Lameness is a common problem in horses. Equine veterinarians are often called upon to diagnose the source of lameness and institute appropriate treatment to return horses to soundness promptly. A lameness examination typically involves perineural and/or intra-articular anesthesia to determine the location of the lameness. Following anatomic localization of the problem, diagnostic imaging is pursued to obtain more specific information about the etiology of the lameness. Advanced diagnostic imaging is pursued when more traditional imaging methods (eg, radiography and ultrasonography) have failed to reveal the specific cause for a lameness. CT and MRI, both of which are cross-sectional imaging modalities, are frequently used in these cases to accomplish the ultimate goal of diagnostic imaging: to obtain a definitive diagnosis.

This article will discuss the basic principles behind CT and MRI, their advantages and disadvantages, the different types of equipment available for clinical use in horses, the typical diagnostic workup prior to pursuing advanced imaging, and common regions where CT and MRI are used in a clinical context. This article focuses on imaging arising out of a lameness examination rather than its use for surgical planning, fracture assessment, or cases of laminitis, sepsis, or penetrating wounds.

Basic Principles

MRI uses strong magnetic fields and radiofrequency pulses to perturb the target tissues. The differing chemical composition of different tissues causes different responses. The responses of the tissues are recorded and constructed into images. Images appear as thin (typically 1 to 5 mm thick) slices in the anatomic plane selected by the operator. Multiple different sequence types are used to obtain different sorts of information; some sequences excel at highlighting anatomy, others at identifying fluid-like signal, and others at imaging articular cartilage. A typical MRI examination of 1 region or joint in a horse takes approximately 30 minutes, but this can vary depending on the exact protocol used.

CT uses x-ray radiation that is received by a detector using the same principles as radiography. It is a structural imaging modality that measures radiodensity. Multiple projections around the axis of the region of interest are obtained as the scanner rotates around the anatomy. These projections are processed to create thin (1 to 3 mm) slices along the plane in which the anatomy was scanned. Different processing parameters highlight different tissue types. Bone and soft tissue algorithms are commonly used for the equine musculoskeletal system. The type of data obtained by a CT scan lends itself to various reconstructions, including 3-D volume renderings and multiplanar reconstructions. A typical CT scan of 1 region or joint in a horse takes only a few minutes.

General advantages of cross-sectional imaging include minimization of superimposition and increased detail. Although the images obtained from both CT and MRI examinations represent thin slices of tissue, the very different properties of the information obtained give them different strengths and...
weaknesses. CT excels at assessing bony anatomy. The high spatial resolution of CT and very thin slices (< 1 mm in some cases) allow detailed examination of bony abnormalities such as fractures and changes in bone opacity. MRI has better contrast resolution than CT, which highlights areas of abnormal tissue in both bone and soft tissues. CT is broadly considered the gold standard for bony pathology and MRI the gold standard for soft tissue pathology, but there are notable exceptions to this generalization, for example the ability of MRI to identify bone marrow lesions.1–5 If both CT and MRI are available options, there should be careful consideration of which modality to choose for a particular case. In the author’s experience, MRI is generally a better choice for most lameness cases because MRI can generate detailed information about both bone and soft tissue pathology, providing more information about more structures than does CT.6–10 Bilateral imaging is often performed for comparison purposes and to identify potential subclinical pathology.3,11–13

The major disadvantages of both CT and MRI are the cost of the equipment and its maintenance and their relative lack of availability outside referral hospitals. Although some scanner types and designs do not require general anesthesia for imaging of the distal limb, others do. This is particularly relevant for MRI, as high-field scanner designs require general anesthesia to image horses, but this disadvantage may be outweighed by improved image quality, which will be discussed below.

Designs

Available MRI scanners vary in both strength and design. Scanners currently in clinical use for horses range between 0.3 and 3.0 T in strength. Many scanners were designed for human use and require general anesthesia to position the horse within the bore of the scanner, but there is 1 low-field (0.3-T) design manufactured for horses that accommodates the distal limb of a standing, sedated horse. Motion can be a problem when imaging a standing horse, particularly as more proximal areas of the limb are imaged.14,15 Higher magnet strength has several clinically relevant advantages, including decreased scan times, increased resolution, larger field of view, availability of specialized sequences (eg, to evaluate articular cartilage), and overall improved image quality.5,16–18 These factors can translate into increased anatomic visibility, greater diagnostic ability, and higher diagnostic confidence in the findings.16–20 One recent study17 comparing low-field standing, low-field general anesthesia, and high-field general anesthesia MRI examinations of the equine foot found that image quality was better in high-field scans than in either type of low-field scan, indicating that higher field strength itself led to improved image quality rather than the use of general anesthesia. Other studies18,21–24 have shown higher detail and/or greater lesion detection in a variety of tissue types with high-field MRI than with low-field MRI in the foot, fetlock region, proximal metacarpus, and carpus. These studies parallel the author’s experience that some lesions are identifiable on low-field scans but many lesions require a high-field scan to identify or characterize completely.

