What a Difference MRI Makes

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A relatively short time after the usefulness of magnetic resonance imaging (MRI) was discovered, it became common in human medicine. MRI, which relies on the reaction of molecules in a magnetic field, was first used in human medicine in 1971, and the first image of a human head was published in 1978.\(^1\) Since then, use of super-cooled magnets for MRI has resulted in increases in the magnetic field strength, improved image resolution, and increased speed of image acquisition. MRI became the imaging modality of choice for neurologic scanning during the 1980s and is now considered by many to be the ultimate imaging modality for the musculoskeletal system because of its ability to simultaneously detect changes in bone and soft tissue.\(^2\)

MRI is a new modality in equine medicine. Some of the larger MRI systems made for human medicine and called high-field magnets have been adapted for horses. Although the larger magnets are expensive to purchase and maintain, they can create high-resolution images. The magnetic field strength, which is measured in tesla units, is usually 1 to 1.5 tesla for most MRI systems used for humans. These high-field magnets have recently been used to image small animals and anesthetized horses\(^3\)–\(^5\) (Figure 1).

A new low-field MRI system (Hallmarq Veterinary Imaging Ltd., Guildford, Surrey, UK) designed for use in standing horses uses an open magnet with a field strength of 0.3 tesla. The open magnet can be positioned around the horse’s lower limb or foot to image the area of interest (Figure 2). The resulting images of the weight-bearing limb allow detection of changes in soft tissue and bone similar to those detected using larger conventional magnets. Images can be obtained from the foot to the carpal or tarsocrural joints, and because movement creates image artifacts, antimotion software is part of the image capture system (Figure 3). In some cases, movement artifacts cannot be corrected and general anesthesia is required to obtain diagnostic images. Because of the lower cost of low-field magnets, MRI is becoming available for all animals, including horses. With all MRI systems, the opening into the magnet restricts MRI use in adult horses from the foot to the distal radius and tibia and on the head.

HOW DOES MRI WORK?

Unlike radiography or ultrasonography, which detect structure based on tissue or fluid density, MRI detects changes in proton resonance. Protons make up the nucleus of atoms, and when placed in the magnet, protons align with the magnetic field and become magnetized (Figure 4). When stimulated by a radiofrequency pulse, protons in different types of tissue have a different resonance. For example, protons in fat resonate differently than do protons in fluid.

To detect different types of tissue or abnormalities in tissue, electromagnetic energy or a radiofrequency pulse is emitted from a coil, which is placed around the part of the limb to be scanned. The radiofrequency pulse alters the magnetization alignment of
protons within the magnetic field. When the radiofrequency pulse is stopped, the protons release energy as they realign within the magnetic field. The released energy or signal is detected by the MRI coil, which transmits it to the computer, where the impulse is transformed into an image (Figure 5).

To detect different types of tissue, the angle of the radiofrequency pulse and its length (known as repetition time), as well as the time during proton realignment when the radiofrequency signal release is transmitted to the MRI computer (known as echo time), are adjusted to image contrast and highlight different types of tissue or fluid. The most common sequences for musculoskeletal imaging are called fast spin echo and gradient echo, which alter the way the radiofrequency pulse is delivered and subsequently detected. Each of these sequences can be weighted based on the length of the radiofrequency pulse and the time when the release of radiofrequency from the tissue is detected. The weighting is referred to as $T1$ and $T2$ weighting.

The MRI scan is collected in slices. The benefit of MRI is that slices can be made in any plane of the limb. In some sequences, the slice is made with a specific length, depth, and width, whereas in others, the slice is made as an average from the information collected from a specific volume of tissue. The slices are normally taken every 3 to 5 mm, making it possible to miss very small lesions. In most cases, the changes in horses are suffi-
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Although the physics and terminology of MRI are not easily understood without some knowledge of the science behind it, MRI has been refined so that the images resemble structures. Nevertheless, when an MRI scan is examined, the evaluator must remember that both the anatomy and physiology of the tissue are being displayed, rather than just density or structure. The chemical makeup is related to tissue density and accurately identifies types of tissue.

WHAT DO MRI SCANS LOOK LIKE?

