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Abstract

The advanced imaging modalities currently available in equine practice are magnetic resonance imaging, computed tomography, and positron emission tomography. First-line imaging modalities such as radiography and ultrasonography generate 2-dimensional images, whereas advanced imaging modalities show anatomy in multiple planes and can provide functional information on an injured area. In equine practice, a lame or poorly performing horse is a common diagnostic challenge. For equine athletes, advanced imaging is critical to detect an injury, make an accurate diagnosis, and target treatment. Because of recent developments, advanced imaging in a standing, sedated horse is now feasible, which allows for minimal disruption to athletic training and avoidance of general anesthesia.



RADIOLOGY/IMAGING

Advanced Imaging Modalities in Equine Practice

Elizabeth Acutt, BVSc, MS, DACVR (EDI)

University of Pennsylvania School of Veterinary Medicine, Philadelphia, Pennsylvania

The mainstays of diagnostic imaging in equine practice remain radiography and ultrasonography. However, these modalities generate 2-dimensional images of complex 3-dimensional structures, where superimposition of anatomic structures may limit or prevent accurate interpretation. If radiographic and/or ultrasonographic findings are equivocal and/or fail to provide a definitive diagnosis that aligns with a horse's clinical signs, or in cases in which a disease process requires further characterization, advanced imaging modalities can be used to garner additional information. The term “advanced imaging” has typically been used to describe modalities that create cross-sectional images (e.g., magnetic resonance imaging [MRI], computed tomography [CT]). In addition, nuclear

medicine modalities, in particular positron emission tomography (PET), may be considered under the umbrella term “advanced imaging.”

As technology continues to develop, the advanced imaging options for equine patients continue to improve. MRI and CT can be performed with the patient either standing sedated or recumbent under general anesthesia. The imaging system used is often dictated by practical considerations such as geographic availability, as well as the specific advantages and disadvantages of each method.

One of the most common challenges in equine practice is diagnosing lameness or poor performance in a horse. The patient's large size

Take-Home Points

- Advanced imaging modalities frequently used in equine practice include magnetic resonance imaging (MRI), computed tomography (CT), and positron emission tomography (PET).
- MRI and CT can provide information about a structural injury in a region that is difficult to image and/or has complex anatomy.
- PET can provide functional information that can precede detection of a structural injury. This information can also indicate clinical relevance as well as injury severity.
- CT and PET show promise for successfully screening racehorses for mild and/or early-onset injuries, ultimately preventing catastrophic injuries.
- MRI, CT, and PET have been refined to enable their use in standing, sedated equine patients.



necessitates regional localization of the suspected injury to target imaging appropriately.¹ Often, an accurate diagnosis requires imaging of the distal limb, where injury is common. Much of the complex anatomy is contained within the hoof capsule, where the capacity of ultrasonography is reduced. Thus, advanced imaging is often required for an accurate diagnosis of injury.

MAGNETIC RESONANCE IMAGING

MRI provides high-contrast resolution for soft tissue structures such as those within the foot (**FIGURE 1**). MRI is the ideal modality when an injury has been localized to a region (often the foot), no abnormalities were detected on first-line imaging (radiography and ultrasonography), and a soft tissue injury is suspected.

MRI may also be useful for patients with injuries in multiple locations and/or an acute injury in which chronic pathologic changes in the affected area are evident. The appearance of an injured area typically changes over time, and MRI can give additional

information about the nature and chronicity of a lesion as well as anatomic and structural information.

Currently, MRI is the only available modality capable of imaging osseous fluid, often called “bone marrow lesions,” an occasional source of equine lameness. (Note that dual-energy CT shows promise in this area.²)

For a long time, the only MRI machines available for horses were those repurposed from use with humans with closed configurations, and their use required general anesthesia to position the patient’s limb within the magnetic field. The amount of time required to obtain an MRI scan—scanning duration frequently exceeds an hour—makes this modality less appropriate for imaging large anatomic areas and as a screening tool. Additionally, longer duration of anesthesia for equine patients has been associated with increased risks for complications, including fatal injuries and peripheral neuropathies.³⁻⁵

