Review of Principles and Clinical Applications of Magnetic Resonance Imaging in the Horse

Natasha M. Werpy, DVM; Charles P. Ho, MD, PhD; Chris E. Kawcak, DVM, PhD, Diplomate ACVS; Norman W. Rantanen, DVM, MS, Diplomate ACVR; and C. Wayne McIlwraith, BVSc, PhD, Diplomate ACVS

Evaluation of magnetic resonance (MR) images requires a knowledge of anatomy and a basic understanding of the physics and principles of MR. This information provides an understanding of the appearance of tissue, both normal and abnormal, on different MR sequences that is necessary for accurate image interpretation. Tissue appearance on MR images is dependent on the sequence used and can vary with different MR systems. Authors’ addresses: Equine Orthopaedic Research Center, College of Veterinary Medicine and Biomedical Sciences, Colorado State University, Fort Collins, CO 80523 (Werpy, Kawcak, McIlwraith); 3301 El Camino Real, Suite 100, Atherton, CA 94027 (Ho); and 1119 South Mission Road #351, Fallbrook, CA 92028 (Rantanen); e-mail: nmwerpy@lamar.colostate.edu. © 2006 AAEP.

1. Introduction

Magnetic resonance imaging (MRI) is an exciting modality that holds great promise in veterinary medicine. It shows abnormalities in bone and soft tissue before they become evident on other imaging modalities.1–7 The physiologic information provided by MRI is invaluable for characterizing lesions. As with any new modality, there are considerable unknowns as well as a large learning curve in achieving accurate diagnoses with minimal image misinterpretation. To ensure that the maximum diagnostic capabilities of MRI are achieved, it is important to understand the basic physics of MR, the MR sequences used for acquisition, and the resulting appearance of different tissues. Installation of MRI systems for equine patients is becoming more common, and therefore, images will be available for evaluation by a diverse group of people. As referral of patients for MRI examination continues to grow, veterinarians will be increasingly exposed to MR images and reports. They may be asked by their clients to explain findings or review studies. This will require a basic knowledge of MRI sequences and image interpretation concepts. The purpose of this article is to present basic MRI principles and to provide an overview of the fundamental information needed to interpret MR images and characterize lesions.

2. Components of an MRI System

A MRI system consists of the magnet, gradient coils, radiofrequency (RF) coils, and a computer software program.8 These components work together to collect information from the tissue and create diagnostic images. When placed in the magnet, protons
within the tissue align along the axis of the main magnetic field and spin, or precess, at a specific frequency that is dependent on the field strength they experience.\(^9\) Gradient coils within the MRI system housing are used to determine the location of different tissues in three dimensions. The gradient coils slightly and precisely increase or decrease the field strength in a controlled manner across the region scanned in all physical axes. Creating a gradient across the magnetic field precisely changes the precessional frequency of the protons based on physical location. The system is able to detect and localize the change in frequency across the anatomy and uses that information to localize the protons in three dimensions. The first step in MRI is for the system to emit a transient RF pulse that excites or increases the energy of the protons. After cessation of the RF pulse, the protons are only under the influence of the main magnetic field and give up energy as they realign along that axis. The energy is emitted as a signal that has a specific frequency characteristic to a precise location within the magnetic field. An RF coil, which is placed around the body part, receives the signal produced by the protons and transmits it to the computer system. This signal is specific to the anatomic and physiologic characteristics of the different tissues within the imaged region.\(^8,9\) Multiple series of pulses are used to determine the tissue types and locations within the imaged anatomy.

After the computer has received the signal from the tissues, a corresponding location and a specific shade of gray is assigned. Specific parameters programmed into the MRI scanner dictate the manner in which this signal is acquired. These specific parameters are referred to as a sequence. There are different types of MR sequences, and the sequence used determines the tissue appearance of the images. Different sequences are used in conjunction to form a given imaging protocol.

### 3. Terminology

“Signal intensity” is used to describe the shade of gray of a specific tissue on a MR image. Tissues that are bright or white are described as hyperintense or as having high signal intensity compared with the surrounding tissues. Hypointense, or low signal intensity, describes tissues that appear dark or black compared with surrounding tissues. Isointense is used as a comparative term for two tissues that have a similar signal intensity. For example, cortical bone and tendons are both hypointense on MR images and therefore, can be considered isointense. Additionally, these terms are used relative to the signal intensity of surrounding structures. On certain sequences, muscle will have a brighter signal intensity than tendons and would be considered hyperintense in comparison to a tendon. The multiple uses of terminology can be confusing; however, the tremendous number of shades of gray requires a basis for comparison to surrounding structures.

