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Anatomy of the Equine Foot as it Pertains to Imaging - What You Need to Know

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Introduction

The vast majority of lameness’s that occur in the horse originate in the foot. Unfortunately the horny hoof capsule severely limits the assessment of the internal structures of the foot. Clinical examination is an essential part of any lameness examination and frequently directs the clinician to an area that is suspected as the source of pain. However, diagnostic analgesia is necessary to isolate the source(s) of pain and to more accurately direct diagnostic imaging. Interpretation of diagnostic analgesia of the foot can be difficult due to significant overlap of these blocks. Inaccuracies in analgesia techniques can also occur due to diffusion of the local anesthetic proximally along the nerve or out of the distal interphalangeal joint/navicular bursa. Diagnostic imaging becomes even more important to further define the cause of the lameness originating in the foot.

Imaging techniques available to the equine practitioner include radiography, ultrasonography, thermography, nuclear scintigraphy, computed tomography and magnetic resonance imaging.

To best utilize all of these imaging modalities the clinician should develop a good working knowledge of the anatomy of the foot. The clinician must also have an appreciation of the advantages, disadvantages and limitations of each imaging modality as well as the appearance of the anatomy and pathophysiology characteristic with each technique. With many of these imaging modalities it is necessary to appreciate the anatomical appearance of many of these structures in cross section, sagittal section and frontal section. With each imaging modality normal anatomical variations exist and it is important that the clinician recognize these variations as normal to prevent developing an inaccurate diagnosis. The opposite limb can and should be used for comparison when possibly recognizing that disease can occur at the same location in the opposite foot. Successful management of foot lameness requires the clinician to incorporate all the information at their disposal from the clinical examination to the imaging results in order to develop an accurate diagnosis and to choose the most appropriate treatment.

This paper is divided into a discussion of the detailed normal anatomy of the foot\(^1,2\) and the imaging techniques frequently utilized to assess the foot. The discussion on imaging will highlight the advantages and limitations of the various imaging modalities in defining the normal anatomy.

Anatomy of the Foot

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The hoof is a highly keratinized stratified squamous epithelium. The external surface of the hoof wall has fine parallel lines that extend from the coronary border to the solar border. These lines are the horn tubules which grow distad from their origin from the basal layer of cells (stratum germinativum) of the coronary epidermis which cover the papillae of the coronary corium. There are also raised transverse ridges in the hoof wall parallel to the coronary band (perpendicular to the horn tubules) which is an indication of the variable growth activity of the hoof wall (influenced by environmental and internal factors). The external surface of the hoof wall is divided into three topographical regions: the dorsal region at the toe which blends medially and laterally into the quarters which blends into the rounded heels. The hoof wall is thickest at the toe and thins through the quarters to the heels. The wall reflects upon itself at the heels to form the bars which are continuous with the sole and are separated from the frog by the paracuneal grooves. The frog is made up of a central groove and two crura. The frog is expanded palmarly and covered by periople to form the bulbs of the heel. The tubular horn and intertubular horn of the frog epidermis is less highly keratinized and has higher moisture content (50%). Merocrine glands secrete onto the surface of the frog.

The internal surface of the hoof wall is excavated proximally by the coronary groove. The groove is perforated by innumerable small openings which receive the papillae of the coronary corium. Below the coronary groove the wall bears about 600 epidermal lamellae each with approximately 100 secondary lamellae. These epidermal lamellae interdigitate with the dermal lamellae of the laminar corium. The laminar corium blends with the subcutis and these further blends into the periosteum of the parietal surface of the distal phalanx. Histologically, the hoof wall is divided into the stratum externum, stratum medium and stratum internum. The stratum medium makes up the bulk of the hoof wall. Cells from the actively proliferating stratum germinativum of the laminar epidermis form the epidermal lamellae of the stratum internum which moves distad. The junction of the stratum internum with the horn of the sole is the white line.

The hoof wall is nourished by the subjacent corium which is a collagenous connective tissue with an extensive arterial supply with a capillary network of large diameter capillaries and interconnecting venous sinuses. Blood vessels of the corium cushion the foot upon impact. The corium is the specially modified and highly vascular continuation of the connective tissue layer of the skin. It supplies attachment and nutrition to the hoof wall. The corium is divided into five regions: perioplic, coronary, laminar, solar and frog. The germinal layers of the epidermis cover the corium and produce the horny components of the hoof.

