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Ultrasound (US) continues to play an important role in the diagnosis of musculoskeletal injury. Magnetic resonance imaging (MRI) is more sensitive to soft tissue injury and can show abnormalities in areas not accessible with US. However, US is superior to MRI for imaging bone margins, and it allows for dynamic examination of structures. Knowledge gained from experience with MRI will advance our US skills. Authors' addresses: Gail Holmes Orthopaedic Research Center, Colorado State University, 2503 Bay Farm Road, Fort Collins, CO 80523 (Werpy); San Dieguito Equine Group, 1202 Calle Maria, San Marcos, CA 92069 (Charles); PO Box 1351, Fallbrook, CA 92088 (Rantanen); email: nmwerpy@colostate.edu. © 2008 AAEP.

1. Introduction
Magnetic resonance imaging (MRI) is becoming an integral part of diagnosis of musculoskeletal injury in the equine patient. It is reported in the literature that, in certain cases, lesions visible on MRI are not readily identifiable with ultrasound (US). Has the addition of MRI to diagnostic capabilities in the horse made US obsolete? Or should emphasis be placed on how US can continue to be used appropriately and with confidence? This abstract will address the strengths and weaknesses of both modalities as they apply to musculoskeletal imaging in the equine patient. A review of longstanding US principles as well as additional techniques to improve US exams will also be described.

2. Discussion
Why do anatomical structures have a different appearance on US images compared with MR images? It seems like a simple question. It is often said that MRI is more sensitive than US, but what exactly does that mean? Can understanding the basic principles of these two modalities make equine veterinarians better ultrasonographers? The acoustic properties of different types of tissue determine their appearance on US images. These properties affect how sound interacts with each tissue and determine what proportion of the sound beam is reflected back to the probe. Tissue echogenicity is a product of that reflected sound beam. Anisotropy, a fancy way of describing the influence of beam angle on echogenicity, is another important principle in ultrasound. The impact of this principle is seen during ultrasound of structures with linear fibers, such as tendons and ligaments. The echogenicity of the structure is determined by the angle of the sound beam. Positioning the beam angle at 90° to tendons and ligaments makes them
bright or hyperechoic, whereas a beam that is not perpendicular results in decreased echogenicity. Tissues such as adipose tissue and muscle fibers are not as dependent on beam angle and therefore, have a characteristic echogenicity or shade of gray regardless of beam angle.\(^3,4\)

In contrast, tissue appearance on MRIs is determined by the magnetic properties of those tissues. MRIs are made based on the interaction of the protons within tissue with the magnetic field. MRI is more sensitive, because, in general, the magnetic properties of different tissues have a greater difference than the acoustic properties. The difference in the magnetic properties of connective tissue and tendon are vastly different, whereas their acoustic properties are more closely related. The large difference in magnetic properties translates into the difference between black (tendon) and white (connective tissue) on MRIs, which is obvious.\(^5\) With US, the difference is much less drastic, and shades of gray, not black and white, distinguish tendon (light gray) from connective tissues (lighter gray). As such, optimizing these shades of gray is crucial. Oversaturation of the US image by increasing the gain makes everything in the image bright, leaving only one shade of gray available for different anatomical structures instead of many. Therefore, appropriate machine settings are imperative in US imaging.\(^3\) The large differences in magnetic properties and the small differences in acoustic properties result in obvious differences between anatomical structures on MRIs and often subtle structure differentiation on US images.

**Appearance of Lesions on MR and US**

When trying to accurately recognize different types of lesions in horses, it is essential to have a basic understanding of both the magnetic and acoustic properties of tissues as well as how these properties influence the appearance of different types of lesions. Having an expectation about the appearance of different tissue types or lesions on US images is critical. For example, lesions that have fiber disruption and contain fluid will be characteristically apparent on both MRIs and US images if the imager is familiar with the magnetic or acoustic properties and the anatomy of the structure (Fig. 1). Tendon and ligament lesions without fluid accumulation can be more difficult to detect with US. The difference in the acoustic properties of normal and damaged tendon or ligament can be substantially less, making the lesion more difficult to detect. In addition, the fiber pattern can remain linear or without marked abnormality, which further complicates lesion detection. In these cases, lesion identification may be not possible with US, making MRI the modality of choice for accurate diagnosis.

