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An Overview of Imaging the Equine Foot

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Take Home Message

Appropriately utilizing digital radiology, digital ultrasound, magnetic resonance imaging, and nuclear scintigraphy for imaging the equine foot will achieve a more consistent and precise diagnosis.

Introduction

Imaging modalities of the foot have significantly improved over the past few years. From conventional radiographs to magnetic resonance imaging (MR), there are numerous changes to the technique as well as the diagnostic quality of the images that can be acquired. As a profession, we must learn what these new technologies can do to enhance our diagnostic capabilities. Radiology is on its way to being entirely digital. The same can also be said for ultrasonography. The development of high frequency ultrasound probes and digital machines along with dramatically improved techniques has enabled us to visualize nearly every aspect of the equine foot. Furthermore, MR has the ability to image structures, which at one time, could only be seen on necropsy. Nuclear scintigraphy is still one of our most sensitive methodologies when investigating and localizing problems with the foot, which can then be further investigated with the other available diagnostic tools. These technologies now enable us to discover lesions in detail and diagnoses that previously could not be elucidated. Let us not forget that a thorough clinical examination has been, and always will be, the core of evaluating and diagnosing any lameness. Imaging without detailed clinical information will be an exercise in frustration.

The dramatic changes in imaging technologies for the foot requires a change in the veterinarians’ thinking, as well as in the veterinarians’ approach to the diagnosis of foot lameness. Gone is the day when veterinarians could block the foot, radiograph it, and say “Well it’s normal so we’ll just watch it”. There are so many other imaging options available to veterinarians that allow them to arrive at a definitive diagnosis. Clients are well educated, aware of the imaging modalities available, and will demand their use.

Clinical Evaluation

A complete and thorough clinical lameness evaluation is still the basis for all imaging examinations and is necessary in the pursuit of an accurate diagnosis. Relevant history from the client should be obtained, including previous examination findings, perineural analgesia performed, and diagnostic images taken. A physical examination noting foot conformation, hoof wall integrity, and shoeing should be performed. Palpation of the distal limb for heat, pain, soft
tissue deformation, joint effusion, and the application of hoof testers is part of a complete physical exam. A moving evaluation should include walking and trotting the horse in a straight line and in a circle over various surfaces including both firm and soft footing. During the exam the footfall, degree of fetlock drop, head bob, and pelvic carriage should be noted. The horse should be lunged in a circle large enough for the horse to walk, trot, and canter comfortably. The authors recommend the circle be approximately 25-35 meters in diameter.

Perineural analgesia to localize the lameness to the foot should be performed in order to determine that imaging of the foot should be pursued. A distal digital nerve block (DDNB) localizes pain to the palmar/plantar heel and solar surface of the foot when performed correctly. Complications of inappropriately performed blocks include inadvertent injection of the anesthetic solution into the navicular bursa, proximal palmar pouch of the coffin joint, and the digital flexor tendon sheath. A proximal digital nerve block (PrDNB) indicates the pain is more generally within the foot, including more proximal and dorsal structures. Complications of poorly performed blocks include inadvertent injection into the digital flexor tendon sheath (DFTS) or missing the nerve by passing the needle deep to the palmar annular ligament (PAL). Diffusion of perineural analgesia is a possibility with all blocks and must be kept in mind when localizing the lameness. Intrasynovial anesthesia of the distal interphalangeal joint (DIP) and intrabursal anesthesia of the navicular bursa may be useful to further localize and differentiate the lameness. One of the most important aspects of blocking a lameness is to determine if a horse that presents with a unilateral lameness then switches to a lameness in the contralateral forelimb after blocking the initially lame leg. Diagnostic imaging of the lame foot can provide important information and ultimately a definitive diagnosis. However, imaging of a sound foot for comparison can be extremely useful and can elucidate sub-clinical pathology.

Radiology

Although digital radiology has not made its way into every practice it is soon to be a necessary tool for every equine clinician. In comparison to conventional films, the use of digital radiology offers significant improvement in image quality as well as almost instantaneous acquisition time. In an effort to obtain the best diagnostic images possible, it is necessary to review the fundamental principles of taking radiographs of the foot, how to best prepare the foot for imaging, the basic views to take, and what structures need to be evaluated and the associated artifacts that are often encountered. First, let’s consider the indications for taking digital radiographs of the foot. We could divide foot radiographs into a podiatry study and a lameness study. A podiatry study would consist of a lateral to medial view (LM) and a dorsopalmar view (DP). These films would evaluate the structures of the foot, the conformation of the foot and the type of farriery needed to make the necessary improvement. If the horse’s lameness blocks with a distal digital or proximal digital nerve block, then radiographs termed a lameness study would be the next logical step. Additionally, if the horse has not had recent radiographs, (within the last 6 months) it is advisable to retake the radiographs.