Distal Interphalangeal Joint & Navicular Apparatus

The bones of the distal limb that make up the digit include the distal phalanx (P3), the middle phalanx (P2), the proximal phalanx (P1) and the navicular bone. The distal interphalangeal (DIP) joint is a complex joint positioned at the distal aspect of the digit encased in a horny hoof capsule (Figs. 1 & 2). The DIP articulation includes the middle phalanx, the distal phalanx and the navicular bone. The proximal interphalangeal (PIP) articulation is made up of the middle phalanx (P2), and the proximal phalanx (P1). The boney column of the DIP joint exists primarily within
the dorsal half of the foot while the energy dissipating soft tissue structures (frog, digital cushion, cartilages of the distal phalanx and the associated venous sinusoids) of the foot reside in the palmar half. The distal phalanx is a uniquely shaped pyramidal bone with three surfaces; the articular, the parietal and the solar surfaces. The proximal aspect of the distal phalanx has two large concave glenoid cavities that articulate with the condyles of the head of the middle phalanx. The middle phalanx has a palmar flattened area that articulates with two shallow depressions on the dorsoproximal aspect navicular bone (NB). The NB also articulates on its distal border by means of a transverse facet with the distal phalanx. The dorsal aspect of the joint is bounded (crossed) by the common digital extensor tendon (CDET) or long digital extensor tendon (LDET) in the hind limb as it courses to its attachment on the extensor process of P3. The fibrous joint capsule blends with the digital extensor tendon and the collateral ligaments of the DIP joint. The relatively short medial and lateral collateral ligaments (CL) of the DIP joint originate more dorsally from the distal aspect of P2 and incline somewhat palmar/plantar to insert on depressions on either side of the extensor process of the distal phalanx. The CLs widen as they course distally and are partially covered by and attached to the collateral cartilages of the foot. These ligaments are oriented vertically (perpendicular to the ground surface) rather than parallel to the axis of the limb. They support the DIP joint during movement primarily in the sagittal plane but also in the frontal and transverse planes. More proximally on the digit the collateral suspensory ligaments (CSLs) attach to the depressions on the distal end of the extremities of distal P1 and extend to the proximal margin of the NB.

The caudal aspect of the joint is more complex because of the navicular suspensory apparatus. The navicular apparatus includes the navicular bone (NB), the collateral suspensory ligaments of the navicular bone (CSL), the distal sesamoidean impar ligament (DSIL), the navicular bursa, the deep digital flexor tendon (DDFT) and the distal digital anular ligament. The distal navicular
bone is shuttle shaped and has two borders, two surfaces (flexor & articular) and two extremities. The navicular suspensory apparatus forms a strong somewhat elastic sling that supports the NB to the back of the DIP joint and is thought to function to maintain a constant angle of insertion and the mechanical advantage of the DDFT onto P3. The CSLs arise from the distal surface of P1 (see above) pass in a distopalmar direction, attaching to P2 to insert on the extremities of the NB. The DSIL extends from the distal margin of the NB to the flexor surface of the termination of the DDFT (Fig. 3). The DDFT flattens and expands medial to lateral over the flexor surface of the NB coursing to it’s insertion with the DSIL onto the entire flexor surface of P3. These parallel fibers of dense connective tissue are separated by loose connective tissue, within which are many sensory nerves and numerous blood vessels.

Figure 3. The navicular suspensory apparatus includes the medial and lateral collateral suspensory ligaments (CSL) of the navicular bone and the distal sesamoid impar ligament (DSIL).

The DIP joint has a large dorsal pouch which blends with the common digital extensor tendon (CDET) dorsally and the CLs abaxially. The DIP joint also has a palmar pouch which is more extensive and is subdivided into a proximal palmar and a small distal palmar pouch. The proximal palmar pouch can extend dorsally around the palmar aspect of the collateral ligaments. Of clinical significance the lateral limits of the proximal pouch extend to the abaxial surfaces of the cartilages of the P3. The palmar pouch is far more extensive than the dorsal pouch and is made up of a proximal and distal pouch.