Like MRI, many CT scanners in clinical use for horses are designed for humans and have been repurposed for the horse, but designs specifically for horses have become available recently. Some designs require general anesthesia to image limbs, while others can accommodate a standing, sedated horse. Due to the shorter scans time as compared with MRI, motion is less of a problem with standing CT, but is still an issue.25–29 There are also differences between cone beam and fan beam CT systems. In a basic sense, fan beam CT collects thin slices of information and cone beam CT collects a volume of information. In both types, the information is then processed into axial slices within operator-selected parameters. However, the differences in how the systems acquire and process data have practical implications that must be considered. Image quality is superior with fan beam CT, compared with the quality in cone beam CT, with fewer artifacts, better signal-to-noise ratio, better contrast resolution, and lower scatter (Figure 1).26,30 However, cone beam CT can be more anatomically versatile in a standing horse.25,26

Figure 1—Transverse CT images of the distal aspect of the third metacarpal bone and proximal sesamoid bones obtained from a fan beam (A) and a cone beam (B) system. Note the superior image quality obtained with the fan beam system.

1114  JAVMA  |  JULY 2022  |  VOL 260  |  NO. 10
Lameness Evaluation Prior to CT/MRI

It is most appropriate to pursue cross-sectional imaging after a complete lameness examination, including regional and/or intra-articular anesthesia (“blocking”) to localize the anatomic site of the lesion as precisely and accurately as possible. This may involve blocking the horse in slightly different ways over the course of multiple days (eg, a horse that blocks to palmar digital perineural anesthesia on day 1 being reblocked with intra-articular anesthesia of the distal interphalangeal joint on day 2). Accurate anatomic localization is important due to the cost of the examinations, the need for general anesthesia in some cases, the patience of the horse, reasonable amounts of sedation for standing examinations, and the amount of time the examination takes for each region. It is not practical to routinely screen an entire limb from the carpus or tarsus distally. If abnormalities in multiple locations are identified, knowing the presumptive anatomic location of the lameness is helpful in determining the clinical significance of those abnormalities. If the contralateral limb will be imaged for comparison, time for those scans needs to be factored in as well.

However, there are limitations to perineural and intra-articular anesthesia. We have learned that the anatomic structures that are anesthetized are often out of the traditional “boundaries” of a block and that regional anesthesia is not as specific as we would hope. Palmar digital perineural anesthesia can diffuse proximally and potentially anesthetize lesions in the fetlock region. Basisesamoid perineural anesthesia can also diffuse proximally and is not specific for the pastern region. Other common sites where local anesthesia can diffuse to (or penetrate) and anesthetize an adjacent structure include anesthesia of the distal tarsal joints anesthetizing the proximal metatarsal region (and vice versa) and anesthesia of the middle carpal/carpometacarpal joints anesthetizing the proximal metacarpal region (and vice versa). These observations are supported by reports of horses that respond to palmar digital perineural anesthesia with MRI-confirmed primary lesions in the pastern or fetlock region and horses that respond to basisesamoid perineural anesthesia with primary lesions in the fetlock region. There are additional reports of horses with a primary MRI diagnosis of distal tarsal disease responding to anesthesia of the proximal metatarsal region and horses with a primary diagnosis of proximal metatarsal disease responding to anesthesia of the distal tarsal joints.

Recognition of the lack of specificity of regional anesthesia should be considered during scan planning. In the author’s practice (and in others), a scan of the foot for a lameness case always includes images as far proximally as the fetlock joint. A scan of the carpus/tarsus should include images of the proximal metacarpal/metatarsal region and vice versa. Even with these adjacent areas included in a typical scan protocol, if a scan requires general anesthesia to perform, it is valuable to have the images reviewed as the scan progresses in case additional anatomic areas need to be added to the examination (eg, adding a fetlock region scan if a foot scan has no significant abnormalities). This can minimize or prevent additional anesthetic episodes. If the scan is performed with standing sedation, the ability to come back later and obtain additional scans is usually readily available.

