Review of Innovative Ultrasound Techniques for the Diagnosis of Musculoskeletal Injury

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Ultrasound examination with the use of standard ultrasound and angle contrast (on- and off-beam angles) ultrasound techniques, as well as imaging the non–weight bearing limb or changing limb position, can contribute valuable information to the diagnosis of musculoskeletal injury. In addition, these techniques may facilitate visualization of an injury by use of ultrasound after magnetic resonance imaging examination. Therefore, the lesion can subsequently be monitored with ultrasound. Authors’ address: 9418 SW 67th Drive, Gainesville, FL 32608; e-mail: equinedxim@yahoo.com.

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1. Introduction

Multiple imaging modalities are available to aid in the diagnosis of tendon and ligament injury.1 Often, a combination of modalities is used to fully characterize musculoskeletal injury. With the advancement and increasing availability of computed tomography (CT) and magnetic resonance imaging (MRI), diagnoses are commonly made through the use of advanced imaging after negative ultrasonographic or radiographic studies are performed. Retrospectively, with knowledge of the location and character of the lesion, many injuries can subsequently be identified through the use of ultrasonography or radiography. This process contributes to the development of improved imaging skills, and, in certain cases, the diagnosis can subsequently be achieved with the use of ultrasound and/or radiographs without the benefit of advanced imaging. CT and MRI may require general anesthesia and a significant financial investment from the client. Ultrasonography is readily accessible, cost-effective, and can easily be performed in the field. These qualities make it a highly advantageous imaging modality and facilitate its use for sequential examinations. Sequential examinations are extremely useful to assess lesions over time and healing responses on the basis of administered therapeutics. However, ultrasound is extremely operator-dependent, relying on the training, skill, and operator experience to obtain diagnostic images. Educated ultrasonographers understand how the ultrasound beam propagates in normal tissue as compared with abnormal tissue. They are able to differentiate injury from artifact and have a practical knowledge of the limitations of ultrasound as an imaging modality.2 The purpose of this review is to describe the use of angle contrast (on-and off-beam angles) ultrasound techniques, to discuss the interpretation of these images, and to demonstrate the benefits of comparing images acquired with the limb in weight bearing and non-weight bearing positions. These ultrasound techniques will be presented in combination with other modalities to provide a better appreciation of ultrasonographic capabilities and how they can be used for the diagnosis of musculoskeletal injury.
Anatomic Variation

The most reliably identified tendon and ligament injuries through the use of ultrasound include enlargement, enthesopathies, and hypoechogenicity indicating inflammation, edema, and/or fiber disruption. These injuries can be described by the structure involved, their exact locations, the extent of injury, and amount of damage. Anatomic knowledge of the structures being examined in both the transverse and longitudinal planes is essential for the diagnosis of these injuries and to recognize artifacts. A successful ultrasonographer is familiar with the normal anatomic appearance (size, shape, position, and textural quality) of each structure examined as well as any anatomic variations.3

Tendons and ligaments are of similar composition and differ in their structural orientation. The fibers are more uniformly distributed in tendons and are more multi-directional in ligaments.4 Normal anatomic variation in the fiber orientation within ligaments causes non-uniform echogenicity on ultrasound examination, such as in the collateral ligaments of the distal interphalangeal joint (Fig. 1).5,6 This variation in fiber orientation also causes magic angle artifact within ligaments on MR images.5,7 When regions of decreased echogenicity are identified in collateral ligaments with multi directional fibers, multiple ultrasound beam angles are then used at the same level to create echogenicity in the different fiber bundles (Fig. 2). In addition, comparison to the contralateral limb can be helpful when attempting to differentiate normal anatomic variation from a clinically significant abnormality.

Identification of Lesions After Advanced Imaging

In most cases, once a lesion has been identified through the use of advanced imaging, it can readily be determined if the lesion should be visible through the use of traditional imaging modalities. This process increases our knowledge of anatomy and identifies structures or artifacts that can prevent visualization of a lesion when traditional imaging modalities are used. Retrospectively evaluating these lesions with the use of ultrasonography leads to the development of new skills and techniques. In certain cases, this process allows the diagnosis of these lesions going forward, without the benefit of advanced imaging. Several innovative ultrasound techniques have been validated through the use of advanced imaging and correlating the anatomic appearance of structures with gross and histologic evaluation.

