Digital imaging has revolutionized how veterinarians evaluate musculoskeletal problems in horses. While it has become much easier to obtain images, veterinarians are still faced with the challenge of interpreting the findings properly. Imaging Is Believing is designed to help equine practitioners meet this challenge and understand all the intricacies of digital imaging.

In skeletal scintigraphy, a radionuclide-labeled pharmaceutical (i.e., a radiopharmaceutical) is injected intravenously, and after a period of time, the distributed radiopharmaceutical is imaged using an external gamma camera. Technetium 99m ($^{99m}$Tc) is the most commonly used radionuclide in equine imaging. $^{99m}$Tc is ideally suited for gamma camera imaging because it has a relatively short half-life (6.02 hours); the gamma rays are energetic enough to leave the horse’s body and are readily absorbed by the sodium iodide crystal within the gamma camera; and the detector physics allow geometric localization of the decaying radionuclide. The matched gamma camera–radionuclide compatibilities are enhanced by the camera’s 0.25-inch thick sodium iodide crystal, which serves as a scintillation detector for gamma rays released from the decaying nucleus of $^{99m}$Tc. Because $^{99m}$Tc decays by isomeric transition, no radioactive particles are released, thereby minimizing radiation exposure to the patient and technicians. The $^{99m}$Tc distribution can then be recorded by the gamma camera as two-dimensional images that can be visually inspected for areas of abnormal uptake.

**Principles of Uptake**

In skeletal scintigraphy, a large dose (5.5 to 7.4 gigabecquerels [1 becquerel = 1 disintegration or decay per sec] or 150 to 200 mCi [1 mCi = 37 megabecquerels]) of $^{99m}$Tc-labeled biphosphonate compound called methylene diphosphonate ($^{99m}$Tc-MDP) is injected intravenously after an indwelling jugular catheter has been placed. The $^{99m}$Tc-MDP initially distributes within the circulatory system and then into the interstitial space following first-order kinetics. Once in the interstitial space, $^{99m}$Tc-MDP binds to areas of organic and, more commonly, inorganic (hydroxyapatite crystals) bone matrix in areas of active osseous turnover. Normally, external cell-secreted proteins cover osteonal units and the associated external organic/inorganic matrix. Because the skeletal system is active and continuously turning over during normal remodeling and replacement, a percentage of the extracellular bone matrix can be accessed by $^{99m}$Tc-MDP. This biodistribution of the radiopharmaceutical is influenced by blood flow to the area and...
the relative activity of the remodeling process of the osteonal unit. Increased blood flow can increase the degree of radiopharmaceutical uptake by a factor of 2; however, increased osseous remodeling can increase the degree of uptake by a factor of 10, thereby allowing direct visualization of the areas of increased osseous turnover. These areas are typically associated with areas of abnormality, such as a stress fracture. However, localization of the radiopharmaceutical does not equate to a “painogram.” In other words, a potential pitfall is incorrect interpretation of an area of increased radiopharmaceutical uptake as the direct cause of a horse’s lameness. Conversely, a lack of radiopharmaceutical uptake can result from an avascular area (actual loss of vascular input to the area in question) or a specific lack of blood supply to an area of bone. These findings can be just as important in documenting abnormal areas of radiopharmaceutical distribution.

Indications

The indications for skeletal scintigraphy are broad, but some of the most common reasons for requesting a scintigraphic study are unlocalized lameness (even after regional or perineural anesthesia); localized lameness as determined by physical examination (with negative radiographic and/or ultrasonographic findings); lameness originating in the proximal thoracic or pelvic limb or localized to the pelvis or spine; a suspected acute stress fracture; assessment of vascular viability to areas of soft tissue or bone injury; suspected osteomyelitis, septic arthritis, or physisis (in foals); and possible acute rhabdomyolysis.

Acquisition Parameters and Techniques

Nuclear medicine imaging is relatively photon (count) deficient compared with routine radiography and computed tomography (CT). In scintigraphy, tens to hundreds of thousands of gamma-ray photons are involved in image formation rather than millions of x-ray photons, as in radiography. Therefore, in scintigraphy, it is critical to ensure an adequate count density for the area being imaged. This might include only 50,000 to 100,000 counts for a distal extremity examination. The alternative is to increase the acquisition time. Standard acquisition techniques usually use a count- or time-based acquisition for an image, ensuring that the right and left sides are obtained using the same imaging times to allow direct comparison. Routinely, 60- to 90-second count images can be acquired. However, this assumes that the patient is standing still during the acquisition. When horses are sedated for scintigraphic imaging, there can be a fine line between adequate sedation and oversedation, which can result in motion artifacts on images due to subtle swaying or ataxia. The newest software iterations on equine camera systems allow dynamic acquisition of data with motion correction software, resulting in a single static image. These systems can correct for a mild degree of motion during the dynamic data set.

