal examinations. From an availability standpoint, the most significant changes have come in the form of small, lightweight, and highly portable ultrasound equipment. If the budget allows, several laptop-type machines are available in the price range of $25,000 to 40,000. Most of today’s ultrasound machines allow for digital storage. In less expensive machines, images may be saved on USB-enabled devices. More expensive machines usually have digital archival systems, where images are saved in the patient file system on the machine; most of which also allow for exportation of digital imaging communications in medicine (DICOM) images to picture archiving communication system (PACS) servers. Few veterinarians currently own a thermal printer to print hard-copy ultrasound images. Veterinarians are much more likely to burn images on a compact disc, upload images to a cloud-based system, or PACS server than to print images on thermal paper. Hard copy images, however, remain useful, especially when comparing between exams.

From a transducer standpoint, more of today’s equine veterinarians own a high-frequency linear transducer designed for musculoskeletal use. Since their introduction in the mid-1990s, image quality has dramatically improved (Fig. 7). Fewer equine practitioners use a rectal transducer for both reproductive and musculoskeletal exams. This can be explained by the shift away from reproductive work in many practices but also to the increased demand for musculoskeletal ultrasound by the horse-owning public. From an availability standpoint, transducers are now available up to 14 to 18 MHz, which enable us to obtain incredible detail of superficial structures. This is especially true of small structures such as nerves, collateral

![Image](image1.png)

**Fig. 13.** Enlarged cecal mesenteric lymph nodes (arrows) in a 20-year-old Arabian gelding with recent weight loss and presumptive neoplasia based on other clinicopathologic findings. This image of the cecal mesentery was obtained with a 4 to 8 MHz microconvex (small curvilinear) transducer from the right paralumbar fossa/flank region. The lateral cecal artery (a) and vein (v) are unremarkable and are typically seen in this location adjacent to the body wall. Visibility of lymph nodes is not typical in the normal horse.

![Image](image2.png)

**Fig. 14.** Ultrasound images from the left 16th (A) and left 13th (B) intercostal spaces of a 19-month-old Morgan cross colt with extensive splenic lymphoma. Only a small amount of normal appearing splenic tissue (S) is visible in both images. Multiple hypoechoic masses, some with hyperechoic centers, are seen in image A. Similar coalescing masses are seen in image B and throughout the left abdomen. The horse was euthanized due to its poor condition and the extent of involvement. Splenic lymphoma was confirmed at necropsy.
ligaments, and ocular structures, among others. The drawbacks of these transducers is that they may not penetrate adequately to visualize the suspensory ligament body. Practitioners with a large musculoskeletal imaging caseload may opt to purchase a second linear transducer in the 5 to 10 MHz range for suspensory imaging. Additionally, some of these very high frequency transducers produce unacceptably slow frame rates.

For deep cavity imaging, low frequency transducers have remained in the 2 to 5 MHz range, yet image quality has steadily improved, mainly driven by advancements in image quality from human medicine. Increasing numbers of equine veterinarians now own this transducer, driven, in part, by the desire to perform abdominal and upper limb ultrasound such as the pelvis and sacroiliac region. The midrange frequency (4–8 MHz) transducer, commonly known as a microconvex, has begun to appear in the hands of veterinarians with a large sport horse population to evaluate the suprasedamoidae region, meniscus, and cervical articular facet joints, among other regions. One of the most significant advances in equine musculoskeletal ultrasound is the availability of durable standoffs that last for more than a few weeks or months. Many practitioners remember the days of purchasing stand-offs for $200 to $300, only to see them tear within a few weeks or months of use. Today’s standoffs are also more ergonomic and less challenging to manage than their bulky predecessors (Fig. 16).

Education
Despite the widespread use of ultrasound and owner expectations that veterinarians can perform ultrasound exams, we continue to lag behind in education at the veterinary student and resident level. Few veterinary schools offer meaningful coursework (didactic or hands-on) in large animal ultrasound, with the exception of those few schools with large animal ultrasound faculty and services. These numbers are growing but at a slow pace. In addition to New Bolton Center and UC Davis, Tufts University, Texas A&M, and Colorado State University have either established or are developing programs.
Many schools primarily rely upon residents to perform ultrasound exams with and without supervision. Some schools still wait for a radiologist to pull away from their lucrative small animal work to perform an equine ultrasound exam.

At the resident level, ultrasound training remains informal and unstructured. Neither the American College of Veterinary Surgeons (ACVS), American College of Veterinary Internal Medicine (ACVIM), nor the American College of Veterinary Radiology (ACVR) have any formal requirements for ultrasound training in large animal species, yet resident graduates are often called upon as “specialists” in this area. It is not difficult to understand why this has occurred in the radiology college where most residents are small animal oriented. This is further confounded by the high demand and financial incentives for small animal work as a board-certified radiologist.