Deep Digital Flexor Tendon

The DDFT courses distally in the pastern after coursing through the fetlock canal. The DDF and SDF are surrounded by the digital flexor tendon sheath (DFTS) proximal to the fetlock and the DDF is surrounded by the DFTS as it courses through the pastern to the distal aspects of the digit (Fig. 4). The DDFT courses through the fetlock canal as an oval structure that begins to expand
in a medial to lateral direction. The DDFT becomes bilobed as it progresses distally. The DDF is surrounded by the two rings of the SDFT called the macula flexoria (MF). The proximal ring is more robust and exists proximal to the fetlock canal while the distal ring is thinner and exists in the mid pastern. The fibers of both rings of the MF are continuous with the SDF tendon. At the mid-pastern area, just distal to the distal ring of the MF, there is a vinculum that attaches to the dorsal aspect of the DDF in the central depression between the two lobes. The DDF tendon continues to widen medial to lateral as it courses more distally before passing over the NB. There is a proximal digital anular ligament (PDAL) and a distal digital anular ligament (DDAL) that holds the DDF tendon centrally in its course through the pastern (Fig. 5).

The DFTS extends further distally on the dorsal surface of the DDFT than on the palmar surface. The dorsal aspect of the DFTS comes in close contact with the navicular bursa and DIP joint and is separated from these by the so called “T” ligament. The T-ligament is a fibrous connection between the DDFT and the middle of the palmar surface of P2. The navicular bursa lies between the DDFT and the flexor surface of the NB. The DDFT continues to course distally expanding to a fan-like shape before inserting on the facies flexoria and semilunar crest of the P3. The dorsal portion of the DDFT blends with the DSIL immediately before insertion on the facies flexoria of the P3. The navicular bursa lies between the DDFT and the DSIL initially until these two structures begin to blend together before inserting on the semilunar crest of P3. The DDFT has a dorsal fibrocartilaginous pad that supports pressure on the transverse prominence of the proximopalmar aspect of P2.

**Cartilages of the Distal Phalanx & Digital Cushion**
The cartilages of the P3 are fibrocartilaginous structures that lie adjacent to and are attached to the dorsal aspect of the CLs and the dorsal aspect of the palmar processes of all feet. The cartilages are attached to adjacent structures by several ligaments including the P1, P2, P3, and the CDET/LDET. The proximal aspect of the collateral cartilages project above the coronary band and are palpable in the palmar/plantar aspect of the foot. The cartilages can have a variable shape and size as well as varying degrees of ossification. When ossification occurs it typically progresses proximad from the attachment of the cartilage. The palmar/plantar aspect of the cartilages is perforated by veins. A complex relationship exists between the cartilages and the digital cushion. It is thought that their combined role is energy dissipation associated with the concussion of the foot with the ground.

The region between the cartilages of the P3 is occupied by the digital cushion which is a modification of the subcutis. It is made up of poorly vascularized fibroelastic tissue which contains depots of adipose tissue and small amounts of fibrocartilage. A venous plexus is interposed between the proximal aspect of the cartilages and the digital cushion. The digital cushion extends from the DDFT to the cuneate corium. The digital cushion extends palmarly and forms the base of each of the heel bulbs.

**Advantages and Limitations of Imaging the Foot**

**Clinical Examination**

The clinical examination is the most important aspect of any lameness evaluation. A thorough clinical examination will determine the most appropriate course of action for the rest of the lameness workup. Imaging should not be performed until the completion of the clinical examination. The clinical examination should begin with a visual assessment of the horse while the horse stands quietly in its stall and while it stands evenly on firm, level ground. Observations should include the horse’s stance; muscle symmetry; enlargements of joints, tendons, or ligaments; and any conformational defects that might predispose to lameness. Specific evaluation of the feet should include a thorough visual assessment including foot shape, symmetry, and type of shoeing. Once the limb is lifted off the ground, the wear patterns of the hooves and/or shoes should be noted and hoof testers applied to each foot in a systemic manner. Lameness suspected to originate in the foot should have provocative tests of the foot (hoof extension stress test, frog pressure test) performed and these can be quite useful in further defining the source of pain. A thorough lameness examination should include observation of the horse at a walk and trot in hand on a hard and soft surface. Distal and proximal limb flexion tests are performed to exaggerate lameness and isolate a painful response associated with a particular joint. A more complete discussion of the examination of the foot will be presented in another section of these proceedings as well as the inaccuracies of these flexion tests. At this stage a presumptive diagnosis is made directing the clinician to perform the most appropriate ancillary diagnostic tool.