T1 and T2 are terms used to describe the magnetic properties of tissue (the response of tissues) and have characteristic values for each type of tissue. MR images may be acquired based primarily on the T1 properties, T2 properties, or a more intermediate combination of the two for the region scanned. The images are then described as T1-weighted, T2-weighted, or proton density (PD; intermediate) images. The various tissue types, with characteristic T1 and T2 properties, will each have specific signal intensities on these respective image weightings. On T1-weighted images, adipose tissue and fat have very high signal and are very bright or white, muscle has low to intermediate signal and is dark to medium gray, and fluid or water normally has low signal and is dark gray. On PD or intermediate weighted images, fat still has quite a high signal and is bright or light gray, muscle has a more intermediate signal and is medium gray, and fluid has an intermediate signal and is medium to lighter gray. On T2-weighted images, fat decreases more in signal and is bright to more medium gray, muscle still has intermediate signal and is medium gray, and fluid has a very high signal and is bright or white (Fig. 1).

### 4. MRI Sequences

There are three major categories of sequences used in MRIs: (1) spin echo or fast spin echo, (2) gradient echo, and (3) inversion recovery. Although the images produced by these sequences can have a similar appearance, they are created quite differently. Spin echo and inversion recovery sequences use multiple RF pulses to change the orientation of the protons within the imaged tissue. In spin echo sequences, a transient RF pulse rotates the protons 90°. After completion of the RF pulse, the protons are solely under the influence of the main magnetic field and realign along its axis. At a specific point in time, the protons are rotated 180° and then allowed to return to the axis of the main magnetic field. As they return to the axis of the main magnetic field, the protons emit a detectable signal that is used to determine the tissue type and location within the imaged region. Fast spin echo sequences are able to send out multiple 180° pulses and collect information in a shorter amount of time compared with spin echo sequences. Fast spin echo sequences are more commonly used than spin echo sequences, because they take less time to acquire the images.

Inversion recovery sequences are a type of spin echo sequence and are produced using a similar method; however, the first step of an inversion recovery sequence is to rotate the protons 180° with a selected time of inversion (TI). This step is specific to an inversion recovery sequence and produces a characteristic image appearance. The remaining steps of an inversion recovery sequence are set to run in the same manner as a spin echo or fast spin...
echo sequence (a 90° RF pulse followed by a 180° RF pulse).

Gradient echo sequences use an initial RF pulse to change the orientation and excite the protons. The degree of rotation, or flip angle, in a gradient echo sequence is usually 90°. After the RF pulse, a gradient or slight alteration in field strength and a reversal of polarity across the magnetic field is used to change the orientation of the protons. These alterations are transient, and the protons emit a characteristic signal as they realign along the axis of the main magnetic field.

5. Tissue Appearance With Different MRI Sequences and Systems

Unlike other diagnostic imaging modalities, MRI produces images in which the same tissue may have different signal intensities depending on the sequence used for image acquisition. The signal intensity of different tissue types on MR images is determined by the sequence and the MRI system used to produce the images. Spin echo sequences can be PD, T1-weighted, or T2-weighted (Fig. 1). PD and T1-weighted images have good anatomical detail; however, fluid usually has higher signal intensity on PD images compared with T1-weighted images. The higher signal intensity of fluid on PD images makes differentiation of fluid from the surrounding soft tissues easier on these images compared with T1-weighted images. The appearance of bone is similar on T1-weighted and PD images. Cortical bone has low signal intensity and is well differentiated from trabecular bone, which has intermediate to high signal intensity because of the presence of adipose tissue. On T2-weighted images, fluid is hyperintense (white), while cortical bone and tendons are hypointense (black; Fig. 1). Compared with PD and T1-weighted images, T2-
weighted images have less anatomical detail but greater contrast. The increased signal intensity of fluid on a T2-weighted image results in greater contrast between fluid and that of the surrounding soft tissues. Therefore, fluid in the soft tissues will be more easily identified on a T2-weighted image compared with PD or T1-weighted images. Adipose tissue has high to intermediate signal on T2-weighted images. Therefore, fluid in bone may not be detectable on T2-weighted images, because it has a signal intensity that may be very close or similar to the adipose tissue in the marrow.