Anisotropy: Understanding the Influence of Ultrasound Beam Angle

Fiber disruption and fluid accumulation in tendons and ligaments can be apparent with ultrasound. In contrast, other types of fiber injury can remain echogenic on ultrasound images despite clinically significant abnormalities. This discrepancy in the diagnostic capability of ultrasound during certain stages or types of injury may result in an ultrasound appearance that is not markedly different from normal, which can make certain types of injury challenging to diagnose with the use of this modality. Tissue echogenicity is determined by the acoustic properties (acoustic impedances) of that tissue. Variations in the acoustic properties and the resulting changes in echogenicity are used to differentiate normal and injured tissues.8

The term “anisotropic” in regard to ultrasonography simply means that the tissue exhibits different acoustic impedances when imaged at different angles. This principle is illustrated when imaging the flexor tendons in the transverse plane. When the probe angle is adjusted proximally or distally to obtain maximum echogenicity, the anisotropic properties of the tendons are demonstrated (Fig. 3). Obtaining a quality image in tissues of varying acoustic impedances is dependent on the ability of
Fig. 2. Transverse ultrasound images (A, C) of a collateral ligament of the distal interphalangeal joint at the level of the middle phalanx with two different beam orientations and the corresponding MR images at the same level (B, D). On the ultrasound images, the central aspect of the ligament changes in echogenicity on the basis of the ultrasound beam angle. The appearance is representative of bundles of fibers with different orientations. This difference in fiber bundle orientation also results in the changes in signal intensity present on the MR images when the position of the limb is altered. The recognition of this ultrasound appearance was the result of the initial identification of the different fiber bundle orientation on MRI. Therefore, MRI was used to develop a more accurate method for evaluation of ultrasound images of the collateral ligaments of the distal interphalangeal joint at this level. Dorsal is to the left of each image.

Fig. 3. Transverse ultrasound images of the superficial and deep digital flexor tendons at the level of the metacarpus that demonstrate the principle of anisotropy, or the dependency of echogenicity on beam angle. A, Ultrasound beam is perpendicular to the tendons creating diffuse echogenicity within the tendon. B, Ultrasound beam is off-angle or oblique incidence to the tendons. In this image, the echogenicity of the tendons are reduced compared with that in A. However, the tendon margins remain echogenic. Medial is to the left of each image.
the ultrasonographer to appropriately adjust the machine and settings (transducer, frequency, depth, focal zones, and gain). In addition, altering the direction of the beam angle is necessary to assess...
the normal anatomy and to identify pathologic change. On the basis of the principles of anisotropy, the off-angle or oblique-incidence ultrasound technique can be used in structures with complicated anatomy to further elucidate the nature of the tissue and any associated anatomic characteristics as well as to aid in the diagnosis of pathologic change. This technique and how it can be used to identify normal anatomy and diagnose musculoskeletal injury is discussed below.

Standard Ultrasound Technique

Ultrasound has traditionally been the imaging modality of choice for diagnosing most soft-tissue injuries because it is non-invasive, cost-effective, and easily accessible. The standard ultrasound technique has been described for the equine distal limb in scholarly veterinary publications and textbooks. The majority of musculoskeletal imaging in the equine distal limb is performed with a linear transducer. The ultrasound probe is placed on the palmar or plantar surface of the limb with the beam oriented perpendicular to the longitudinal axis of the tendons or ligaments of interest with the limb in a weight bearing position. In addition, transverse images are obtained. The size, shape, margins, and echogenicity of the structures should be evaluated and a measurement system, with the use of distance (cm) or zones, should be used to obtain images at regular intervals. Comparison to the contralateral limb is a critical step in most cases, even those with obvious injury in the primary limb. This system will facilitate sequential examinations. In certain cases, the medial and lateral extent of the tendons and ligaments cannot be imaged in the same field of view, and the probe should be directed toward the medial and lateral aspects of the structure to obtain peripheral margin images.