There are two types of acquisitions in nuclear medicine: list mode and frame mode. This article focuses on the latter because it is used most commonly. Frame-mode acquisitions are either static (a single still-frame image is acquired for a set time or a set number of counts) or dynamic (a number of images or frames are acquired according to a predefined timing and number; e.g., 30 frames for 3 seconds each, meaning the entire study takes 90 seconds). In the frame-mode setup, images have a predefined frame size (128 × 128 or 256 × 256 pixels) and an image depth of 16 bits (which can display up to 65,535 shades of gray). In a motion-corrected data set, an initial dynamic 60- or 90-second image is acquired, and then the data are motion corrected into one image containing all of the counts collected during the acquisition.

Three-Phase Skeletal Scintigraphy

Imaging the skeletal system consists of three phases (TABLE 1). Not all phases are routinely imaged; therefore, before the examination, the type of information and the anatomic area of interest need to be identified for initial assessment. First, vascular and soft tissue (blood-pool) phases can be obtained only at a specific time; therefore, the imager may have only one opportunity to obtain the data. In contrast, bone-phase images can be obtained 2 to 4 hours after injection of the radiopharmaceutical. Additionally, delayed images can be obtained up to 24 hours after injection; however, after 24 hours, the images are severely count limited because the radiopharmaceutical activity has decayed to 12.5% of the
original injected dose. This assumes that all of the radiopharmaceutical has remained in the patient, which is not the case with 99mTc-MDP because of normal renal excretion.

The nuclear angiogram or vascular phase is acquired as a true dynamic data set over the area of interest. If possible, the nuclear angiogram should include the contralateral limb for direct comparison (e.g., a dorsal/cranial image of the thoracic limbs or a plantar/caudal image of the pelvic limbs). Vascular-phase acquisition begins at the same time as injection of 99mTc-MDP. The data set is acquired for 120 seconds at one frame per second and can be reformatted into 3, 4, or 5 seconds per frame after acquisition. Soft tissue or blood-pool images are acquired as static images, first of the area of interest and the affected side; then the horse is turned around for the contralateral view. This is repeated for a total of two images. The horse is then turned around again to acquire a final static image of the area of interest. Therefore, the soft tissue phase represents four static images. Because blood-pool imaging is a dynamic process, these images have to be interpreted over time. This allows interpretation of active changes within the blood pool and soft tissue equilibration versus true abnormalities in soft tissues (FIGURE 1). Soft tissue–phase imaging begins 5 minutes after radiopharmaceutical injection and is usually complete by 20 minutes after injection. Soft tissue–phase imaging is most rewarding for imaging the distal extremities because of the ability to block gamma rays from the contralateral limb by placing a lead shield between the distal extremities. Circumferential emission of 140-keV gamma rays can lead to crosstalk and cross-contamination between the soft tissues of the proximal limb or other superimposed anatomy (e.g., the thoracic spine and thorax superimposed over the scapula and humerus/cubital joint). Additionally, because osseous uptake of 99mTc-MDP is relatively rapid, areas of severe uptake can be seen during soft tissue–phase imaging and should not be misinterpreted as abnormal areas of 99mTc-MDP accumulation within the soft tissues. Accumulation of 99mTc-MDP during the soft tissue phase is purely secondary to capillary breakdown or neovascularization associated with trauma, inflammation, or neoplasia.

There is a 2- to 4-hour delay between soft tissue–phase and bone-phase imaging. This allows the kidneys to adequately clear 99mTc-MDP from the soft tissues, increasing the contrast-to-background ratio of the area of interest. Bone-phase images consist of static frame-mode acquisitions (which are acquired as a dynamic data set if motion correction software is being used). For static frame-mode acquisitions, the imager should determine whether to use a time-limited or count-limited acquisition. For a time-limited acquisition, 60 to 90 seconds is typically used. Distal extremity images should be reviewed before the horse is released so that if the counts are <75,000, the images can be repeated for a longer time. If static acquisition will be count limited (usually 50,000 to 300,000 counts) or terminated based on a set

### Critical Point

Equine skeletal scintigraphy can be used to image parts of a horse that cannot be imaged using standard techniques for ultrasonography, MRI, or CT.
number of counts, the time for each image should be recorded. To compare the symmetry of \(^{99m}\text{Tc-MDP}\) uptake, the contralateral images should be acquired for the same time allotted for the original image. Because of low count rates, images of the distal extremities are often acquired for relatively small total counts (e.g., 75,000), whereas images of the proximal limb and axial skeleton should be acquired for at least 150,000 counts to maximize target-to-background contrast.