The three main substances detected by MRI include fluids (e.g., joint fluid, edema), water-rich tissue (e.g., muscle, cartilage), and fat (which is found in bone marrow). MRI can detect changes in these components due to inflammation, bruising, fracture, or scarring. The signal is the amount of information on the image. The images are made from pixels, each representing the amount of signal from a specific site in the tissue. Tissue that appears white has high signal intensity, whereas tissue that is dark has low signal intensity. In most T1 and T2 sequences, fat appears bright with a high signal intensity (Figure 6).

In T1-weighted images, fluid appears gray; in T2-weighted images, fluid is white, and cortical bone, tendons, and ligaments appear black. Cartilage, which has a high water content, is white in both sequences. A short T1-inversion recovery (STIR) sequence uses pulse radiofrequency to invert the proton alignment, thereby suppressing the signal from fat. This allows examination of all structures, particularly the bone marrow cavity, so abnormal fluid or blood can be identified (Figure 7).

DOES MRI MAKE A DIFFERENCE IN DIAGNOSIS?

The value of MRI in diagnosing musculoskeletal disorders is the ability to detect active inflammation at a specific anatomic site. Although changes in bone mineralization can be detected with radiography, these processes take time, and alterations in bone density may not be evident at the onset of acute inflammation. Scintigraphy can help localize lesions but is not sensitive enough to detect specific morphologic changes. Ultrasonography is a very effective technique for detecting changes in soft tissue structure but cannot always detect early evidence of inflammation or discriminate between fibrous tissue and active inflammation. Detecting inflammation or structural change is even more difficult in a horse’s foot because of the limited ability to evaluate structures within the hoof capsule.

MRI can detect changes in bone and soft tissue that are not evident with the other imaging modalities. Since use of MRI in horses was first described in 1996, MRI has been used to detect injuries to tendons, ligaments of the distal interphalangeal joints, the metacarpal phalangeal joint, the suspensory ligament, the hock, the carpus, subchondral bone, cartilage, fractures, hoof lamina, the navicular bursa, navicular bone, and the impar ligament.

In a study of 199 horses with caudal heel pain, 59% of lesions associated with navicular disease. Because pain can come from several structures surrounding and supporting the navicular bone, MRI is helpful in determining which structure(s) is inflamed or scarred. When radiographs and ultrasonograms are normal, MRI can often detect bone edema, navicular suspensory ligament inflammation, deep digital flexor tendinitis, navicular bursa adhesions, and changes in the impar ligament. In a study of 199 horses with caudal heel pain, 59% of lesions...
detected by MRI were injuries to the deep digital flexor tendon (Figure 8). The prognosis for full return to soundness for horses with this lesion was only 28%, suggesting that these lesions are potentially chronic and not always amenable to currently available treatments.

Lesions identified by MRI in the caudal heel region may make the diagnosis of navicular disease a dilemma in some horses. Although navicular disease is characteristically thought to be due to pain originating from the navicular bone and bursa, MRI is able to distinguish between inflammation of the navicular bone, deep digital flexor tendon, bursa, or suspensory ligament. As a result, MRI has shown that lameness associated with navicular or caudal heel pain can be due to inflammation in different structures.

Injury to the collateral ligaments of the distal interphalangeal joint has been detected with MRI (Figure 9). In fact, in one clinical study,\textsuperscript{9} distal interphalangeal collateral ligament desmitis was the second most frequent diagnosis related to foot pain based on MRI findings. However, lesions identified by MRI do not always

\textbf{Figure 5.} The pulse of the radiofrequency changes the proton axis alignment. Once the radiofrequency pulse stops, the proton axis is realigned in the magnetic field, releasing a radiofrequency that is acquired by the computer at specific times (i.e., echo time) to make images with specific types of tissue contrast.

\textbf{Figure 6.} A TI-weighted gradient echo image. The fat in the marrow cavity has a high signal (i.e., white), whereas cortical bone and tendon have a low signal (i.e., black). Fluid has a medium signal (i.e., gray).
correlate with ultrasonographic findings. As clinicians become better able to distinguish specific diseases with MRI, its value in prognostication will undoubtedly increase.

Figure 7. A STIR sequence suppresses the signal from fat.