The standard ultrasound technique (single-beam angle with the limb in a weight bearing position)
does not always demonstrate important anatomic features of tendons and ligaments. This technique was selected to create maximum echogenicity in the structure, to prevent decreased echogenicity caused by variations in beam angle (anisotropy) that could be mistaken for a lesion. In addition, this technique was designed to prevent relaxation artifact from causing false decreases in echogenicity that could be mistaken for a lesion. However, decreased tension on certain structures may actually increase the conspicuity of lesions. The angle contrast ultrasound technique uses perpendicular and oblique beam (on- and off-beam) angles to identify bundles of fibers with different orientations. This technique, along with changes in limb position and weight bearing, can be used to identify abnormalities that are less apparent or not visible with the standard technique.

Angle Contrast Ultrasound Technique (On- and Off-Beam Angles)

The angle contrast (on- and off-beam angles) ultrasound technique is typically used after examination with the standard ultrasound technique. To perform the angle contrast ultrasound technique, the ultrasound beam is placed at perpendicular and oblique angles of incidence relative to the longitudinal axis of the tendon or ligament fibers. To achieve an oblique incidence image, the ultrasound beam is first positioned perpendicular to the tendon or ligament to create maximum echogenicity, and this image is saved and compared with an oblique incidence image at the same level (Fig. 4). To create the oblique incidence image, the probe angle is then changed by moving the probe cable proximally or distally, depending on the structure being imaged and the specific region of interest (Fig. 5). The least amount of angle that results in decreased echogenicity of the tendon or ligament fibers should be used. The shape, size, and location of the imaged structure and any other anatomic landmarks, such as osseous margins, in the oblique incidence image should be compared with the original perpendicular beam angle image. The shape, size, and location of the soft tissue and osseous structures should match in the two different images to ensure that similar levels of the tendon or ligament are being evaluated and can then be compared. The angle contrast ultrasound technique has been incorporated as part of the standard examination in all musculoskeletal examinations by the author.

This technique has proven to be effective when imaging the suspensory ligament through the use of ultrasound. It facilitates differentiating regions of fibers from adipose tissue and muscle (Fig. 6). Anisotropic properties of tendon and ligament fibers differ from that of adipose tissue and muscle. Muscle echogenicity is much less dependent on beam angle compared with tendon and ligament fibers. Adipose tissue echogenicity is not dependent on beam angle. Regions of adipose tissue, and, to a lesser extent, muscle, will remain echogenic regardless of beam angle. In contrast, tendon and ligament fibers will become hypoechogenic when the beam angle is not perpendicular to the longitudinal
axis of the tendon or ligament fibers. By use of variations in the ultrasound beam angle, regions of scarring and injury in soft-tissue structures can be identified. Scarring is echogenic regardless of ultrasound beam angle. Areas of fiber disruption are anechoic regardless of beam angle. Therefore, comparing the echogenicity of soft tissues structures with on-beam angle (perpendicular) and off-beam angle can provide additional information.

![Fig. 8. Transverse ultrasound images of the cranial aspect of the medial meniscus. A, Weight bearing image shows two regions of decreased echogenicity in the distal aspect of the medial meniscus with an irregular tibial margin. B, Non–weight bearing image shows enlargement and coalescence of the previously identified regions of abnormality with a further decrease in echogenicity consistent with presence of fluid and fiber loss, indicating a tear in the medial meniscus.]

![Fig. 9. Ultrasound (A) and MR (B, C) images of an 11-year-old Dutch Warmblood mare that presented for right forelimb lameness localized to the digital sheath. No significant soft tissue lesions were identified on initial ultrasound examination. High-field MRI was performed under general anesthesia of the left fore fetlock region and revealed abnormalities in the deep digital flexor tendon and straight sesamoidean ligament with associated synovial proliferation. A, On retrospective ultrasound examination, these abnormalities could be identified after flexion of the limb and manual displacement of the ergot. B, MR image at the level of the injuries. C, Localizer image denoting the slice position relative to the ergot. Note that tissue manipulation of the ergot is necessary to fully examine the tendons at the level of the fetlock. Medial is to the left of each image.]