Foot

Advanced imaging of the foot is generally more useful with MRI than with CT. Radiography and ultrasonography are limited in their diagnostic abilities, and MRI provides a diagnosis in many cases where these modalities have failed to do so. An example of an imaging decision tree for a horse that blocks to palmar digital perineural anesthesia or intra-articular anesthesia of the distal interphalangeal joint is provided (Figure 2). Some of the more common pathologies identified include navicular bone flexor cortex defects, distal margin fragments, degenerative change, impar or navicular suspensory ligament desmopathy, deep digital flexor tendinopathy, proximal or distal interphalangeal joint osteoarthritis, fracture, resorptive or subchondral lesions, and distal interphalangeal joint collateral ligament...
desmopathy. MRI also allows evaluation of bone marrow lesions, which may be seen alone or at entheses in combination with soft tissue pathology. MRI findings have been shown to correlate well with histologic findings of abnormalities of the deep digital flexor tendon, navicular bone, impar ligament, and navicular suspensory ligament and to correlate reasonably well for the collateral ligaments of the distal interphalangeal joint.

CT excels at assessment of bony structures, and more detailed information about the bones of the foot can be obtained as compared with radiography and, in some instances, as compared with MRI. CT provides some information about soft tissues, although MRI provides superior visualization of soft tissue anatomy and lesion detection. The use of intra-articular and intrathecal contrast to improve identification of lesions of the flexor tendons in the distal limb has been described and can identify pathology of these structures reasonably well.

Fetlock Region

CT and MRI are both valuable in the diagnosis of fetlock region lameness. When considering soft tissue injury, lesions of the distal sesamoidean ligaments, flexor tendons, and suspensory ligament branches are common diagnoses made with MRI in the fetlock region, with abnormalities in these structures characterized by increases in size and changes in signal intensity. Changes in size and signal intensity on MRI images are associated with histologic abnormalities of the oblique distal sesamoidean ligaments. Lesions of the distal sesamoidean ligaments and suspensory ligament branches are not always identifiable or able to be characterized fully ultrasonographically, even retrospectively, and represent a common source of lameness. CT provides some detail about the tendons and ligaments of the fetlock region, but not to the degree that MRI can.

Subchondral bone and/or articular cartilage lesions including sclerosis, resorption, bone marrow lesions, osteophytosis, fracture, and cartilage damage are also common pathologies seen with MRI or CT in many types of horses with fetlock region lameness. CT and MRI are superior to radiography in the diagnosis of bony injury in the fetlock region in a variety of types of horses. Many of these types of bony injuries are suspected to originate from an accumulation of damage rather than a 1-time event, so the use of CT/MRI to identify pathology sooner could potentially prevent more severe or permanent damage as well as providing a more prompt, accurate diagnosis. In sport horses, subchondral bone disease often presents as a bone marrow lesion or fissure fracture in the distal metacarpal or third metacarpal bone or the proximal part of the first phalanx.

Palmar/plantar osteochondral disease of the distal metacarpal or third metacarpal bone is an important cause of lameness in Thoroughbred racehorses and is common both clinically and subclinically. Radiography is insensitive for diagnosis compared with the sensitivity of CT and MRI, so these modalities provide an opportunity for earlier diagnosis before permanent change has occurred. Catastrophic musculoskeletal injury in racehorses is another area of potential utility. Although differences in the palmar condyles of the distal metacarpal or third metacarpal bone and the proximal sesamoid bones between racehorses that have and have not sustained metacarpal or tarsal or proximal sesamoid bone fracture have been documented on both CT and MRI, there is currently no reliable way to differentiate changes that are a normal response to training and changes that are indicative of pathology that will likely lead to catastrophic injury in an individual horse. As of now, CT and MRI are not appropriate as a clinical screening tool for predicting impending breakdown injuries, but work is ongoing. Positron emission tomography also shows promise in this area, and the reader is referred to a companion Currents in One Health by Sprriet, AJVR, July 2022, for further information.

Proximal Metacarpus/Metatarsus and Carpal/Tarsal Regions

When considering MRI or CT of horses that respond to intra-articular anesthesia of the middle carpal/carpometacarpal joints and distal tarsal joints or regional anesthesia of the proximal metacarpal/metatarsal regions, the lack of specificity of these blocks must be borne in mind. For this reason, a scan of the proximal metacarpal/metatarsal region (suspenory ligament origin) should include images of the middle carpal/carpometacarpal joints or distal tarsal/tarsometatarsal joints and vice versa. In the author’s experience, as well as in that of others, there have been many horses with lesions in the “wrong” location, and MRI and CT of the entire region has been invaluable in treating these horses appropriately.