Tendinosis, or tendon degeneration, is used to describe a form of injury and has characteristic signal patterns on MRIs.\(^6\) Degeneration of tendons and ligaments can be identified on MRIs and can be

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Fig. 1. A superficial digital flexor tendon lesion located at the mid-metacarpus on an (A) US image and an (B) MRI. The tendon is enlarged with a small area of fiber disruption and fluid accumulation. This lesion is evident on both images. The size and shape differences could be attributed to the weight-bearing status (weight-bearing stance in US versus non—weight-bearing stance in MRI). The shape of the superficial digital flexor tendon as well as the shape of lesion differ between the two studies. Despite this difference, an expected shape and size based on established criteria for both US and MRI would allow identification of the lesion. This lesion is equally evident on US images and MRIs because of the presence of fluid in the area of fiber disruption.
clinically significant. The severity of degeneration is based on the signal pattern present on MRIs. Unfortunately, certain stages of degeneration do not have fluid or fiber disruption, making abnormalities difficult to identify with US. Tendons and ligaments with areas of degeneration can have a relatively normal fiber alignment and appear echogenic. Tendon and ligament scarring can also be present without marked change in fiber pattern and/or echogenicity. Areas of degeneration and/or scarring in tendons and ligaments remain bright on ultrasound when the probe is placed perpendicular to the fibers and may only display a mild reduction in the linear pattern of the fibers.

When a structure appears normal on US, what should remain on the differential list? How should enlargement of a structure that is echogenic be interpreted? Unfortunately, a normal US exam does not equal a normal structure. It does mean certain abnormalities have been ruled out. However, degeneration without fluid accumulation and scarring should remain on the differential list. Lesion detection in these cases will require MRI.

Importance of Anatomy
MRI is forcing equine veterinarians to learn detailed anatomy in a way never before possible. The differences in magnetic properties of different types of tissues make anatomic structures more obvious. The same anatomy is present when performing an US exam, but with only slight differences in gray scale between anatomic structures, a discerning eye and excellent image quality are required to properly identify them. MRI and anatomy books detailing cross-sectional anatomy have significantly improved US imaging. With cross-sectional anatomical references, the exact size, shape, position, and margins of the structures can be identified. The relationship between adjacent structures is readily ascertained. Armed with this knowledge, US examination of each area of anatomy can be performed in a systematic and methodical manner. To facilitate accurate diagnoses, the clinician’s understanding of which structures can reliably be visualized with US and which cannot is paramount. Injury to structures not readily visualized with US should remain on the differential diagnosis list.

Fig. 2. (A) A transverse T2 weighted image at the distal aspect of the first phalanx (0.27T). The medial aspect of the distal digital annular ligament (DDAL) located at the top of the image is normal. The lateral aspect of the DDAL is enlarged with an irregular margin and areas of increased signal intensity. These findings indicate diffuse injury. The white box on the MRI represents the location of the US images. (B) Normal US image of a DDAL. A smooth bone margin, linear fiber pattern, and uniform echogenicity are present with no evidence of enlargement. (C) Abnormal US image of a DDAL. The bone margin is irregular because of enthesophyte formation, and the ligament is enlarged with a focal area of fiber disruption. The DDAL is very easily identified with MRI, but it can also be well demonstrated with US from the level of first phalanx to the proximal aspect of the navicular bone.
when no other abnormalities are detected during the US exam of a region.

Structures such as the abaxial and axial ligaments of the proximal interphalangeal joint and the distal digital annular ligament were seldom part of a standard US exam until seen on MRIs. Now, it is possible to evaluate and identify abnormalities in these ligaments (Fig. 2). The distribution of adipose tissue and muscle fibers in the suspensory ligament, which greatly complicates US examination, is much more clearly understood because of MR imaging. This complex anatomy should be taken into account when interpreting US images of the suspensory ligaments.