Preparing the foot for radiographs may seem remedial, but there are several important steps to remember. The shoe must be removed. There are likely several arguments to the contrary, but complete evaluation of the foot cannot be achieved with the shoe in place. Take the time to properly clean the frog, sole, and hoof wall. A hoof knife may be used to exfoliate the sole and
frog, and remove excess debris. Many artifacts can be avoided by simple cleaning of the entire foot. This is especially important when you are suspicious of a coffin bone fracture. Both the central cuneal and the paracuneal sulci should be packed to avoid air artifacts. There are several products that can be used, but the authors recommend using Play-Doh®.

The five views in the lameness study used to achieve optimal imaging of the foot include: lateral to medial (LM), dorsopalmar (DP), palmar 45 degrees proximal-palmarodistal oblique (navicular skyline), and dorsoproximal-palmarodistal oblique (DPr-PaDiO). Each view has specific areas of interest, and eliminating one of these views from your protocol will prevent you from doing a complete radiographic evaluation of the foot. Additional views that may be taken are discussed later in this section.

Assuming that appropriate technique is used, the lateral to medial view allows you to visualize not only the bony column of the foot, but also the laminar and hoof wall thickness. The clarity of a digital image removes the need for wire or barium paste for angle evaluation as the details of the dorsal hoof wall are quite evident (Fig. 1). When reviewing the dorsopalmar view, you want to evaluate for medial to lateral balance. Consider taking both a weighted (picking up the opposite foot) and un-weighted (standing on both feet squarely) horizontal DP view. The navicular skyline view allows clear evaluation of the palmar cortex of the navicular bone, the synovial fossa, and evaluation of sclerotic change of the spongiosum of the navicular bone (Fig. 2). Additionally, you can clearly evaluate the palmar processes of P3 for wing fractures. Packing the foot for this view is imperative to properly evaluate the navicular bone. When taking the DPr-PaDiO view, you want to carefully evaluate the shape of the navicular bone. Additionally, you may evaluate the solar margin and palmar processes of P3. Be sure to pack the foot for this view and the navicular skyline, as there are many artifacts that may interfere with the image. When acquiring the navicular skyline and DPr-PaDiO views, there are commercially available blocks which make these films much easier to achieve.

Figure 1: The laminar thickness (arrow heads) and hoof wall thickness (arrows) can be assessed on the lateral to medial view when taken with high quality digital radiographs.

Figure 2: A palmar cortical erosion identified on the palmaroproximal –palmarodistal oblique (nuclear scintigraphy Image 4)

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a Eklin Tunnel, Eklin Medical Systems, Santa Clara, CA
b Redden Navicular Block, Nanric Inc., Lawrenceburg, KY
Traditionally the 65 degree dorsopalmar view (solar margin) was included as part of a complete foot series; however, the authors have found that the solar margin can be sufficiently evaluated on the DPr-PaDiO view when using high-quality digital equipment and therefore have discontinued taking this radiographic view except when specifically indicated (P3 fracture, pedal osteitis, etc). If the solar margin view is taken, it is important the image is not overexposed so the full extent of the solar margin can be evaluated. There are always exceptions to every rule, and if there is no way to remove the shoe for radiographs, there are additional views that can be taken to optimize your ability to fully evaluate the foot. The additional views are as follows: 60 degree dorsopalmar medial and lateral obliques and the DPR-PaDiO medial and lateral obliques. The goal of these views is to visualize the entirety of the palmar processes of P3 and wings of the navicular bone.

**Ultrasonography**

The development of high-frequency probes has significantly improved ultrasound technology. The resolution and detail of the images we can acquire makes it possible to identify structures and lesions that were previously elusive. In addition, the advent of digital ultrasound makes the long-term storage and sharing of images much more feasible. A comprehensive ultrasound of the foot requires not only anatomical knowledge of the structures but also advanced training in acquiring the diagnostic images. Whenever possible, ultrasonography should be performed as part of a thorough lameness evaluation.

The decision to pursue diagnostic ultrasound of the foot should be made with the following criteria in mind. The lameness should be localized to the foot with perineural anesthesia, intrasynovial anesthesia of the digital flexor tendon sheath or DIP joint, or anesthesia of the navicular bursa. Radiographic findings may or may not have been significant, but no definitive diagnosis was made on radiographs. A suspicion of a soft tissue injury based on the history or physical exam may be a primary indication. The authors recommend that ultrasound of the foot be attempted before sending a horse for MR because it is significantly less expensive (approximately 1/10 the cost) and if a definitive diagnosis can be made the owner is saved the expense and time associated with MR.