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angle (oblique) ultrasound beam orientations can be used to characterize regions of pathologic change from normal anatomic variation.\textsuperscript{14}

**Limb Position, Tissue Manipulation, and Probe Pressure**

Limb position can affect visualization of certain structures. When examining the palmar or plantar soft tissues at the level of the pastern and the foot, have the horse standing squarely on all four limbs and then place the foot of interest caudal from this square stance to facilitate examination. Visualization of the medial aspect of the elbow with ultrasound can be greatly improved with the limb extended. The degree of extension is variable. The location of the lesion or area of interest within this region of the elbow will affect the degree of extension that is necessary. In contrast, examination of the medial aspect of the stifle is best performed with the limb placed squarely underneath the body. When the limb is positioned forward or behind, the vertical visualization of certain structures of the stifle is limited.

Evaluating the limb in weight bearing and non–weight bearing positions can provide additional information and aid the diagnosis of pathologic change. In certain anatomic regions, standard and angle contrast ultrasound techniques can be combined with changes in weight bearing and tissue manipulation to achieve more information. This is especially true when imaging the front and hind limb suspensory ligaments. Placing the limb in a non–weight bearing position has many advantages. The decreased tension in the flexor tendons allows manipulation of their position. They can be manipulated to create a wider skin surface for the ultrasound probe, increasing visualization of the medial and lateral aspects of the ligaments (Fig. 4). Vasculature that may have been creating artifact with the limb in a weight bearing position can often be manipulated to decrease the amount of artifact. In addition, this process decreases the depth between the probe and the suspensory ligament, which often allows use of a higher frequency that increases image resolution.

For ultrasonographic examination of the proximal metacarpal region, the limb is placed in a non–weight bearing position with the lower leg suspended and minimal carpal flexion while the metatarsal region can be examined with the horse standing squarely on all four limbs.
resting on the toe, in most cases. Once images of the proximal metacarpus have been obtained, the carpus can be flexed further to maintain a more comfortable position. When imaging the proximal metatarsal region, placing the limb of interest in a non–weight bearing position (resting on the toe) can allow flexor tendon manipulation. However, increased limb flexion results in greater tendon laxity, which can be beneficial when tendon manipulation cannot be adequately performed with the horse resting on its toe.

A complete ultrasonographic examination of joints often requires imaging the joint in flexion after examination of the joint in a weight bearing position. When examining the fetlocks and carpi, joint flexion allows visualization of regions of the joint that are not accessible with ultrasound when the limb is in a weight bearing position. This position aids in identification of the dorsal articular surfaces of the medial and lateral condyles of the third metacarpal bone in the fetlock (Fig. 7). This examination is an excellent adjunct to radiographs, especially if an abnormality is suspected on the basis of radiographic appearance. In the stifle joint, flexion of the limb is required to examine the cranial tibial meniscal ligaments and to identify certain types of meniscal tears. This can often be achieved with the horse resting on its toe. However, visualization of the distal margin of the medial femoral condyle and the distal aspect of the cranial cruciate ligament is best achieved with more pronounced joint flexion. In addition, small meniscal tears may become more apparent, revealing the maximum extent of their margins with greater joint flexion. After evaluation with the horse resting on its toe, it is best to reevaluate any findings with more pronounced flexion of the joint. This technique is used to determine if the findings change with different limb positions or degree of flexion. Examination of the stifle joint with the limb in weight bearing and non–weight bearing positions allows protrusion of the meniscus to be more easily identified. In many cases, the meniscus will be further displaced outside the joint margins with the limb in a weight bearing position and then will return within the joint space with the limb in a non–weight bearing position. Ultrasonographic examination can be used to reliably identify the menisci, collateral ligaments, cranial meniscal ligaments, and the distal portion of the cranial cruciate ligaments.18