When comparing MRIs with US images, some differences exist in the size and shape of structures. Many MRI studies are performed during a non-weight-bearing stance, which can cause relaxation of the soft tissue structures. This relaxation may account for the size and shape discrepancies between the two modalities. Despite these differences, MRIs provide invaluable information about cross-sectional anatomy that can be used as a guide for improving US image acquisition. Standards for normal shape and size of specific structures in non-weight-bearing studies will help abnormalities be more easily recognized when comparing images. Even with appropriate US technique, MRI will always be more diagnostic if the person performing the US exam does not know detailed anatomy.

Techniques for Improving US Examinations

How can a new and improved knowledge of anatomy be combined with the longstanding principles of US to make better ultrasonographers? Careful review of the anatomy and understanding of the normal appearance, shape, and size of regions being imaged as well as their relationship with surrounding structures and expected echogenicity is essential. To determine size, shape, and margins with US, a clear pathway for the US beam is necessary. This fact alone limits the structures that can be seen. Certain structures, such as the soft tissues in the foot and the interosseous ligaments of the carpus and tarsus, require MRI for diagnosis, because they are not accessible to an US beam. What about the metacarpal and metatarsal regions? US is an appropriate modality to use as a diagnostic tool in these regions, because they are accessible to an US beam, and most equine veterinarians perform US exams of these areas regularly. However, do current US techniques for these regions maximize what can be seen? Examination of these areas has traditionally been performed from the palmar or plantar aspect of the limb. A more detailed understanding of the anatomy of these regions as seen on MRIs requires a new approach to the routine evaluation of these structures. New head positions for scans to window different aspects of the metacarpal and metatarsal anatomy provide more information, which can then lead to accurate diagnosis.

For example, the medial and lateral margins of the check and suspensory ligaments extend beyond what is visualized when the probe is placed on the palmar aspect of the limb. (B) When the probe is placed on the medial or lateral aspect of the limb, the margins of the check ligament and suspensory ligaments and any lesions in these areas are easily examined. A complete exam of the check and suspensory ligaments should include images from the palmar aspect of the limb as well as the medial and lateral aspects of the limb. If only the palmar approach is used, lesions associated with the medial and lateral aspects of these structures may be missed.
Traditionally, ultrasonographers are trained to image tendons and ligament with the beam angle perpendicular to the linear fibers to make these structures as bright as possible. This is an important part of the examination. However, off-angle imaging or oblique incidence adds critical information to the exam. Off-angle images are those acquired in cross-section images with the US beam slightly greater or less than perpendicular to the tendon or ligament. Important information is gained when the US beam is not perpendicular to the tendon or ligament fibers. Using this information for diagnostic purposes requires incorporation of basic US principles. Normal tendon or ligament fibers as well as certain types of abnormalities and

Fig. 4. Comparison of a lesion in the medial lobe of the deep digital flexor tendon at level of the pastern on (A) an US image and (B) an MRI. The US image was made with the beam off angle or not perpendicular to the tendon fibers. The red arrow indicates an area of fiber disruption with focal fluid accumulation. This finding was equally evident on both modalities and was independent of beam angle on US images. The yellow line designates an area of tendon degeneration that did not have fiber disruption or focal fluid accumulation. This area was clearly evident on the MRI, but it was not readily seen on the US image until the probe was placed slightly off angle. Evidence of medial lobe enlargement was evident on both the US image and the MRI.