4. Where We Need To Go

Despite the use of MRI in equine veterinary medicine, ultrasound remains a dynamic and exciting area with tremendous potential for growth, but we must also take a critical look at the current state of ultrasound as we plan for the future. The following discussion represents the author’s opinions and a compilation of those expressed by Drs. Ron Genovese (Cleveland Equine Clinic), Carol Gillis (Equine Ultrasound and Rehabilitation, Aiken, SC), Norm Rantanen, Virginia Reef (University of Pennsylvania), and Johanna Reimer (Lexington, KY); all well-respected ultrasound leaders with ties to the past and present of equine ultrasound.

Ultrasound has come a long way since its origins, but it is particularly curious that several colleagues felt vehemently that ultrasound had taken steps backwards in recent years. Concerns include a lack of accountability, especially when exams are not properly documented or cannot be traced to a patient or limb due to a lack of labeling. Additional concerns previously mentioned include the proliferation of costly yet unproven intralesional therapies (often client-driven), a lack of understanding of the significance of hypoechoic areas (created or real) within many anatomic structures, and the tendency to leap to imaging before appropriately localizing the lameness. Many also commented on the lack of education in veterinary school that leaves new practitioners untrained and ill-prepared to perform a diagnostic exam and the tendency to make a diagnosis without consulting on the significance of suspect lesions. With these concerns in mind, future directions for ultrasound will be consolidated into the following three categories: Education, Best Practices, and Research.

Education

It is the strong opinion of the author and fellow ultrasound colleagues that education is the key to advancing ultrasound in equine practice and that it should begin with foundational skills at the veterinary school level (Fig. 17). Ultrasound is a highly operator-dependent imaging modality, with interpretation occurring during both real-time scanning and captured still images. The ability to perform and interpret ultrasound studies is a major challenge for many practitioners. Instruction at the veterinary school level provides students with the freedom to make mistakes since there are no pre-conceived notions of ability levels. Such an environment allows students to develop those foundational skills that can be used throughout their scanning career. These skills become much more challenging to teach after graduation, where CE attendees are often more focused on scanning specific regions rather than learning those foundational skills necessary to obtain diagnostic images.

Continuing education events provide the mainstay of today’s ultrasound education, and CE dedicated to ultrasound has proliferated across the country. Because of the lack of training in veterinary school, these events are important to advance the state of ultrasound in equine practice. However, attendees must continually remind themselves that learning ultrasound requires practice, dedication, a critical eye and humility to reach out to experts on a regular basis. Although many of us teach at these events, we have become increasingly concerned with the predominance of events produced solely by the private profit driven sector of ultrasound companies. While their efforts are to be commended, this creates potential conflicts of interest. Practitioners can be led to believe they will obtain a level of competence after an afternoon, one day, or weekend ultrasound course. It cannot be overstated that ultrasound is an art with many nuances. Attendees must understand that ultrasound takes time to learn and that proficiency is not
CASE-BASED IMAGING: ANY AND ALL DISEASES

rapidly learned. It takes years to develop the expertise to scan some of the regions presented in short courses, yet some instructors have felt discouraged from telling this truth to attendees.

From a residency training standpoint, large animal ultrasound should become a formal requirement for board certification in many residency programs. Some level of ultrasound expertise is often assumed after completion of an equine surgery, internal medicine, or imaging residency. While residents are exposed to varying levels of ultrasound experience, most residents receive little, if any, formal didactic or hands-on ultrasound instruction. It is surprising that ultrasound education is not a formal requirement for the ACVS, ACVIM, or ACVR. This does little to legitimize an imaging modality that is in widespread use and fraught with potential interpretative errors. Progress towards this end has been made within the European College of Veterinary Diagnostic Imaging (ECVDI), who recently began a large animal imaging residency program. To expand the number of qualified mentors for their programs, the ECVDI inducted several non-ECVDI boarded experts in large animal imaging as associate members. The ACVR has also made efforts to develop an equine imaging residency program, but the outcome is not yet clear. In any case, the formal incorporation of ultrasound into ACVR training programs should help to legitimize equine ultrasound, develop standardized exams and techniques, increase student exposure in veterinary school, and encourage a more balanced approach to comparative imaging studies.