Image Interpretation

Image interpretation is based on the premise that radiopharmaceutical uptake should be symmetric. The same area on the right and left sides of the horse should be directly compared and should look the same. Therefore, during image acquisition, the same anatomic area on the right and left sides should be incorporated into one of the images. Normally, a mild to moderate amount of radiopharmaceutical uptake is associated with each bone in a horse’s body. In young horses, increased uptake is seen at the level of the physeal–metaphyseal junction\(^4\) (FIGURE 2). However, interpretation of the scan is based on increased or decreased areas of radiopharmaceutical distribution. Distribution abnormalities should be characterized as increased or decreased and focal, multifocal, or diffuse; in addition, the degree of severity should be noted. The anatomic area of increased radiopharmaceutical uptake and the intensity of uptake become critical for formulating a differential diagnosis, as specific areas of performance horses are prone to problems such as stress fractures and degenerative joint disease.

Abnormalities in Performance Horses

Stress fractures are common in performance and endurance horses.\(^9\)–\(^20\) Moderate to severe focal areas of \(^{99m}\text{Tc-MDP}\) uptake are characteristic of stress fractures. Common locations of stress fractures in various types of performance horses are summarized in TABLE 2. Examples of these fractures are shown in FIGURES 3 through 5. Detection of occult fractures is possible with bone scintigraphy because active remodeling precedes the resorptive changes that occur before an incomplete cortical defect appears on radiographs. Increased radiopharmaceutical uptake can be seen within 24 hours of injury, whereas radiographic evidence of a fracture line may not be seen for 7 to 10 days after injury.

Because horses are large, most pelvic and axial skeletal abnormalities are difficult to diag-
TABLE 2 Common Sites of Stress Fractures and Abnormal Areas of Increased Radiopharmaceutical Uptake in Skeletal Scintigraphy

<table>
<thead>
<tr>
<th>Horse Breed/Performance Application</th>
<th>Anatomic Sites</th>
<th>Intensity of Abnormal Uptake</th>
<th>Focal, Multifocal, or Diffuse</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Racing Thoroughbreds</td>
<td>Caudal cortex of the proximal humerus</td>
<td>Moderate to severe</td>
<td>Focal lesions can be diffusely involved at all sites except the dorsal aspect of McIII</td>
<td>Not typically bilateral, except for C3 and McIII lesions. Proximal McIII lesions are typically secondary to proximal lesions associated with a suspensory origin.</td>
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<td></td>
<td>Dorsal cortex of McIII</td>
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<td></td>
<td>Cranial cortex of the distal humerus</td>
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<td></td>
<td>Caudal cortex of the distal tibia</td>
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<td>Iliac wing</td>
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<td></td>
<td>Caudal border of the neck of the scapula</td>
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<td></td>
<td>Midradial diaphysis</td>
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<tr>
<td></td>
<td>Proximal McIII</td>
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<td></td>
<td>Third carpal bone (while in training)</td>
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<td></td>
<td>Dorsal cortex (diffuse), McIII</td>
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<tr>
<td></td>
<td>Palmaroproximal McIII</td>
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<tr>
<td></td>
<td>Tarsus</td>
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<td></td>
<td>Palmar distal aspect of McIII</td>
<td></td>
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<tr>
<td>Standardbreds and trotters</td>
<td>Mid-diaphyseal tibia</td>
<td>Moderate to severe</td>
<td>Focal</td>
<td>—</td>
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<tr>
<td></td>
<td>Third carpal bone</td>
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<tr>
<td></td>
<td>Proximal sesamoid bones</td>
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<tr>
<td></td>
<td>Metatarsophalangeal joints</td>
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<tr>
<td></td>
<td>Other areas listed for Thoroughbreds are also possible</td>
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<tr>
<td>Jumping/event horses</td>
<td>Dorsal cortex of the proximal phalanx of the thoracic limb</td>
<td>Moderate to severe</td>
<td>Focal</td>
<td>Proximal phalangeal lesions do not have concurrent radiographic abnormalities.</td>
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<tr>
<td></td>
<td>Thoracic spinous processes</td>
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McIII = the third metacarpal bone.