**Ancillary Diagnostics**

The clinician should attempt to confirm the source of pain by utilizing diagnostic anesthesia. There are many inaccuracies that can occur with regional and intra-articular/bursal anesthesia.
Numerous recent studies pertaining to anesthetic techniques of the foot should be reviewed to understand the current concepts of what may or may not be blocked by these different blocks and these will be discussed in another section of these proceedings. Once the foot has been identified as the cause of lameness and the pain localized, diagnostic imaging techniques should be utilized to assess internal structures of the foot. Imaging techniques that are utilized in the horse include radiography (plain film, computed & digital), ultrasonography, thermography, scintigraphy, computed tomography and more recently magnetic resonance imaging.

Every lameness examination associated with the foot should have a radiographic examination. If the radiographic examination does not reveal any significant boney abnormalities then an ultrasonographic examination should be performed to evaluate the soft tissue structures available to this imaging technique. When radiographic and ultrasonographic examinations are unable to elaborate a significant abnormality then nuclear scintigraphy, computed tomography, and magnetic resonance imaging should be considered. The advantages and disadvantages of each modality should be weighed against the risks and expense before proceeding.

Radiography

Radiography of the digit is the most common imaging study performed by the equine clinician. As always the clinician should utilize the information gained from the clinical and lameness exam to direct the radiographic examination. Good radiographic technique and an understanding of the relationship of limb position, cassette position and x-ray tube angle is critical. Inadequate foot preparation, inappropriate projections and motion (of the animal and/or the examiner) create artifacts that compromise the diagnostic quality of the radiographic study. These correctable technical problems if not addressed can cause major errors in interpretation. In addition, good radiographic technique requires a detailed knowledge of anatomy of the foot and an understanding of the pathophysiology of the diseases. There are many sites that might appear to be a manifestation of disease but are simply normal variation in anatomy or occur because of an abnormal oblique projection. For example, nutrient foramen locations can be variable but are characterized by a slight lifting of the endosteum not seen with fractures. Enthesis which is new bone at sites of attachment of tendon, ligaments and joint capsules to bone surfaces can appear similar to reactive new bone. However, the clinician must recognize that certain sites of enthesis can occur commonly without clinical manifestation of lameness. This is particularly true at the dorsal aspect of P2 and the extensor process of P3. Other incidental findings associated with the foot include the dorsal notch in the toe of P3 (crena) and various stages of ossification of the collateral cartilages (side bones). Anatomical specimens and text books can be quite helpful to understand the radiographic appearance of a structure that can appear on a radiograph due to a change in the radiographic positioning.

The clinician should perform a standard radiographic examination consisting of a minimal number of projections. A standard radiographic study of the foot should include a dorso 0° palmar (D0Pr), lateromedial, dorso 65° proximal-palmarodistal oblique (D45Pr-PaDiO P3 technique), dorso 65° proximal-palmarodistal oblique (D65Pr-PaDiO coned down navicular technique), palmaro 40-75° proximal-dorsodistal oblique (Pa45Pr-PaDiO navicular skyline), and a dorso 45° proximal-palmarodistal oblique (D45Pr-PaDiO). These will be discussed in detail in another section of these proceedings. Special projections may be necessary to highlight an area
to confirm that a structure is indeed abnormal or to demonstrate a specific anatomical area more completely. As a rule the central beam should be directed at the area of interest. For example, when looking at the position of the distal phalanx within the hoof capsule, a block is necessary to elevate the foot off the ground and place the central beam at or just above the solar surface of the foot. When looking at the navicular area the central beam should be directed just below the coronary band midway between the toe and the heels. Special techniques are helpful to elaborate specific areas and include contrast arthrography of the DIP and/or PIP joints, stress radiographs, navicular bursagrams, digital venograms and fistulagrams. It may be helpful to place radiopaque markers at specific locations on the hoof wall (most commonly barium paste is coated on the dorsal hoof wall at the toe for a laminitis study) to demonstrate the relationship of the hoof wall and distal phalanx.