Figure 3—Parasagittal (A), dorsal (B), and transverse (C) plane MRI of a bone cyst (arrows) in the dorsomedial aspect of the third tarsal bone in a lame horse that responded to anesthesia of the proximal metatarsal region. Radiographic and ultrasonographic examinations prior to MRI were normal. No other significant abnormalities were identified in this region on MRI. Medial and dorsal are to the left of the images.
MRI is more sensitive for detection and characterization of lesions of the suspensory ligament, and its bony origin as compared with radiography and ultrasonography.\textsuperscript{1,3,4,44,103-106} There is good correlation of suspensory ligament lesion detection with MRI and histopathology.\textsuperscript{103} Bone marrow lesions, sclerosis, resorption, and enthesophyte formation within the metacarpal or third metacarpal bone associated with the origin of the ligament can be readily identified in addition to pathology within the ligament itself, including enlargement, irregular margins, and abnormal signal intensity patterns.\textsuperscript{3,40,43,106,107} Pathology in the accessory ligament of the deep digital flexor tendon or the flexor tendons in the metacarpal/metatarsal region has also been identified in horses that responded to anesthesia of the proximal metacarpal/tarsal region with normal ultrasonographic findings in the metacarpal/tarsal region.\textsuperscript{3,40} CT can also provide some information about the suspensory ligament but is inferior to MRI.\textsuperscript{108}

MRI is well suited to identify pathology in the tarsal joints, including osteoarthritis, subchondral bone cysts, intertarsal ligament desmopathy, sclerosis, fracture, and bone marrow lesions.\textsuperscript{3,43,109,110} CT can identify subchondral bone disease, subchondral bone cysts, degenerative joint disease, and fracture in the tarsus.\textsuperscript{111-113} Less work has been performed on MRI and CT of the carpus, but similar pathology would be expected to be identified as is seen in other joints.\textsuperscript{105,114-117}

**Stifle Region**

Although not as commonly performed as distal limb CT and MRI due to the challenges of positioning the stifle region within the bore of a scanner, advanced imaging of the stifle region is useful particularly due to the inability of ultrasonography, radiography, and arthroscopy to completely image the area.\textsuperscript{118-120} MRI allows excellent visualization of the soft tissues, including menisci, meniscofemoral and meniscotibial ligaments, cruciate ligaments, collateral ligaments, and patellar ligaments.\textsuperscript{121,122} Bone marrow lesions and subchondral bone disease can also be identified.\textsuperscript{122} Noncontrast CT has improved detection of enthesopathy and subchondral bone disease as compared with stifle region radiography.\textsuperscript{119} CT arthrography (ie, intra-articular injection of positive contrast material) is useful in the diagnosis of intra-articular soft tissue injuries in the stifle region, including meniscal damage, cranial medial meniscotibial ligament desmopathy, articular cartilage damage, collateral ligament desmopathy, and cruciate ligament pathology.\textsuperscript{119,123,124} For some soft tissue structures, the diagnostic performance of CT arthrography was comparable to MRI for experimentally induced lesions.\textsuperscript{125}

**Cervical Spine**

One area in which there has been interesting new work is in CT of the cervical spine in horses with poor performance or an “unblockable” lameness. The advent of large-bore and robotic scanner designs has allowed routine accommodation of the entire cervical spine and the cranialmost thoracic vertebrae in live adult horses (Figure 4).\textsuperscript{125-129} This has enhanced our diagnostic abilities significantly, as radiography of this area is limited by superimposition, the degree of muscle mass present, and the reality of only being able to obtain lateral-lateral and oblique views in the adult horse. Ultrasonography can only evaluate the bony margins of the vertebral canal and not the soft tissues within it. The 3-D nature of CT imaging allows evaluation in any plane without superimposition, allowing complete evaluation of the spinal column. Spinal cord compression, subarachnoid space narrowing, articular process enlargement, intervertebral foramen narrowing, osteoarthritis, osteochondral fragmentation, and intervertebral disc disease have all been diagnosed using plain or myelographic CT (ie, CT after injection of positive contrast material into the subarachnoid space).\textsuperscript{126-130} In many cases, radiography or radiographic myelography is not sufficient to make a complete diagnosis (Figure 5).\textsuperscript{126,127}