Fig. 5. US images obtained with the forelimb in a non—weight-bearing position, and the superficial digital flexor tendon is displaced medially. (A) The beam angle is perpendicular to suspensory ligament fibers, and the image is relatively echogenic despite the fact that the limb is in a non—weight-bearing position. The entire ligament can be identified, and the individual lobes can be differentiated. (B) The suspensory ligament fibers are hypoechoic compared with the muscle fibers and adipose tissue when the beam is not perpendicular to the ligament margins. (C) An MRI at same level in a different horse for comparison. This US technique allows visualization of the suspensory ligament anatomy, because the adipose tissue and muscle can be distinguished from the ligament fibers. However, further investigation is necessary to determine the accuracy of this technique for detection of pathologic change.
other tissues like adipose tissue are echogenic with a perpendicular US beam. However, when the US beam is no longer perpendicular, normal tendon or ligament fibers become more echolucent. Fibrosis and adipose tissue, which do not have the same beam angle dependency as tendons and ligaments, remain echogenic. Maligned fibers can also remain echogenic, depending on the fiber orientation to the sound beam. Off-angle imaging allows differentiation between normal fibers and other tissue; abnormalities appear echogenic with perpendicular orientation of the US beam and become echolucent with off-angle orientation of the US beam (Fig. 4). Small changes in echogenicity resulting from tendon degeneration can be detected with off-angle imaging in this manner.

This technique is useful for determining structure margins. In situations where fibrosis or tissue proliferation are adjacent to the structure being imaged, defining its margins can be challenging. Off-angle imaging highlights the tendon and ligament margins, which are not dependent on US beam angle. This technique ensures accurate assessment of structure size and shape. The beam should be angled only slightly when performing anatomical measurements so that the measurements are accurate. A severe angle results in loss of true structure margins, because obliquity defeats the purpose of the technique.

Off-angle imaging provides invaluable information when evaluating the suspensory ligament, which is one of the most difficult ligaments in the horse to examine with US because of its complex anatomy. Off-angle imaging helps but cannot completely alleviate this difficulty. As previously stated, the appearance of ligament fibers is sensitive to US beam angle. Muscle and adipose tissue are not as sensitive to US beam angle. Therefore, it is possible to differentiate the anatomy of this structure using off-angle imaging. The suspensory ligament has a unique pattern of ligament fibers, muscle fibers, and adipose tissue that varies between limbs and among horses. However, the pattern does have some consistencies that are better elucidated with off-angle imaging. In the forelimb, the proximal aspect of the suspensory ligament is bilobed. The majority of the ligament fibers are located around the lobe periphery and along midline where the two lobes join. Most commonly, varying amounts of adipose tissue and muscle fibers are

Fig. 6. (A) A parasagittal lesion (arrow) is located in the medial lobe of the deep digital flexor tendon. The lesion is linear and extends through the dorsal margin of the tendon. Abnormal low signal intensity (black) tissue is present in the proximal recess of the navicular bursa and appears to extend from the deep digital flexor tendon to the collateral sesamoidean ligament, which suggests adhesions between the two structures (arrowheads). (B) After distension of navicular bursa, tissue no longer extends from the deep digital flexor tendon to the collateral sesamoidean ligament. The white area between the deep digital flexor tendon and collateral sesamoidean ligament is fluid in the navicular bursa, and it continues along the dorsal surface of the deep digital flexor tendon. The presence of fluid in the navicular bursa indicates that the deep digital flexor tendon and collateral sesamoidean ligament are not adhered, despite the appearance of the initial image. When adjacent structures have the same sig-

nal intensity, it may not be possible to distinguish between their margins. Structures can, therefore, appear continuous, which is similar to the appearance of adhesions. In certain cases, tissue in the navicular bursa cannot be distinguished from adhesions. In this case, the initial MRI interpreted in isolation would have led to an incorrect diagnosis. A correct diagnosis was made only after distension of the navicular bursa. In cases where the tissues are accessible with US, US is superior to MRI for determining the presence of adhesions, because dynamic exams can be performed.
located in the center of each lobe. However, adipose tissue and muscle fibers can extend to the ligament margins in some horses. The hind suspensory ligament, although a different shape, has a similar repeatable pattern. Wider dorsally, it narrows toward the plantar aspect of the ligament. The hind suspensory ligament is not bilobed; however, the ligament fibers are most prominent around the periphery and on midline, and the adipose tissue and muscle fibers are located in the central aspect of each one-half of the ligament. Evaluation of the suspensory ligaments on MRIs has given a clear understanding of the anatomy of the suspensory ligament. Using off-angle imaging, ligament fibers can be differentiated from regions of muscle fibers and adipose tissue.