Best Practices

The concept of best practices and education go hand-in-hand. Well-known in the business world, best practices are usually formulated by experts in the field who have a strong sense of what is necessary to develop guidelines that optimize the value of a technique or process. Specific to ultrasound, best practices should include the development of standardized exams, indications, exam documentation, proficiency standards, and ethics, among others. With no such standards or practices set in place, clinicians do not have a bar to which they can rise.

Proficiency Standards

Ultrasound is highly operator-dependent, much more so than any other imaging modality. Unfortunately, few veterinarians possess the natural spatial orientation skills to translate three-dimensional anatomical structures into two-dimensional ultrasound images. For those lucky few, ultrasound will seem more straightforward. For the majority of veterinarians, ultrasound is a struggle. This is further compounded by the fact that some regions are much more challenging to evaluate than others. It would, therefore, seem prudent to assign levels of difficulty to individual regions and structures (e.g., Levels 1–5, with 1 being easiest and 5 being most challenging). Doing so would help budding ultrasonographers better match their ability levels with structures of interest and leave the more challenging structures to advanced or expert imagers.

Proficiency standards would be more challenging to define, but attempts should be made to do so. Because of variations in natural ability level, it is impossible to state how many exams are required before a level of proficiency is achieved with a specific region. Proposed proficiency levels up for discussion could be: beginner (1–30 scans), intermediate (31–100 scans), advanced (101–300 scans), and expert level (>300 scans).

Study Indications

Indications will vary depending on the type of exam being performed, i.e., abdomen, cardiac, metacarpal, pastern, stifle, sacroiliac, etc. Although a detailed discussion of study indications for all regions is beyond the scope of this presentation, some regions deserve special mention. From a musculoskeletal standpoint, we must become more diligent and critical in lameness localization prior to performing imaging studies. Ultrasound is clearly indicated in the presence of swelling, wounds, effusion, or regional atrophy. Otherwise, lameness should be localized via nerve blocks and/or intrasynovial anesthesia prior to ultrasound. It is continually surprising how many owners and veterinarians believe they can see a shoulder, stifle, or sacroiliac lameness without the use of diagnostic nerve blocks. Referral clinics are often faced with such cases that subsequently block to the foot. It is recognized that clients sometimes resist the expense of blocking; however, it is good insurance against the expense of a long-term rehabilitation program for a clinically insignificant injury. We must also be diligent and consider the possibility that perineural blocks may have entered synovial structures, such as that which can occur in the proximal metacarpus and metatarsus.

Exam Standardization

Similar to that for radiographic studies, standardized exams for ultrasound studies should be defined. While it may be challenging to obtain a consensus on standardized studies, it should be relatively straightforward to define what would be considered basic “views” and what would be considered a “special” or perhaps “advanced” view. For example, a basic pastern ultrasound exam traditionally entails imaging of the deep digital flexor tendon and straight distal sesamoid ligament along the palmar (plantar) midline from the ergot to the proximal interphalangeal (PIP) joint and then abaxial views to image the branches of the superficial digital flexor tendon and origins of the oblique distal sesamoid ligament. Evaluation of the axial and abaxial palmar (plantar) ligaments or collateral ligaments of the pastern joint would likely be considered special
views due to their inherent difficulty level. Evaluation of the suprasesamoidean region at the level of P2 between the heel bulbs is a regular part of the pastern exam at UC Davis, but it would likely be considered a special view since relatively few practitioners own the transducer (microconvex) necessary for this exam.\textsuperscript{126} Such standards would better allow us to compare ‘apples to apples.’ Had standardization been present during the early years of MRI, it is possible that some injuries described as visible only with MRI could have been detected with ultrasound, provided that standardized exams had been performed on all cases.

**Exam Documentation**

Although ultrasound has been in routine use for 20 to 30 years, it remains the only imaging modality without standards for image acquisition and study documentation. At a minimum, every image should identify the patient, name of the performing clinic or veterinarian, and the limb, region, or structure being evaluated as well as some indicator of the location of the image (Fig. 18). It is quite surprising to the author and many ultrasound colleagues how frequently images are sent for review without any identifying information. This is widely considered unacceptable for radiographic, scintigraphic, CT, or MRI studies and should be considered equally unacceptable for ultrasonographic studies. Practitioners are not solely at fault. Ultrasound manu-

facturers and distributors are also partially responsible for this problem. On some machines, labels and text are sometimes set to disappear each time an image is unfrozen. The veterinarian is then left to relabel each image, which is both time-consuming and discourages proper labeling. This issue can sometimes be corrected within the menu settings, but sales representatives can be reluctant to do so and practitioners often are completely unaware of this possibility.