Suppression of the signal from fat makes the marrow cavity of the middle phalanx and distal phalanx appear gray, whereas fluid in the coffin joint has a high signal and appears white (arrow).

A STIR sequence from a horse with a bone bruise (arrow) in the proximal aspect of the middle phalanx. The abnormal fluid in the bone has a high signal in contrast to the low signal from fat.

Figure 8. T2-weighted image of a deep digital flexor tendon injury adjacent to the navicular bone (N). The focal increased signal in the tendon (arrow), which is normally black, is indicative of fluid within the tendon. (Courtesy of Wisconsin Equine Clinic and Hospital, Oconomowoc, WI)

Figure 9. Increased signal in a transverse view of a collateral ligament of the distal interphalangeal joint (arrow). The ligament should have a low signal (i.e., black) as seen in the contralateral ligament.

Inflammation within the proximal and distal suspensory ligaments can be detected with MRI and seen without ultrasonographic evidence of injury. MRI can detect changes in size as well as evidence of fluid accumulation within ligaments before there is ultrasono-
graphic evidence of fluid accumulation or fiber damage. This capability of MRI is extremely valuable in horses with acute injuries (Figure 10).

One of the most valuable features of MRI is its ability to detect inflammation in bone. Both fluid (e.g., bone edema) and sclerosis (e.g., increased bone density) are detectable with MRI; these findings are difficult to impossible to detect by radiography. Bone bruises, infection (Figure 11), subchondral damage due to joint disease, and bone remodeling can all be visualized with MRI before they are evident radiographically. Bone sclerosis with remodeling in young athletic horses is evidence of stress remodeling and, with clinical experience, allows early detection of bone injury before appearance of stress fractures on radiographs. Subchondral sclerosis can indicate chronic injury in joints (Figure 12).

Cartilage changes are often difficult to detect, but full-thickness defects, which are large enough to be intersected at one of the MRI slices, can be identified. Changes to subchondral bone are often concurrent with cartilage damage and can be an early indicator of joint disease or degenerative joint disease6,14,15 (Figure 13).

**WHAT’S NEXT FOR MRI?**

With the advent of the MRI system for standing horses, the number of horses being examined with MRI is increasing rapidly. However, it is important to recognize that interpretation of the resulting images is in its infancy. Interpreting MRI scans requires new knowledge, with an understanding of what the images represent. Veterinarians trained and experienced in evaluating radiographs and ultrasonograms require additional training to read MRI scans. Otherwise, it could be extremely easy to misinterpret variations within normal tissue as lesions. Nevertheless, MRI can be used to find tissue changes and pathology that cannot be identified using other imaging modalities.

As with ultrasonography and radiography, artifacts exist with MRI and must be recognized.16 Because imperfections can exist in the magnetic field and MRI is new in horses, interpretations of abnormalities must be corroborated with findings from other modalities, including gross and histologic evaluation of affected tissue. To minimize misinterpretation of artifacts, a com-
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A complete MRI examination protocol with an adequate number of sequences should be used on each region being examined to ensure that all pertinent structures are properly imaged. Interpretation of findings must be made with enough skepticism and objectivity to ensure the diagnosis is based on appropriate criteria rather than conveniently fitting the clinical picture. Although MRI studies of normal anatomy have been published, it is clear that many more horses must be scanned to establish normal variations and the limits of this modality.

MRI does not replace other imaging modalities. Lesions identified with MRI can often be detected retrospectively by reexamining ultrasonograms or radiographs, albeit with the knowledge that a lesion exists. Although it does not make sense to use MRI to facilitate a radiographic diagnosis, it does make sense to conduct MRI evaluations on straightforward cases to increase the available data for corroboration of diseases and create a resource for future reference.

If the future of equine MRI is anything like what has occurred in human and small animal medicine, the only limitation to its usefulness in horses will be the size of the magnet. Motion correction software for use with the standing MRI system is improving. Current limitations are based on machines adapted from human medi-
MRI. As MRI technology advances, there are likely to be larger open magnets, which can be used to image more of a horse. It is already clear that MRI is taking equine imaging to a new and exciting level. Although evaluating MRI scans is challenging, the greater challenge will likely be treating what can now be detected with MRI.

REFERENCES