The sequence used to produce an image can be determined by evaluation of the characteristic appearance of the tissues. The sequence parameters, which are usually present on the images, are also indicative of the type of sequence used to produce an image. The time of repetition (TR) and time of echo (TE) are specific numbers, representing time in milliseconds, that are programmed into the MR computer. The TR is the time interval between the 90° RF pulses. The TE is time that the system listens for an echo from the tissue. A T1-weighted sequence has a short TR and TE. A T2-weighted sequence has a long TR and TE. A proton density sequence has a long TR and short TE.

Table 1. Tissue Weighting in Spin Echo Sequences is Determined By the Time of Repetition (TR) and the Time of Echo (TE)

<table>
<thead>
<tr>
<th></th>
<th>TR (ms)</th>
<th>TE (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>450–700</td>
<td>5–30</td>
</tr>
<tr>
<td></td>
<td>Short</td>
<td>Short</td>
</tr>
<tr>
<td>T2</td>
<td>1500–4000</td>
<td>60–150</td>
</tr>
<tr>
<td></td>
<td>Long</td>
<td>Long</td>
</tr>
<tr>
<td>PD</td>
<td>1500–4000</td>
<td>5–30</td>
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<td>Long</td>
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Sequences used in MRI can be customized to produce images with a wide variance of signal intensities. Manipulation of the TR and TE can generate images in which the same tissue will have different signal intensities, despite the fact that the images were produced by the same sequence. Increasing the TR from 1500 to 3400 ms and the TE from 60 to 100 ms using a fast spin echo sequence will produce a more heavily T2-weighted image. There will be a decreased signal intensity of adipose tissue and an increased signal intensity of the fluid on the image with the increased TR and TE compared with the original image (Fig. 2). The images are both considered T2-weighted because of the TR and TE used to produce the images; however, there will be a significant difference in the appearance of the images. As a result of the ability to manipulate the sequence settings, sequences with the same name produced by different MRI systems may appear quite different. This is important to consider when evaluating images from an unfamiliar MRI system. Evaluation of known anatomical areas such as synovial fluid and trabecular bone can be helpful in determining the signal intensity of the different tissues on images from an unfamiliar MRI system.

Gradient echo sequences can be T1-weighted or T2-weighted, which will determine the appearance of the imaged tissue (Fig. 1). After an initial RF pulse at a flip angle that is <90°, gradient echo sequences use a gradient across the magnetic field to alter the position of the protons in the imaged tissue. The flip angle, or degree of rotation of the protons by the RF pulse, plays a major role in determining T1 versus T2 weighting. A larger flip angle will produce a more T1-weighted image, whereas a smaller flip angle will produce a more T2-weighted image. A flip angle of <30° produces a T2-weighted image. Increasing the flip angle from this point gradually moves the image toward T1 weighting. Other factors such as TR and TE affect the tissue contrast. Because of the major contribution of the flip angle on tissue contrast, the range of TR and TE used to
determine the tissue weighting on a spin echo image cannot be used on a gradient echo image.

There are important differences between gradient echo and spin echo sequences. Spin echo sequences acquire information from the anatomy as individual slices. Gradient echo sequences can acquire information as a volume and then divide the anatomy into individual image slices. The use of volume acquisition by gradient echo sequences makes them preferable for three-dimensional reconstruction of images. The reduced number of steps and gradient induced proton rotation used by gradient echo sequences require less time compared with the steps required to complete a fast spin sequence. Therefore, gradient echo sequences have shorter acquisition times compared with fast spin echo and inversion recovery sequences.

Disadvantages of gradient echo sequences include increased susceptibility to artifact and decreased soft tissue contrast. Gradient echo sequences are more susceptible to specific artifacts from magnetic field inhomogeneity (inconsistency) than are spin echo or inversion recovery sequences. Gradient echo sequences lack a step performed in spin echo and inversion recovery sequences that removes the artifactual signal before image formation. The artifactual signal can result from magnetic field inhomogeneity of the MRI system or the imaged tissue. An inconsistent magnetic field caused by system imperfections, temperature fluctuation, or various other causes can result in image artifacts. Severe changes in the magnetic properties of adjacent tissues at interfaces can cause distortion of the magnetic field and image artifacts.