Documentation of the specific site of image acquisition is particularly important for metacarpal and metatarsal studies and especially for recheck purposes. The zone system described by Dr. Genovese and co-authors in the mid 1980s remains in use by some practitioners.\textsuperscript{8} Another common technique is to measure in centimeters distal (or proximal) to the point of the accessory carpal bone in the forelimb or to the point of the hock (calcaneal tuberosity) in the hind limb. A ruler or measuring tape can be used for this technique. It is important to use the measurement that bisects the transducer in both transverse and longitudinal views (Fig. 19). Accurate localization of image acquisition is especially important when comparing images between exams. Tendon and lesion cross-sectional area measurements can vary substantially within a few centimeters of an injured area. This could lead to a misinterpretation of healing progress (or lack thereof) if an image is accidentally acquired slightly proximal or distal to the original site of image acquisition.

Finally, standards are also necessary to define the minimum number of images that adequately document an exam or injury (Fig. 20). Many ultrasound exams are performed without any documentation whatsoever or with inadequate documentation. While image capture or printing may not be practical for acute abdominal imaging or routine broodmare work, it is not acceptable for musculoskeletal ultrasound, just as it is not considered acceptable for radiographs, scintigraphy, CT, or MRI.

**Ethics**

Ultrasound ethics covers a wide range of issues; many of which have already been presented. These include recognition of one’s limitations, divulging proficiency levels to clients, seeking expertise whenever possible, and remaining objective in interpretation, especially when the lameness has blocked to that region. One of the most challenging aspects of ultrasound is to tell a client that an ultrasound exam is unremarkable. Ultrasound is often the last resort to diagnose a lameness and one must resist the temptation to overdiagnose in such situations because “the lameness blocks there.” This is especially a problem in horses with metacarpal or metatarsal lameness where hypoechoic areas (due to fat and muscle) within the suspensory ligament can be easily overinterpreted as injury. When in doubt, a consultation should be requested or, at a minimum, recommended in challenging situations.
Perhaps more importantly, a certain responsibility comes with the use of an ultrasound machine. A user should feel obligated to become familiar with basic artifacts, machine instrumentation, and, of course, knowledge of regional anatomy. Its use requires a level of dedication to learning the modality, which includes CE and practice, practice, practice.

Research

As we look forward, there are many areas of research that would improve the value of ultrasound in equine practice. Although not meant to be exclusive, the following areas represent exciting areas of research as well as areas of perceived need, as identified by the author and ultrasound thought-leaders.

**Healing/Rehabilitation**

An improved knowledge of ultrasonographic features of tendon and ligament healing is necessary to better advise our clients throughout the rehabilitation process. This information is also relevant in horses with injuries diagnosed on MRI since ultrasound may be used to monitor after the initial MRI diagnosis. This information is important whether we are evaluating healing with or without intrallesional therapies.

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**Fig. 19.** Use of a ruler to document the anatomic location of images obtained from the metacarpus. Cross-sectional area measurements of the tendon/ligament and injured region are also obtained on each captured image.

**Fig. 20.** A well-documented exam of a forelimb SDFT injury extending from 4 to 24 cm distal to the accessory carpal bone. Transverse and longitudinal images were obtained every 4 cm (in each zone). Cross-sectional area measurements were obtained of the tendon and lesion to calculate percent tendon damage. These images were then used for comparison during recheck ultrasound examinations.
We must first improve our knowledge of expected healing properties as they relate to the ultrasonographic appearance of injuries throughout rehabilitation. Much of our current knowledge of tendon and ligament healing is based on studies of SDFT injuries. Little information is available regarding short- or long-term healing patterns of other structures, yet the known ultrasonographic features of SDFT healing are routinely extrapolated to other tendons and ligaments. Experienced ultrasonographers with a discerning eye know that some structures show minimal, if any, ultrasonographic improvement on repeat ultrasound exams. Unfortunately, this information is not widely known, especially among practitioners with intermittent exposure to these injuries. In such a scenario, the lack of ultrasonographic improvement can be erroneously interpreted as inadequate or poor healing and recommendations made to repeat or begin intralesional therapies to “stimulate” healing. Such an approach entails substantial economic costs to the client and can unnecessarily prolong the rehabilitative process. This information is also important to define in horses treated with the various intralesional products so that we can better assess their efficacy.

Second, and perhaps more importantly, equine practitioners must become more critical regarding ultrasonographic assessment of healing during recheck exams. The temptation to describe an image as “improved,” despite a nearly identical appearance, is not uncommon. This can be further influenced if the client has spent significant resources on intralesional therapies. We must also become more comfortable informing owners that the ultrasonographic appearance of their horse’s injury has not changed in the recheck interim if, in fact, that is the case. Just as clients are made aware of the lack of radiographic healing of proximal and distal sesamoid bone fractures, clients should be aware of realistic expectations on recheck ultrasound exams.