nose, and general anesthesia is usually required to evaluate the pelvis9,18–20 (FIGURE 6). However, because of the soft tissue mass associated with the gluteal musculature, false-negative results are possible. During the initial phase of the study, a significant degree of increased radiopharmaceutical uptake may be hampered by soft tissue attenuation of the gamma ray because the soft tissue half-value layer for a 140-keV gamma ray for 99mTc is 5 cm. This means that for every 5 cm of soft tissue, 50% of the gamma rays released deep in the tissues (the ilium or iliac crest) are attenuated or absorbed, never reaching the gamma camera to contribute to the image.

Areas of increased radiopharmaceutical uptake at the level of a synovial joint are common in mild to severe cases of osteoarthritis (FIGURE 7). In older horses with inactive ankylosis (e.g., distal intertarsal joint), abnormal radiopharmaceutical uptake may not be significant. Additionally, in older horses, the overall radiopharmaceutical distribution is normal but appears to be generally reduced because of an inherent poor target-to-background contrast. Several unique imaging findings in horses with chronic lameness include a generalized increase or decrease in radiopharmaceutical uptake compared with the contralateral limb. Additionally, climatic conditions (cold weather) can cause a generalized lack of uptake within the distal
Extremity at the time of radiopharmaceutical injection if the horse has not had 24 hours to acclimate to the warmer temperature within the hospital before a nuclear scintigraphy study.

Navicular syndrome can be diagnosed using nuclear scintigraphy. On soft tissue-phase images, inflammation of the navicular bursa and soft tissues surrounding the palmar aspect of the navicular bone results in a band of radiopharmaceutical uptake proximally to distally within the normal photopenic dorsal palmar stripe associated with the lamina of the hoof wall. There can also be osseous uptake by the navicular bone, which is normally a photopenic area relative to the remaining distal extremity osseous structures.

The equine skull is a complex structure that is difficult to evaluate by radiography because of superimposition of the anatomy (FIGURE 8).

Osseous scintigraphy allows interpretation of (1) active remodeling associated with tooth root abscesses or other dental abnormalities; (2) abnormal uptake within the nasal cavity, paranasal sinuses, temporomandibular joints, and tympanic bullae; and (3) chronic inflammation associated with the stylohyoid bone(s) or calvarium. Unlike CT and magnetic resonance imaging (MRI), scintigraphy does not require general anesthesia. Additionally, osseous scintigraphy is based on changes in normal physiology and not only on anatomic localization protons, as in MRI, or physical density attenuation characteristics, as in CT.

Acute rhabdomyolysis usually appears as

Critical Point

Because the skeletal system is active and continuously turning over during normal remodeling and replacement, a percentage of the extracellular bone matrix can be accessed by $^{99m}$Tc-labeled MDP.
Fusiform areas of moderate to severe increased radiopharmaceutical uptake within the soft tissues (usually associated with the gluteal musculature or muscles of the caudal proximal hindlimb; FIGURE 9). In rhabdomyolysis, $^{99m}$Tc-MDP binds to calcium salts due to muscle necrosis and not due to increased extracellular volume or capillary bed inflammation and associated leakage. Other causes of soft tissue uptake of $^{99m}$Tc-MDP in horses include various differentials that have been described for metastatic or dystrophic mineralization.

Horses undergoing scintigraphy have typically had some form of lameness evaluation and have possibly received local or regional anesthetics, including perineural or articular anesthetic blocks. Focal uptake in soft tissue-phase images can be present for up to 17 days after perineural injection of 2% lidocaine into soft tissue. Similar soft tissue abnormalities can be seen after intraarticular injections. Although perineural or intraarticular anesthetic injections have not been reported to affect bone-phase images, in our experience, occasional areas of increased radiopharmaceutical uptake may be seen on bone-phase images, particularly at the level of proximal or distal intertarsal or tarsometatarsal joint blocks.

**Conclusion**

Despite advances in cross-sectional CT and MRI of horses, skeletal scintigraphy remains a valuable tool in the evaluation of musculoskeletal disease.
Critical Point

A potential pitfall is incorrect interpretation of an area of increased radiopharmaceutical uptake as the direct cause of a horse’s lameness. Conversely, a lack of radiopharmaceutical uptake can result from an avascular area (actual loss of vascular input to the area in question) or a specific lack of blood supply to an area of bone.

References