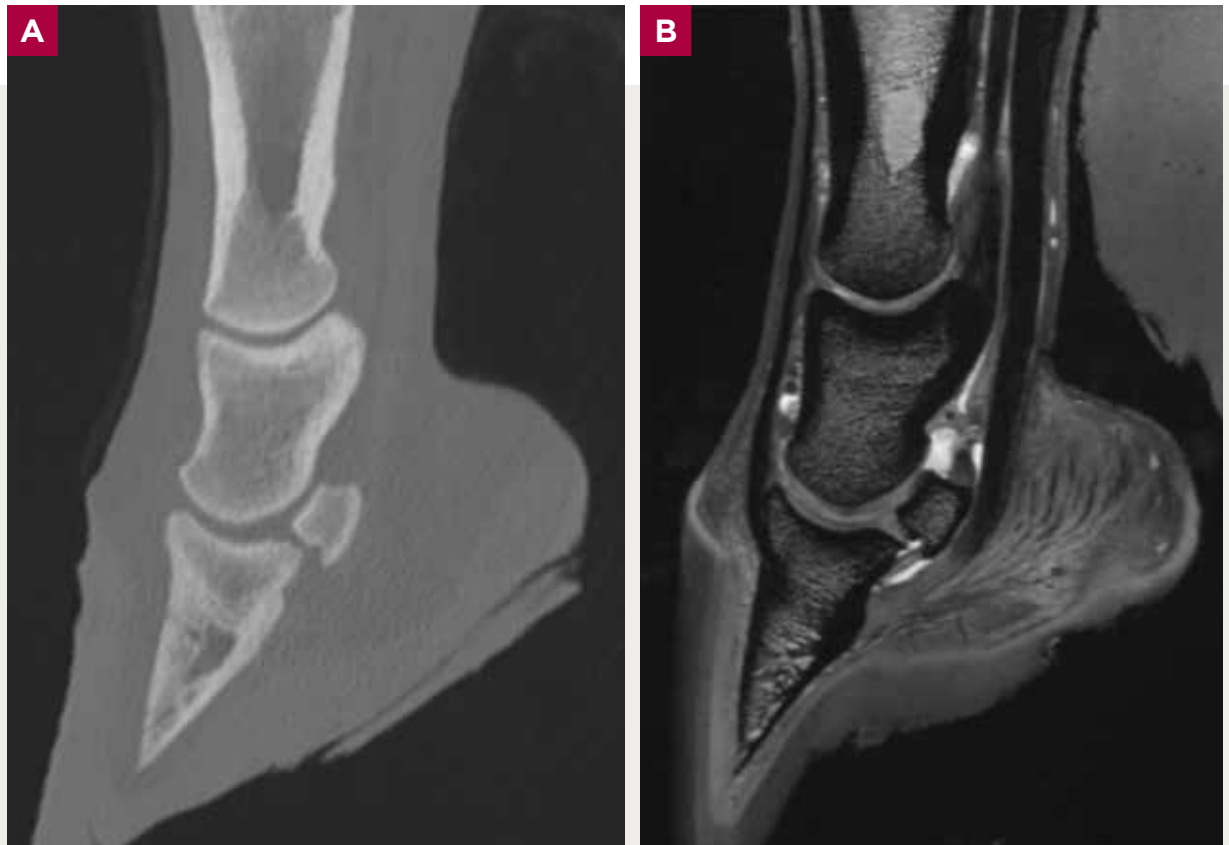


FIGURE 1. Comparative (**A**) computed tomography (CT) and (**B**) magnetic resonance imaging (MRI) sagittal plane scans of the equine foot. In the CT image, the osseous structures are clearly visible, but soft tissue structures have limited details. In the MRI scan, the soft tissue structures are well defined.



Standing MRI

A standing MRI system is configured with an open magnet into which a horse can walk. This system was developed to evaluate the distal limb of equine patients, and it is now widely available in equine clinics globally. However, current standing MRI systems use only low magnetic field strengths of <0.5 tesla.

During scanning, the patient is standing and sedated. The ideal plane of sedation immobilizes the horse and minimizes motion, as motion degrades image quality.⁶ The effects of motion generally become more pronounced on images of the more proximal distal limb.⁷

If initial results from a standing MRI do not correlate with clinical signs, the study can be extended to examine another anatomic site. Doing so in a closed-magnet, recumbent system would prolong anesthesia time, which would place the horse at greater risk for complications. Additional standing MRI scans can even be obtained on consecutive days without the expense, inconvenience, and risk for adverse events associated with repeated anesthesia episodes. For these reasons, standing MRI with sequential scans is often the system of choice to monitor injury healing.

Other MRI Systems

Because of the effects of motion and limited resolution of low-field standing MRI, high-field MRI continues to be used in equine patients despite the necessity for general anesthesia, especially for assessing articular cartilage.⁸ The term “high-field” describes any magnet strength exceeding 1 tesla. High-field MRI is ideal for patients with mild lameness caused by a subtle injury and/or articular cartilage damage. The term “ultra-high-field” describes any magnet strength exceeding 3 tesla. Ultra-high-field MRI systems provide images of exceptional quality, yet only a limited number have been installed at veterinary teaching hospitals.