Acute injuries may not initially demonstrate a radiographically apparent abnormality. However, it may take a period of 5-7 days before the inflammatory reaction causes resorption or production of enough bone to be evident radiographically. Therefore, it may be necessary to repeat the radiographic study after a sufficient period of time before declaring that a radiographic abnormality doesn’t exist. Distal phalanx fractures are frequently not apparent on initial radiographic study but become apparent on later examinations.

Ultrasonography

Diagnostic ultrasonography is a two dimensional real-time imaging technique that utilizes the transfer and propagation of sound waves into soft tissue. Ultrasonography has proven to be very effective at evaluating soft tissue structures of the palmar/plantar metacarpus/metatarsus of the distal limb in the horse. However, when used in combination with radiography, ultrasonography can supply more information about any number of orthopedic problems than when each modality is used alone. In horses with lameness found to be in the foot, ultrasonography can be quite valuable when the radiographic study is inconclusive and the presumed injury is soft tissue in nature. Ultrasonography can also be particularly useful when the radiographic survey of the foot demonstrates an abnormality but further evaluation of the soft tissues of this area are needed. The structures in the equine foot that can be examined with ultrasonography include the DDFT, CSL of the NB, the DSIL, the DDAL, the navicular bursa, the NB (flexor surface, proximal and distal borders), the palmar/plantar surface of P3, the CLs of the DIP and the digital cushion. However, the examiner must recognize that the various tissue types and tissue orientation (specifically the tendon and ligament fibers) can significantly affect the transmission and reception of sound. For example, the exterior hoof wall has very low water content and acts as a barrier to sound transmission while the frog has higher water content (than the hoof wall) and can transmit sound. The standard ultrasonographic examinations of the foot will be discussed in another section.

The accuracy of ultrasonography depends on the skill and experience of the operator both during image acquisition and image interpretation. The operator must understand some basic sound-tissue interactions and recognize how this will affect the information and misinformation (artifacts) created during the examination. To be of maximum diagnostic quality the sound beam should be perpendicular to the fiber orientation of the tendon or ligament being examined. However, because the course the deep digital tendon is not perpendicular to the windows
normally utilized to image within the foot it is impossible to obtain the 90° beam angle to the fibers of the deep flexor tendon through the existing windows (frog and bulbs of the heel). A lack of a perpendicular beam angle to the DDFT in the foot creates significant beam angle artifact (hypoechoic artifacts within the DDFT) seen most often on transverse images. This beam angle artifact compromises the accurate interpretation of architectural change. Image acquisition is further complicated by a lack of an adequate window for sound transmission. The examination of many of the soft tissue structures within the foot is limited to the proximal aspect of the structure present above the horny hoof capsule or through the frog. Access through the frog can be influenced by environmental conditions which influence the water content of the frog. Dry conditions may require soaking the foot to increase sound transmission and the quality of the image. In addition the horse with chronic lameness associated with the foot will frequently have an atrophied frog further limiting the window available to evaluate the internal structures of the foot. In addition MR studies of the foot have demonstrated that most of the DDF lesions are more abaxial either in the medial or lateral lobes and probably not apparent during the ultrasonographic examination.