Susceptibility artifacts on gradient echo images are best identified by comparison with spin echo or fast spin echo images. Real abnormalities in signal intensity should be present on both spin echo and gradient echo images, providing that the proper sequences are used for comparison. Changes in signal intensity caused by susceptibility artifact will appear on gradient echo images and will be absent on spin echo images. In general, susceptibility artifact is undesirable but can assist in detection of hemorrhage. The ferrous breakdown products of blood have paramagnetic properties and therefore, create a susceptibility artifact. Hemorrhage is visualized on fast spin echo images; however, its size will be magnified on gradient echo images because of the susceptibility artifact. The magnification on gradient echo images aids with confirmation of the presence of ferrous material and visualization of hemorrhage. This magnification of susceptibility changes can also be exploited to “enhance” conspicuity of interfaces between specific tissues.

Gradient echo images have less tissue contrast than spin echo images. This is most evident when comparing soft tissue but can be detected when comparing bony structures. Tendons will have low signal on both fast spin echo and gradient echo sequences and have less variability in signal intensity than ligaments. The differences in soft tissue contrast are most evident when comparing ligamentous structures. Normal ligaments will vary in signal intensity from light gray to black. The degree of variability is dependent on the specific ligament, the density of collagen bundles, and the sequence used for imaging. The decreased soft tissue contrast of gradient echo sequences results in more difficulty detecting ligament margins that blend into a gray background of surrounding soft tissue. This difference will be more apparent on low field images compared with high field images (Fig. 3). The decreased soft tissue contrast also may result in greater difficulty in detecting and differentiating articular cartilage changes from adjacent joint fluid and synovial tissues.

Inversion recovery sequences use the initial 180° RF pulse and TI to eliminate the returning signal from a specific tissue; this is usually chosen to suppress the signal of fat. Elimination of the returning signal causes that tissue (e.g., adipose tissue) to appear black on the images. Suppression of the signal from adipose tissue produces images that have hyperintense fluid and hypointense soft tissues and bone, causing fluid to stand out as an area of bright signal intensity on a dark background (Fig. 1). The short T1-inversion recovery (STIR) sequence is commonly used in orthopedics to increase conspicuity of abnormal fluid in bone and soft tissues. Unlike certain T2-weighted images, fluid and adipose tissue have distinctly different signal intensities on inversion recovery images, allowing detection of fluid within the marrow cavity of bones. The fluid attenuated inversion recovery (FLAIR) sequence is used in brain imaging to suppress the signal from normal cerebrospinal fluid, which allows for identification of abnormal fluid within the brain. Compared with spin echo and gradient echo sequences, inversion recovery sequences have a longer acquisition time and a lower signal to noise ratio, which results in decreased resolution. The enhanced visualization of fluid aids in detection of pathologic change in bone and soft tissue, making inversion recovery sequences of value despite the disadvantages of increased acquisition time, decreased signal to noise ratio, and decreased resolution. Unlike spin echo and gradient echo sequences, there is minimal variability in the signal intensity of the different tissues on inversion recovery images produced from different MRI systems. The tissue contrast of STIR images from different systems will appear similar; however, because inversion recovery sequences have the lowest signal to noise ratio, there can be a substantial difference in the image quality between systems.

The most challenging images to acquire will best show the differences in resolution and magnetic-field uniformity between MR systems. Fat suppression techniques, such as fat saturation or inversion recovery, require homogeneity of the MRI system’s main magnetic field. When this field is
not homogeneous, the fat suppression will be uneven and therefore, unreliable across the MR image. Comparing fat suppressed images is an effective and simple method to evaluate the differences in field homogeneity between MR systems.

Because of the low signal and resolution of STIR sequences, preserving anatomic detail can be difficult. Comparison of STIR images is an effective way of evaluating differences in resolution between MR systems. Differences in resolution will be less apparent on T1-weighted images, because they have good signal, good resolution, and good resulting anatomic detail. Small or thin structures, such as the impar ligament, flexor surface of the navicular bone, and articular cartilage, challenge the resolving power of an MRI system. Articular cartilage of the metacarpophalangeal and metatarsophalangeal joints is the most difficult to visualize because of the curvature of the third metacarpus and metatarsus and the thin layer of articular cartilage. Resolution of fine detail can be assessed by evaluating a system’s ability to differentiate articular cartilage from synovial fluid in the fetlock joint. The differentiation is necessary for identification of articular cartilage damage. The anatomy of the impar ligament and the flexor surface of the navicular bone make them difficult to accurately resolve. Therefore, differences in resolution between systems will be most evident when evaluating these types of structures. The multiple fluid fiber interfaces of the impar ligament and its relationship with the distal palmar recess of the distal interphalangeal joint can obscure ligament margins. Because of the curvature of the navicular bone, the thin layer of fibrocartilage, and the close proximity of the navicular bursa and deep digital flexor tendon, accurately resolving small areas of abnormality on the navicular bone flexor surface is challenging.