**Comparative Imaging Studies**

As previously mentioned, comparative imaging reports tend to show heavy bias towards MRI and often dismiss the utility of ultrasound to diagnose soft tissue injuries. Admittedly, MRI provides more detailed information than ultrasound, but MRI remains impractical for many equine patients. It is possible that some injuries described as visible only with MRI could be detected with ultrasound, provided that standardized exams or appropriate techniques had been performed. More recently, some studies have been published with an eye to maximize the information obtainable from all imaging modalities rather than dismissing the value of one to enhance the value of another.\(^{66,127}\)

**New Techniques**

Preliminary studies to evaluate innovative ultrasonographic techniques to detect early tendon/ligament injuries include elastography, acoustoelastography, contrast ultrasound, and off-normal incident angle scanning. **Elastography** measures tissue strain properties that may be altered in the presence of tendon and ligament injuries. The use of elastography was recently validated in normal equine flexor tendons in the metacarpus.\(^{128}\) **Acoustoelastography** has also been recently described in normal equine superficial digital flexor tendons to evaluate tissue stiffness gradients.\(^{129}\) A preliminary study on the use of **ultrasound contrast agents** in the distal extremity was recently presented at the ACVR.\(^{130}\) Although the technique was performed in only three horses, no adverse effects were noted in the short term. None of these techniques are widely available. Their utility and acceptance by horse owners will remain to be seen, but all are interesting areas for research that may improve our ability to detect pathology in horses. **Off-normal incident angle ultrasound** has been used for some time to improve visualization of tendon borders or injuries that appear isoechoic with on-beam scanning (Fig. 21) and has recently gained traction to evaluate the suspensory ligament body using non-weight-bearing techniques. Recent studies have shed new light on this valuable technique to help differentiate between ligament, fat, muscle, and injuries within the suspensory ligament body.\(^{127,131}\) Continued investigation into these techniques, along with MRI and histologic validation, should prove even more enlightening to help diagnose suspensory and other injuries.

Fig. 21. Use of “off-beam” or off-normal incident angle ultrasound in a horse with a healing core lesion of the superficial digital flexor tendon. The left image was obtained with the transducer intentionally held “off beam.” This technique improves visibility of the tendon margins and the hyperechoic core lesion compared with the image on the right. The right image was obtained with the transducer oriented 90° to the SDFT to produce an “on beam” or bright image of the tendon. Due to clot formation within the lesion (arrow), it appears nearly isoechoic to the surrounding normal SDFT and is therefore difficult to visualize.
Interventional Procedures

The widespread use of ultrasound-guidance to assist with intralesional and intra-synovial injections has improved our overall comfort level with ultrasound-guidance. Continued validation of ultrasound-guided versus blind techniques is important, similar to that recently performed for shoulder synovial structures. The importance of dynamic real-time imaging throughout the entire ultrasound-guided procedure is another area of investigation. It is our experience that many practitioners use ultrasound to guide the needle to the site, but do not always monitor throughout the injection procedure (see Fig. 11).

Multiple techniques for ultrasound-guided intrathecal puncture for cerebrospinal fluid collection have been published in the past decade, including two recent studies that describe standing techniques at the level of C1-C2 and at the atlanto-occipital junction, respectively133–135 Although the authors of both studies reported good results, relatively few horses were used, the majority of which were normal. Further studies on a larger group of horses with a focus on safety would seem prudent, given the potential for serious consequences.

We would also benefit from the development of new minimally invasive procedures, such as ultrasound-guided removal of foreign bodies in standing horses. Ultrasound can also be integrated into the surgical suite in nontraditional ways, such as ultrasound-assisted tenoscopy or hardware removal. We recently performed both procedures at UC Davis and found that ultrasound provided assistance to direct instrumentation during digital sheath tenoscopy in a bull with synovial sepsis (Fig. 22). We also found it surprisingly valuable to locate screw heads for plate removal in a horse that had previously undergone pastern arthrodesis.

5. Conclusion

It is the author’s hope that these proceedings and its accompanying presentation will serve as a ‘call to arms’ for the profession to raise the bar for ultrasound in equine practice. Ultrasound is a powerful tool and has much to offer our equine patients and their owners, even in situations where MRI is available and affordable. As we continue to expand the use of ultrasound, we must also continue to scrutinize and maintain a critical eye towards image quality, acquisition, and interpretation.

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Conflict of Interest

The Author declares no conflicts of interest.

References and Footnotes