**Nuclear Scintigraphy**

Nuclear scintigraphy has become routinely utilized in the horse for detection of orthopedic disease. A radiopharmaceutical is injected into the intravenous system and is distributed throughout the body. Technetium pertechnetate is bound to a pharmaceutical called methylene diphosphonate (MDP). Methylene diphosphonate binds to osteoblasts that are actively remodeling bone. By doing this, the radioactive Technetium is deposited at the site of osteoblastic activity and as the radioactive material decays, it emits a gamma ray. This gamma radiation escapes the body for external detection and measurement by a scintillation camera. The camera detects the gamma radiation and a dedicated computer creates an image of radiation distribution. This makes scintigraphy an especially valuable tool to diagnose early orthopedic injury. Musculoskeletal scans are divided into vascular phase, pool phase and bone phase (first pass, soft tissue and osseous). An area of increased uptake of radiopharmaceutical can indicate active inflammation in pool phase images and bone modeling in bone phase images. The metabolic rate of bone significantly influences the uptake of the radiopharmaceutical during the osseous phase making younger animals in training ideal candidates for scintigraphy. Older mature animals that have minimal bone turnover and are not actively training are poor candidates. In the appropriate candidate nuclear imaging of bone disease is very sensitive at detecting bone modeling but is less specific at defining the specific site of involvement. To assist with localization of lesion(s) the scans should be acquired in two planes (lateral and dorsopalmar) and should be compared to the paired opposite foot. The main drawback to nuclear medicine is that the images generated are very sensitive for disease, but not very specific. It is difficult to know the clinical importance of the lesions identified or whether these lesions are acute or chronic. Active bone remodeling after an incomplete stress fracture can persist for up to 2-3 years after the injury. Also, perineural and intra-articular anesthesia can cause increased vascularity to the regions injected and provide false positive results for several days after the procedure.

It must be recognized that there are limitations in interpreting the uptake of radiopharmaceutical in the foot of the horse. Image interpretation is subjective and bone modeling does not always
equate with pathological conditions or pain. Some conditions in the foot such as navicular disease occur bilaterally making it difficult to compare bone modeling between the feet. Regions of interest (ROI) analysis can reduce some of the subjectivity of interpretation of the foot.\textsuperscript{8} In particular the two areas of most clinical concern in the foot are the navicular bone and the insertion site of the deep digital flexor tendon on the distal phalanx which are in close apposition. ROI analysis allows these areas to be compared to the uptake in the toe region.

Scintigraphy examinations must always be combined with radiographic and ultrasonographic evaluation. The indications for nuclear scintigraphy in the horse with foot lameness include: when there is localization of pain to the foot region but no radiographic or ultrasonographic evidence of a problem; an acute onset of lameness thought due to a fracture but without radiographic evidence of a fracture; intermittent lameness that cannot be reproduced to perform anesthesia of the digit; lameness in several limbs making local anesthesia interpretation difficult and finally in the assessment of the significance of equivocal radiographic abnormalities. Again, increased radionuclide uptake does not always equate with clinical significance emphasizing that interpretation of nuclear scintigraphic images without reference to the clinical examination and other imaging results can be potentially misleading.

\textit{Computed Tomography}

In some cases of foot lameness radiography, ultrasonography and nuclear scintigraphy may not be helpful in defining the anatomic origin of the lameness. In addition some changes seen with these imaging modalities may need more definition At this point the clinician has a choice between computed tomography (CT) and magnetic resonance imaging (MRI). Computed tomography can detect more subtle density differences than radiography making it a much more sensitive tool to evaluate boney disease. Cross sectional imaging allows visualization of the bones of the foot in much more detail than with conventional radiography.\textsuperscript{13} CT uses a rotating X-ray beam to penetrate body tissues and generates multiple slice tomographs which can be utilized to develop three-dimensional rendering of the area of interest. Newer 8-16 multi-slice CTs are able to acquire the study in minutes allowing the clinician to read the study develop a strategy for repair of a fracture, and perform surgery within the same anesthetic period. Multi-planar reformatting can yield better anatomic orientation of an area and provide for more sensitive detection and characterization of disease extension. CT is more sensitive detecting changes of bone contour and has proven to be particularly useful in the evaluation of stress-induced bone remodeling, focal bone lesions, and defining fracture configuration prior to fracture repair. However, CT requires general anesthesia to acquire the images or sequences. The foot is ideal for CT evaluation because of the complex anatomic arrangement with the superimposition of the distal and middle phalanx and the navicular bone significantly compromises image interpretation. However, the soft tissue detail in CT is deficient when compared to MRI. The use of intravascular contrast agents can enhance the soft tissue detail but not comparable to the soft tissue detail obtained with MRI.