A second major difficulty with the front suspensory ligament is its location. It is located deep to the check ligament and flexor tendons. At that depth, detail is lost; this detail is necessary to properly identify the ligament’s complex anatomy. In addition, even with use of a stand-off pad, the entire ligament cannot be visualized in one image from the palmar aspect of the limb. Placing the limb in a non-weight-bearing position decreases the tension on the flexor tendons and check ligament. The flexor tendons can then be displaced, and this allows placement of the US probe directly over the suspensory ligament. Image quality and detail are improved, and the entire ligament can be visualized in one image (Fig. 5). This technique, combined with off-angle imaging, can further characterize the anatomy of the suspensory ligament and allows complete examination of this structure. Relaxation artifact as a result of a non-weight-bearing stance is a factor with this technique. The ligament fibers still have differential echogenicity depending on the beam angle, but it is not as apparent as when the limb is in a non-weight-bearing position. However, comparison of weight-bearing and non-weight-bearing images needs to be made.

Limitations of US and MR
Although MRI is more sensitive, US is superior to MRI in a few areas. Small abnormalities on bone margins, difficult to see on MRIs, are clearly evident on US images. Although proliferation on bone margins can be detected on an MRI, it will be evident sooner on US. The ease of detection of bone proliferation on MRIs is partially determined by the adjacent tissue and sequence used. Mineral in soft tissue structures stands out on US images by creating acoustic shadows and is difficult or impossible to see on MRIs, depending on the affected structure. Despite its limitations, MRI can detect abnormalities below the bone surface that are not detectable with US.

US also allows dynamic imaging of structures, which is a significant advantage over MRI. For example, findings on MRIs can result in a high degree of suspicion for the presence of adhesions. However, tissue that is not adhered and adhesions can appear identical on MRIs (Fig. 6). Using US, the presence or absence of adhesions can be definitively determined if the structure in question can be examined while manipulating the limb or with digital manipulation of the structure and surrounding tissues.

MRI is far superior to US when evaluating soft tissue contrast. Mature scar tissue, however, has low-signal intensity (black) in MRIs as does normal tendons. Therefore, mature scar tissue can be difficult to identify, because its appearance is similar to normal tendon fibers. In these cases, enlargement or abnormal shape can indicate the presence of mature scar tissue in a tendon. Mature scar tissue in ligaments is easier to identify because of the mixed signal pattern and variation depending on the MRI sequence used. Scarring can be a difficult abnormality to identify on both US images and MRIs, depending on the structure affected and the severity of the injury.

3. Conclusion
Increased use of MRI in horses is not a reason to abandon US. Rather, MRI provides additional knowledge for better US technique. Basic US principles, such as comparison with the opposite limb and proper use of the US beam angle, still apply. The experience gained from looking at MRIs only adds to the ultrasonographer’s repertoire. Understanding of the anatomy is improved; therefore, structures, such as the axial and abaxial ligaments of the proximal interphalangeal (PIP) joint that were previously disregarded in routine US examination of the pastern, are now routinely examined. Recognizing that the front suspensory and check ligaments cannot be seen in their entirety from the back of the limb allows new approaches for US examination of these structures to be implemented.

How does this information affect the systematic approach to diagnosis of musculoskeletal injury with US and MRI? US should continue to be used in accessible regions of anatomy. Approaching the examination with extensive knowledge of anatomy and keeping the principles of US in mind can lead to an accurate diagnosis. Abnormalities that can be found with US include fiber disruption, fluid accumulation, mineralization, bone-margin change, enlargement, and abnormal shape. Performing dynamic US exams can confirm the presence or absence of adhesions. Remember, normal US still leaves a differential diagnosis list that may require further investigation and further diagnostics such as advanced imaging. Even with a diagnosis using US, MRI can provide additional information about a lesion, which can impact treatment and prognosis.

References