The signal that is produced by the tissues during imaging is directly proportional to the field strength of the magnet. The increased signal generated by a higher field-strength magnet translates to improved resolution and faster imaging times. Higher resolution images increase the conspicuity of small and
low contrast lesions. Therefore, certain structures and lesions are better characterized using a high-field system. Faster imaging times decrease anesthetic time and patient motion. Comparative studies correlating clinical findings and lesion size are needed to determine if the difference in diagnostic accuracy between high field and low field systems significantly affects patient management.

6. Clinical Applications and Image Interpretation

Tissue characteristics change as disease occurs, resulting in alterations in signal intensity compared with normal. Bone sclerosis, increased tissue fluid, and presence of fibrous tissue can be detected because of alterations in signal intensity. Certain sequences are preferred for identifying different types of signal abnormalities.

7. Bone Sclerosis Versus Fluid in Bone

Bone sclerosis is most easily identified on T1-weighted or PD images because of the high signal intensity in the trabecular bone caused by the presence of adipose tissue. Trabecular thickening will result in an area of hypointensity in the medullary cavity as the adipose tissue is replaced by bone. On T1-weighted images, fluid and bone sclerosis have low signal intensity and cannot be reliably differentiated. Therefore, regions of abnormal low signal intensity within trabecular bone on T1-weighted images must be compared with images produced by another sequence, such as a STIR image. The comparison allows for the determination of the cause of the signal abnormality. Bone sclerosis will have low signal intensity on T1-weighted and STIR images (Fig. 4). Fluid within the bone will have low signal intensity on both T1-weighted images and high or increased signal intensity on STIR images (Fig. 4). In cases where there is high or intermediate signal intensity in the bone on T1-weighted images and corresponding high signal intensity on STIR images, hemorrhage or proteinaceous fluid should be con-
sidered as a possible cause of the abnormal signal intensity (Fig. 5). Hemorrhage breakdown products have variable signal intensity over time.10

8. Focal Versus Diffuse Fluid Accumulation in Soft Tissue and Bone

Injury resulting in increased fluid in tissue will be most evident on T2-weighted or fat suppressed images. Fluid has high signal intensity, whereas normal soft tissue structures and bone have lower signal intensity in comparison. On T2-weighted images, fluid in the trabecular bone may be difficult to appreciate, but fluid in the soft tissues can be identified (Fig. 6). Inflammation and granulation tissue have variable signal intensities depending on the amount of fluid, the stage or degree of fibrosis, and the chronicity of the disease process. Focal fluid collections (Figs. 5 and 7) within tissue will have distinct margins compared with diffuse fluid infiltration that has more ill-defined margins (Figs. 4 and 8). Compared with focal fluid accumulation, diffuse fluid accumulation may have more variable signal intensity. This is again dependent on the amount, type, and content of the...
Fluid. Fluid in combination with tissue or debris will have lower signal and often less uniform signal intensity compared with pure fluid.

9. Tendon Lesions

Dorsal margin abrasions, dorsal margin tears, core lesions, and parasagittal tears have been identified in equine tendons.2,11 The amount of fluid associated with a tendon lesion is difficult to determine and unreliably evaluated on a T1-weighted or PD image (Fig. 7). Certain tendon lesions can have increased signal intensity on T1-weighted and PD images for a prolonged period of time and are unlikely to reverse. Equine patients have had follow-up studies ≈2 yr after a deep digital flexor tendon injury with minimal or no change in signal intensity on T1-weighted or PD images (Fig. 9).a

Certain tendon lesions, such as intrasubstance strain or partial tearing, have increased signal intensity on T2-weighted and STIR images, and over time, this signal intensity will decrease if scar tissue develops and matures. If fibrous tissue forms as a result of the original injury, the immature scar initially will have increased signal intensity on T1-weighted and PD images compared with the surrounding normal tendon (Fig. 10). Mature scar or chronic fibrosis will have low signal intensity on all sequences similar to normal tendon tissue. The scarred tendon may have an abnormal shape with irregular thickening compared with the smooth and uniformly thick normal tendon. Chronic degenerative changes without associated fluid can have lower signal intensity on T2-weighted and STIR images compared with T1-weighted and PD images; therefore, they will be less detectable adjacent to normal tendon fibers (Fig. 10). The progression of signal changes on T2-weighted and STIR images is dependent on the healing process.
10. Tendonitis Versus Tendonosis