COMPUTED TOMOGRAPHY

Similar to radiography, CT uses ionizing radiation. Through a rotating cone beam or fan beam, x-rays are emitted and then rapidly captured by multiple detectors, yielding volumetric data that a computer reconstructs into images with multiple planes. Fan-beam CT generally produces images of higher diagnostic quality than cone-beam CT, especially for regions of soft tissue. However, fan-beam CT requires a closed system through which the horse must pass.

Fan Beam Versus Cone Beam

Both fan-beam and cone-beam CT systems have been widely used to image the complex osseous and soft tissue structures of the equine skull (**FIGURE 2**). Several studies have demonstrated that CT is superior to radiography for the detection and characterization of dental and sinus disease. For example, a 2017 study found that only 53% of infected equine teeth were identified by radiography compared with 100% by CT.⁹ Sinusitis, which often accompanies equine tooth infections, can be difficult to localize on radiographs. The sphenopalatine sinus is particularly challenging to



FIGURE 2. Computed tomography of the skull via 2 different fan-beam systems. **(A)** System configured for scanning under general anesthesia. **(B)** System configured for scanning using standing sedation.



Several studies have demonstrated that CT is superior to radiography for the detection and characterization of dental and sinus disease.

view; a 2015 study identified its involvement in only 17% of equine patients for which radiography was used compared with 100% of patients for which CT was used.¹⁰ Accurate identification and localization of pathologic changes are critical when performing targeted procedures such as dental extractions, trephinations, and sinus flap surgeries.

Recently, some clinics have installed CT equipment, either fan or cone beam, to obtain cervical spine scans. A promising application of this equipment is diagnosing neurologic diseases such as cervical vertebral stenotic myelopathy. Historically, the diagnosis of this condition has relied on a combination of radiographic myelography and ruling out other causes of neurologic signs. Yet, radiographic myelography can identify only spinal cord compression in a dorsoventral plane due to the limitations of 2-dimensional images and patient size. However, spinal cord compression can occur in a mediolateral plane, and axial compression can be identified via CT myelography. A recent study found that CT myelography indicated spinal cord

compression in 61% of equine patients compared with radiographic myelography indicating merely 22%.¹¹

Until recently, primarily cone-beam CT has been used to assess equine patients with lameness because it can be configured in various ways to image a horse's limbs in a standing position. Novel configurations of fan-beam CT have facilitated their use for that purpose as well. In addition, these new iterations of fan-beam CT machines have enabled veterinarians to image, with general anesthesia, previously inaccessible anatomic regions, including the elbow, back, and pelvis. Recently, a group successfully positioned 99 horses within a fan-beam CT machine to obtain images of the elbow, leading to the diagnosis of injuries such as arthritis, bone cysts, and fractures.¹²

Standing CT

Standing CT is of particular interest for racehorses, whose intense training regimens predispose them to specific osseous pathologic changes (**FIGURE 1**). Standing CT can be used to identify prodromal remodeling patterns and early subchondral injuries, which can be critical for identifying a horse at high risk and appropriately reducing its workload to prevent a catastrophic injury. Furthermore, standing CT identifies those lesions without the loss of training days and associated risks of general anesthesia.¹³