In general, a lack of tension in soft-tissue structures can increase the visibility of lesions, especially when adjacent fluid can enter regions of fiber disruption. Although this has been shown repeatedly when evaluating meniscal tears in the stifle (Fig. 8), reduced pressure can also aid in the diagnosis of soft-tissue injury in other anatomic regions. The benefit of this technique is somewhat related to lesion configuration. However, it appears to increase the conspicuity of many different types of injuries being diagnosed with ultrasound. Longitudinal splits and margin tears are substantially affected by this technique. This premise has developed from comparing ultrasound and MRI images of lesions. Although there are certain types of injury that can be identified with MRI that will not be evident on ultrasound images, other lesions, especially those with fiber disruption, should be evident with ultrasound if the structure is accessible. When MRI lesions with fiber disruption are identified, they may appear smaller when imaged with ultrasound. This can occur when the periphery of the lesion is

Fig. 11. Transverse ultrasound images of a tear in the lateral aspect of the superficial digital flexor tendon both acquired with the limb in a non–weight bearing position. A, The ultrasound probe is positioned such that it is in contact with the skin surface. However, no pressure is applied to the probe and the tear is quite evident. B, With pressure on the ultrasound probe, the tear in the superficial digital flexor tendon appears smaller, is less conspicuous, and does not obviously extend through the plantar margin. This injury was less evident with the limb in a weight bearing position.
less severely affected and will therefore be more apparent on MR images when compared with ultrasound images. However, in certain cases, this discrepancy appears to be the result of differences in tension on the basis of weight bearing. These differences are most apparent when comparing recum-

Fig. 12. Transverse ultrasound images at the level of the pastern made with the limb in a non–weight bearing position. Possible adhesions exist between the deep digital flexor tendon and the straight sesamoidean ligament in the left forelimb distally (A, B) and more proximally (C, D). Ballottement can be used to determine if adhesions are present. Digital pressure on the sheath can displace structures. Fluid completely separates the deep digital flexor tendon and the straight sesamoidean ligament (B) after ballottement and manipulation of the fluid in the digital sheath. However, the deep digital flexor tendon and the straight sesamoidean ligament do not separate in the more proximal image (D) indicating adhesion formation. The proximal images (C, D) of the deep digital flexor tendon are off-angle.
bent MR images with standing ultrasound images. In these cases, the lesions are more similarly sized and shaped when MR images obtained in a recumbent horse are compared with ultrasound images with the limb in a non-weight bearing position.

Comparison of MRI and ultrasound images also reveals lesions in anatomic regions that are ultrasound accessible. However, additional steps must be taken to adequately visualize these regions with ultrasound if these regions have not been part of the standard ultrasound examination previously. The palmar or plantar fetlock under the ergot is one of these regions. At the level of the ergot, there are many important anatomic structures on midline, such as the straight and intersesamoidean ligaments and the cruciate ligaments. This region can be obscured by the ergot and is more challenging because of the curvature of the limb and ligaments at this level. Complete examination of the region can require both flexion and tissue manipulation (Fig. 9). Flexion results in relaxation of the palmar or plantar soft tissues, whereas manipulation of the ergot allows visualization of these midline structures. Lesions of the straight sesamoidean ligament at the junction with the intersesamoidean ligament are frequently identified retrospectively after MRI with the use of this technique (Fig. 10). Regions that may not have been specifically imaged with previous ultrasound include fibers of the hind suspensory ligament that extend proximally to the fourth tarsal bone. This area demonstrates injury on MRI images and is ultrasound accessible. In this case, adjusting the proximal anatomic limits of a hind suspensory ligament ultrasound study will facilitate identification of lesions in this region.

As previously discussed, limb position and tension on soft-tissue structures can affect the visibility of lesions. In addition, probe pressure can also markedly affect the visibility of certain lesions. Changes in the amount of probe pressure at the region of interest can be used to increase the conspicuity of certain lesions (Fig. 11). Alterations in probe pressure in combination with tissue manipulation are a benefit, especially when evaluating the digital sheath. With the limb in a non-weight bearing position, digital pressure can be used to force fluid into different regions of the sheath to aid in determining the presence or absence of adhesion formation (Fig. 12).

Summary and Conclusions
Although ultrasound has limitations compared with advanced imaging, the continued development of innovative techniques will aid the diagnosis of musculoskeletal injury in horses. Advanced imaging provides the best method for the development of these techniques and furthers our educational process about imaging and the pathologic changes associated with musculoskeletal injury.

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