In human medicine, the term tendonosis is used to describe specific pathologic changes such as seen in the Achilles tendon on imaging studies and histology.\textsuperscript{12–21} In these cases, the term tendonitis has been replaced by tendonosis, because signs of inflammatory response have not been present histologically.\textsuperscript{13,14} Histologically, tendonosis is characterized by collagen disorientation, collagen disorganization, and collagen fiber separation as well as an increase in mucoid ground substance, an increased prominence of cells and vascular space with or without neovascularization, and focal necrosis or calcification.\textsuperscript{12–14} The exact etiology of tendonosis is unclear, and there are multiple theories.\textsuperscript{14} Overuse of the tendon resulting in chronic repetitive microtrauma that exceeds the repair capacity and results in scar deposition and tendon degeneration.

![Image](157x581_to_473x736.png)

Fig. 7. (A) T1-weighted and (B) STIR transverse images of a foot at the level of the second phalanx acquired using a Hallmarq distal limb scanner (0.27 T). The red arrows designate a well marginated lesion that has high signal intensity on the STIR and T1-weighted images. The blue arrows designate a lesion that has high signal intensity on the T1-weighted image and low signal intensity on the STIR image. Although the lesions appear the same on the T1-weighted image, the STIR image indicates that they are very different. Previous injury or degeneration of a tendon without associated fluid may have high signal intensity on T1-weighted images (blue arrow on A) and may not appear different from focal fluid accumulation (red arrow on A); however, on the STIR image, the lesion cannot be differentiated from the surrounding tendon (blue arrow on B). The lesion designated by the blue arrows does not have any fluid associated with it. The increased signal intensity on the T1-weighted image (blue arrow on A) is most likely the result of tendon degeneration or chronic injury. The lesion designated by the red arrows, caused by the signal intensity on the STIR image, indicates focal fluid accumulation in the tendon. Increased signal intensity on T1-weighted images in soft tissue structures must be compared with other sequences to determine the nature of the signal change.

![Image](166x132_to_465x308.png)

Fig. 8. (A) Proton density and (B) STIR images of a foot with multiple areas of abnormality acquired using an ONI OrthOne (1.0 T). There is diffuse fluid accumulation in the deep digital flexor tendon characterized by ill-defined increased signal intensity along the palmar margins of the tendon (arrow). The fiber architecture of the tendon is still visible. The margins of this lesion are quite different from the focal fluid accumulation in figure 7. This case shows that margins can help to distinguish focal fluid accumulation from diffuse fluid accumulation, which implies a different disease process. This horse had diffuse tendonitis from infection in addition to other lesions.
Fig. 9. (A and B) T1-weighted transverse images at the mid aspect of the second phalanx that were acquired using a Hallmarq distal limb scanner (0.27 T). These images are from the same horse and were acquired 9 months apart. Areas of abnormality can be identified in both lobes of the deep digital flexor tendon. There is minimal difference in the lesions between the original and recheck examination. The lesions are slightly different in shape, but the signal intensity appears unchanged. Evaluation of the shape of the second phalanx would indicate that there are mild differences in positioning between the two studies. This may account for the difference in the shape of the lesions between the two studies. This case shows that the signal intensity of tendon lesions on T1-weighted images can remain unchanged for a prolonged period of time and is not a reliable indicator of lesion age.