The diagnosis of cervical stenotic myelopathy (CSM) using CT provides a good example of how CT adds to the diagnostic toolbox. Previous work evaluating decision criteria of both plain radiography and radiographic myelography for a diagnosis of CSM has demonstrated less-than-ideal combinations of sensitivity, specificity, and interobserver agreement to identify specific sites of spinal cord compression.\textsuperscript{131-135} CT myelography can assess...
the spinal cord more fully, as lateral compression can be identified in addition to the dorsoventral compression that can be identified with a radiographic myelogram. It is hoped that future research investigating the association between CT findings, clinical signs, and histologic lesions of the spinal cord will lead to improved decision criteria for CSM. It is important to note that most CT scanners are unable to accommodate the degree of flexion and extension typically obtained during a radiographic myelography study, so in the opinion of this author and others, it is most appropriate to combine CT and radiographic myelography. Although MRI of cadavers has been shown to be useful in predicting a diagnosis of CSM and would provide superior information about the spinal cord, spinal nerves, and soft tissues of the vertebral canal as compared with CT, there are no designs that allow routine MR imaging of the complete cervical spine in a live adult horse.

Radiographic identification of osteoarthropathy in the cervical spine is another clinical challenge as radiographic abnormalities of the articular processes in the cervical spine are poorly associated with clinical signs. However, there does appear to be an association between articular process abnormalities identified on CT and clinical signs including neurologic deficits localized to the cervical spine, an “unblockable” forelimb lameness, and neck pain. Although much work remains to be done, CT shows a great deal of potential in helping to define the clinical significance of bony pathology in this area.

Figure 5—Transverse (A) multiplanar reconstruction image of the cervical spine at C6-7 of a horse with grade 2/3 neurologic signs in the pelvic limbs undergoing CT myelography. The radiographic myelographic images are shown in B (neutral), C (flexion), and D (extension). Measurements of the contrast column on the radiographic myelogram do not support a diagnosis of spinal cord compression at C6-7 (black arrows), but the CT myelogram shows spinal cord compression and displacement to the right (white arrowhead) due to lateral compression by marked enlargement and osteoarthropathy of the left articular processes (white arrows). Cranial and right are to the left of the images.
Conclusion

As with all imaging modalities, integrating the history and clinical/lameness examination findings into both the decision to pursue advanced imaging as well as the interpretation of the results is of paramount importance. CT and MRI are not tools that should be used in isolation, and although there is discussion of possible future use as screening tools to help prevent catastrophic injury, we are not at that stage currently, and even then, clinical information will need to be considered. Therefore, a thorough lameness examination to localize the source of the lameness as much as possible, including reblocking some horses, is extremely important.

For obvious financial and logistical reasons, CT and MRI are unlikely to become tools that are available outside referral settings, so these procedures frequently necessitate cooperation between the primary veterinarian and the referral center providing the advanced imaging. Both parties need to be comfortable with the clinical presentation and lameness examination findings, the region that will be imaged, the plan if significant pathology is not found within the requested area (particularly if general anesthesia is involved), and how communication with the client will be handled. In the author’s experience, there are 2 important factors to keep in mind to keep these relationships productive. First, the goal is to find the reason for the lameness in the most efficient way possible. To accomplish this, the referral center may wish to reblock the horse to confirm or narrow down the site to be imaged, particularly if the lameness examination findings were not straightforward or a less specific block was previously performed (eg, basisesamoid perineural anesthesia was performed without palmar digital perineural anesthesia being performed before it). Second, MRI and CT are inherently more sensitive tools than radiography and ultrasonography. Referring a horse for advanced imaging does not mean that a veterinarian is unskilled, it means that more sensitive modalities are needed to make a diagnosis in the case.

CT and MRI have greatly enhanced our diagnostic capabilities in equine lameness. They provide a better determination of the exact anatomic structures that are abnormal, including location, extent, and severity of lesions. This superior diagnostic information has direct relevance to prognostication and treatment recommendations. Different pathologies may present with a similar clinical picture but benefit from different treatments, highlighting the importance of an accurate diagnosis. Consider a group of lame horses that respond to a palmar digital perineural anesthesia. Rather than simply diagnosing all of them with “navicular disease,” we can pinpoint the source of the problem, be it navicular bone degenerative changes, a core lesion in the deep digital flexor tendon, distal interphalangeal joint osteoarthritis, collateral ligament desmitis, or distal sesamoidean ligament desmitis. These horses have different prognoses and require different treatment strategies. We have come a long way from treating all these horses the same way. Advanced imaging is truly a situation of “knowledge is power.”

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