\textit{Magnetic Resonance Imaging}

Magnetic resonance imaging (MRI) is the most recent imaging tool available to evaluate occult lameness originating from the distal limb of the horse.\textsuperscript{14-17} MRI images are produced by
reconstruction of a data set that is produced by an MR scanner. The MR scanner consists of a powerful magnet (.3 to 1.5 Tesla) that generates a static magnetic field. Essentially MRI images protons in hydrogen atoms which are present in all animal tissue. Protons in hydrogen line up when placed in the magnetic field. Multiple radiofrequency (RF) coils placed around the area of interest send and receive RF pulses. The brief RF pulse alters the orientation of hydrogen atoms within the magnetic field. As the protons relax or precess they emit measurable energy that is measured by the scanner. In short, MR produces a grey-scale image of hydrogen protons in tissues. The number and density of these protons in the different tissue types and the weighting of the particular MR sequence will produce a MR signal of different intensity. The protons in hydrogen exist in many different microenvironments and concentrations in the body and MR techniques measure these differences. For example, tissues with low numbers of protons appear dark on all image sequences. In addition, tissue alterations caused by inflammation and tissue remodeling will change the proton content and density, and therefore the MRI characteristics of that particular tissue. Therefore MR can demonstrate structural and physiologic alterations within the tissues early in the course of disease, before they are detectable by most other imaging modalities.

Magnetic resonance imaging (MRI) has proven to be the gold standard for the diagnosis of musculoskeletal injuries in human medicine and now in the horse. It provides superior anatomical detail and contrast resolution. The images are displayed as a cross-sectional tomographic slice of the area of interest (Figs. 6 & 7). The slice thickness may be as thin as 1.5 mm and can be acquired in any plane. Knowledge of normal anatomy and ‘normal’ variations is mandatory. The paired limb should be imaged to allow comparisons of the anatomical appearance of all structures. Like all other imaging techniques it is necessary to confirm the presence of a lesion seen in one plane by visualization of that lesion in the orthogonal plane.

Figure 6. Cross sectional anatomy specimen at the level just proximal to the navicular bone. The DDF and the suspensory ligament of the navicular (CSL) are seen just palmar to the middle phalanx and the proximal aspect of the collateral ligaments of the DIP joint.

Figure 7. MRI image at the same location as figure 6 representing a cross sectional anatomy specimen at the level just proximal to the navicular bone. The DDF and the suspensory ligament of the navicular (CSL) are seen just palmar to the middle phalanx and the proximal aspect of the collateral ligaments of the DIP joint. This is a proton density sequence from a 1.5 Tesla Siemens Symphony MR system.
Objective of MR imaging is to generate contrast between pathological and normal tissue. Generally, pathologic tissues have more hydration than normal tissue and this results in an increase in signal on T2 weighted images and a decreased signal (often hard to detect) on T1 weighted images. It is easier to see bright pathology against a dark background of normal tissue. MRI has generally high sensitivity and high negative predictive value but its specificity varies depending on the condition.

There are several major disadvantages of using MR in equine orthopedics. The cost of performing an MR on the horse is quite high. MR should not be used as a screening study but should be utilized as a problem solving tool. Careful clinical evaluation with diagnostic anesthesia, radiography and ultrasonography should be performed prior to MR. Once the area of interest is defined the horse must be positioned with the area of interest in the isocenter of the magnet. With low field systems this requires heavy sedation and high field systems general anesthetized is required. Based on the inherent problems with anesthesia in the horse, a finite time constraint must be enforced which will limit the number of sequences performed. There is a steep learning curve necessary to understand the technology used to generate the diagnostic images (especially with high field strength systems) as well as to read the MR studies and apply this information to managing the problems identified.

Conclusion

Lameness associated with structures inside the foot can be difficult to accurately define. Careful detailed clinical examination of the foot including timed and sequential nerve and/or joint blocks is often necessary to further isolate the region that is the source of pain. Knowing the region that is the source of pain can help direct the clinician in choosing the most appropriate diagnostic tool. Diagnostic imaging techniques that are available to the clinician include radiology, ultrasonography, nuclear scintigraphy, computed tomography and magnetic resonance imaging. To best determine the specific structure(s) involved may require that these imaging techniques be utilized alone or in combination. A good working knowledge of the normal anatomy and the normal variations of the anatomy of the foot are critical to achieve an accurate diagnosis. Errors in interpretation can occur with each of these imaging techniques and are often the result of correctable technical problems or a lack of knowledge of the normal anatomy of this area. Accurately defining the structure(s) involved leads to employment of the most appropriate treatment strategy and the best chance for a return to soundness.

References