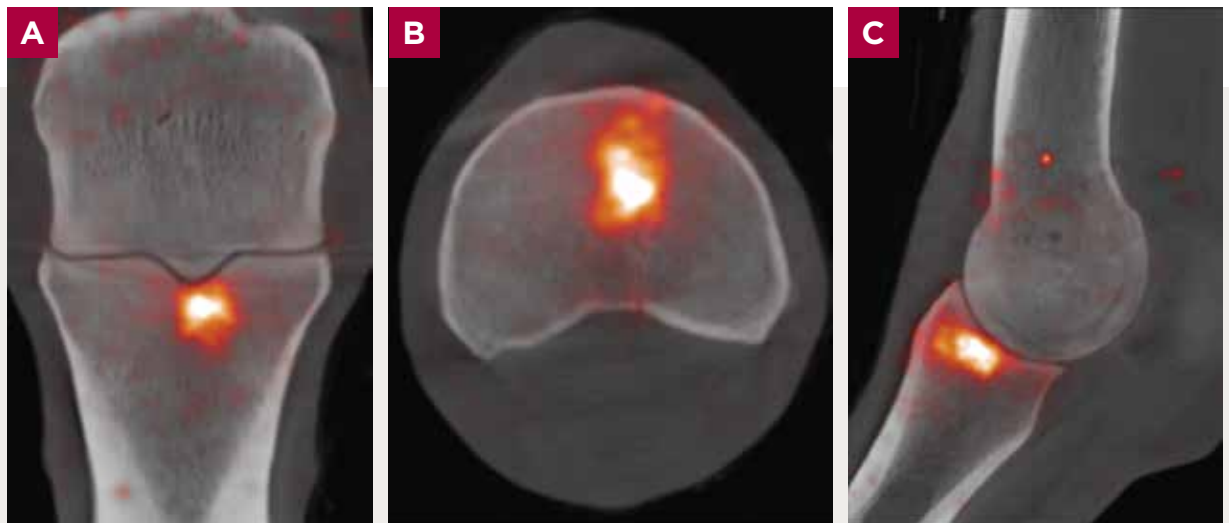


FIGURE 3. Fused computed tomography and positron emission tomography images in (A) dorsal, (B) transverse, and (C) sagittal planes depicting increased radioactivity in the sagittal groove of the proximal phalanx.



Other CT Applications

CT is more accurate than radiography for assessing fractures. A recent study revealed that CT is superior to radiography for assessing key features of third carpal bone fractures, including the number of fragments and involvement of the joint surface.¹⁴ CT can also be used before surgical fixation to plan and during surgical fixation to guide the placement of orthopedic implants. A recent review of the use of CT for surgical planning at a large equine hospital found that CT provided additional information or significantly changed the surgical plan for 62% of cases.¹⁵ As the number of surgical procedures performed on standing horses increases (including simple fracture repairs), the benefits of preoperative standing CT for surgical planning may be fully realized because the need for general anesthesia may be eliminated for many patients.

POSITRON EMISSION TOMOGRAPHY

PET, a nuclear imaging modality that produces cross-sectional images, is another newly emerging technology in equine practice. PET scans initially required general anesthesia, yet more recent equine PET machines enable easy, rapid scanning of horses under standing sedation.

In the past, PET has been used mostly in small animal practice to detect metabolically active neoplasia via radiotracers. More recently in equine medicine, PET has been used to diagnose musculoskeletal injuries using soft tissue and osseous radiotracers, fluorodeoxyglucose F 18 (¹⁸F-FDG) and 18F-sodium fluoride (¹⁸F-NaF), respectively. ¹⁸F-FDG concentrates in regions of increased glucose metabolism, which typically represent inflammation of injured tendons and ligaments in horses. ¹⁸F-NaF, the more commonly used radiotracer, concentrates in regions of increased bone turnover, which identifies osseous pathology.

There is evidence that radiotracer uptake on PET can be used to identify a functional injury before structural damage has occurred.¹⁶ In addition, PET scans show promise as a tool that can indicate if a structural injury is active, and therefore more likely a source of pain, or more chronic.¹⁶ Because the degree of radiotracer uptake can be measured in standardized uptake values, PET can also provide quantitative data regarding injury severity.¹⁶ These standardized uptake values have been used to create a grading system. That system is currently being used to screen for injuries and guide

decisions regarding treatment and strategies for rest and training of racehorses.¹⁷

In equine populations outside of racehorses, PET is typically performed in conjunction with another cross-sectional imaging modality. PET does not provide images with good anatomic detail; thus, MRI and CT can assist with localizing injury and characterizing structural changes in regions of radiotracer uptake (**FIGURE 3**). Unlike in small animal patients, for which PET and CT or MRI scans are typically obtained sequentially, PET scans for equine patients must be obtained separately and then manually combined.

SUMMARY

As rigorous athletic demands continue to be placed on equine patients, advanced imaging techniques have expanded rapidly to meet diagnostic needs in both availability and capability. By eliminating the technical difficulties, costliness, and risks of general anesthesia in equine practice, the recent development of standing imaging systems is revolutionary, especially for equine athletes. **TVP**

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Elizabeth Acutt

Dr. Acutt obtained her veterinary degree from the University of Bristol, United Kingdom. She then traveled to the University of California, Davis, to undergo additional training in her areas of interest, equine orthopedics and sports medicine. She completed a residency at Colorado State University where she was the first person to specialize in equine diagnostic imaging (EDI). She became a diplomate of the American College of Veterinary Radiologists (EDl) in 2022. She joined the University of Pennsylvania's New Bolton Center in 2023 as an assistant professor of clinical large animal diagnostic imaging. Dr. Acutt's clinical and research interests focus on comparative imaging in the equine athlete.



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