Fig. 10. T1-weighted (A), T2-weighted (B), and STIR (C) images immediately proximal to the navicular bone acquired using an ONI OrthOne (1.0 T). There is a linear area of increased signal intensity in the deep digital flexor tendon on the T1-weighted image. This finding cannot be identified on the STIR image. There is a slight area of increased signal intensity on the T2-weighted image. This finding represents a previous parasagittal tear or split in the deep digital flexor tendon. The lack of increased signal intensity on the STIR image would indicate that there is no fluid associated with this lesion.
Fig. 11. (A) T1-weighted, (B) T2-weighted, and (C) STIR images acquired with a Hallmarq distal limb scanner (0.27 T). These images are from a 5-yr-old Quarter Horse with a chronic history of low grade lameness localized to the foot that presented because of an acute exacerbation of the lameness. The lateral lobe of the deep digital flexor tendon is focally enlarged (arrows on A–C), and there is a small area of adhesions between the deep digital flexor tendon and the collateral sesamoidean ligament of the navicular bone. The area of abnormal signal intensity in the deep digital flexor tendon could be identified from the mid aspect of the second phalanx to the distal aspect of the navicular bone. It has increased signal intensity on the T1-weighted image. On the T2-weighted image, there is a very mild increase in signal intensity, which is not consistent with fluid. Fluid in the navicular bursa is visible and can be used for comparison. There is no increase in signal intensity in the tendon on the STIR image; however, the tendon enlargement and focal adhesions can still be identified. The signal intensity of this tendon lesion is consistent with tendonosis. At the distal extent of the navicular bone, the signal characteristics of the lesion changed. (D) T2-weighted and (E) STIR images located distal to the navicular bone show a tear in the lateral lobe of the deep digital flexor tendon. There is a defect in the tendon, and the dorsal margin is disrupted and frayed. There is increased signal intensity in the defect that is consistent with focal fluid accumulation. This case shows a tendon tear extending from the distal margin of a tendonosis lesion. This tear continued to the insertion of the tendon on the third phalanx. (F) A T2-weighed image of a normal deep digital flexor tendon is provided for comparison to the injured tendon in D.
The characteristics of tendonosis on MR images has been described. It appears as a diffuse area of intermediate signal intensity on PD or T1-weighted images. The reported appearance of tendonosis on T2-weighted and STIR images is somewhat variable; however, this may be partially caused by the difference in imaging protocols as well as the different stages of the disease.20,21,23 It is reported to have minimally increased signal intensity on STIR and T2-weighted images;21 however, high signal intensity on STIR images has been correlated histologically with more focal and severe tendon degeneration.20 The necrosis and myxoid degeneration resulting from severe chronic tendon degeneration can result in fluid signal intensity in a tendon on STIR images.20 The intensity of the signal increase on T2-weighted and STIR images correlates well with the severity of tendon degeneration.21–23 Although signal intensity on MR images indicative of fluid in soft tissue has been traditionally thought of as an indicator of acute inflammation, it can be seen with chronic disease such as severe degeneration and necrosis.

A signal pattern on MR images consistent with tendonosis has been identified in horses (Fig. 11).11 In Busoni et al.,11 the tendons identified as degenerative on MR images had histologic findings similar to the histologic description of tendonosis lesions in the human literature. MRI allows us to characterize lesions in a way that is vitally important, because the specific pathologic change underlying a patient’s symptoms determines the prognosis and treatment. Small differences in signal intensity associated with a lesion may indicate large differences in gross findings (Fig. 12). It is important to scrutinize images to detect small differences in the signal intensity of lesions. Continued research correlating MRI and histology is needed to understand these differences in lesion appearance on MRI images. Correlation of these findings between equine and human subjects will be beneficial to patients and practitioners in both patient populations. The results of these studies will help us design treatment plans based on a more precise understanding of the injury.

11. Conclusions
In summary, study interpretation requires knowledge of anatomy and MRI sequences. In addition, knowledge of MR artifacts, which was not discussed in this paper, is necessary for accurate image interpretation. Imaging planes that are most effective for identification of specific structures of the foot have been proposed.24 The normal appearance of structures on MR images related to age and exercise must be identified to determine clinically significant lesions. Because MRI is gaining clinical use, it is important at this time to determine appropriate imaging protocols and techniques. Ensuring this modality is properly used will provide our profession with optimal interpretation and diagnoses. We are at the beginning of this process and need to understand our limitations at this time. MRI is an excellent diagnostic tool. Time and further studies are needed to understand the uses, advantages, and limitations of this modality.
Figures 1, 2, 3C, 3D, 4C, 4D, 5, 8, 10, and 12 are courtesy of the Equine Orthopaedic Research Center at Colorado State University, Fort Collins, CO. Figures 3A, 3B, 4A, 4B, 6, and 9 are courtesy of Equest Diagnostic Imaging Center in San Marcos, CA. Figure 7 is courtesy of Wisconsin Equine Clinic and Hospital in Oconomomoc, WI. Figure 11 is courtesy of Arizona Equine Hospital in Gilbert, AZ.

References and Footnote

‘Mair T. Personal communication. 2006.’