The first step in performing a detailed ultrasound of the foot is proper preparation. The hair around the coronary band, heels, and on the palmar pastern must be clipped with a #40 or #50 blade to obtain the highest quality images. The area should be thoroughly wet with alcohol or water and coupling gel should be applied. In order to perform the transcuneal view, the frog must be pared down to a smooth, flat, soft, surface. In dry climates, it may be beneficial to soak the foot overnight in order to soften the frog enough to ultrasound through it.

There are essentially four “approaches” to the foot to acquire the necessary ultrasound views: the transverse view of the collateral ligaments of the distal interphalangeal joint (DIP), longitudinal and transverse views of the palmar pastern, the palmar sagittal view between the heel bulbs, and the transcuneal view through the frog. The technique for these approaches is described in great detail elsewhere but the authors’ techniques and the anatomical structures visualized are summarized below.
The proximal portion of the collateral ligaments of the DIP joint can be seen on ultrasound. Either an 8 to 10 MHz linear probe or microconvex (with a standoff) can be utilized to obtain the images with the depth set at approximately 3cm. The probe is placed in a transverse orientation at the coronary band and directed with the tail of the probe about 10-20 degrees above perpendicular to the floor. At the dorsal most aspect of the coronary band the extensor process of P3 can be visualized. The probe is then moved medially and laterally to find the fossa of P2 in which the collateral ligament sits. Comparisons should be made between the medial and lateral collateral ligaments on the same foot and between medial to medial and lateral to lateral ligaments on opposite front feet. The authors find a transverse view most useful to evaluate size and fiber pattern. The probe should then be rotated and a longitudinal view should be taken.\(^5\) It is important to remember that approximately one half of the collateral ligament of the DIPJ is not visualized on ultrasound as it passes deep to the hoof wall. MRI is required to completely assess these structures.

Longitudinal and transverse images of the structures of the palmar pastern should be acquired with a 12 or 14MHz linear probe, with or without a standoff, at a depth of approximately 4cm. The medial and lateral lobes of the deep digital flexor tendon (DDFT), branches of the superficial digital flexor tendon (SDFT), straight sesamoidean ligament (SSL), oblique sesamoidean ligaments (OSL), and cruciate sesamoidean ligaments (CSL) should be evaluated along the length of the pastern from just distal to the fetlock to the heels. Since perineural analgesia can migrate these structures should be evaluated even if the horse blocked to a DDNB.\(^5\) Structures should be evaluated for size and fiber pattern. Effusion within the DFTS can also be seen on this view. Again, it may be very useful to evaluate these structures in both forelimbs for comparison.

A palmar view taken between the heel bulbs can provide an immense amount of information. A microconvex probe at 6MHz or a macroconvex probe at 6MHz is positioned sagittally between the heel bulbs with the beam aiming slightly down towards the toe (Fig. 3). A depth of about 5cm is required. The microconvex probe is best for upright feet while the macroconvex is recommended for horses with a low heel conformation. The palmar aspect of P2, navicular bone and navicular bursa, palmar pouch of the DIPJ, DDFT, and distal digital annular ligament (DDAL) can be evaluated. Excess effusion of the navicular bursa may be best identified by fanning the probe medially and laterally from the sagittal view. A significant portion of the DDFT, particularly the portion that passes over the navicular bone, is visible in this view. However, it is important to note that not all lesions of the DDFT will fall within the sagittal plane of the tendon and so may not be identified on ultrasound.\(^3\)

The transcuneal view is obtained by using a 6MHz macroconvex probe in sagittal orientation on the bottom of the foot, imaging through the frog. Depth is set at approximately 4-5cm and the image should be inverted on the ultrasound screen for interpretation. The DDFT as it passes over the navicular bone and inserts on the coffin bone is seen as an echoic to hypoechoic band. This is due to the orientation of its fiber pattern relative to the ultrasound beam.\(^8\) The coffin bone, flexor surface of the navicular bone, and impar ligament (distal sesamoidean ligament) can also be identified. Thickening or fibrillation of the DDFT may be identified; however, the anechoic to hypoechoic appearance of the tendon may make it difficult to assess injuries at this level.\(^5\) The distal sesamoidean impar ligament can be difficult to assess, minor injuries may not be detected although severe injuries can be readily apparent.\(^5\)
Image 3: Palmar view between the heel bulbs visualizes several structures and in this case identified moderate navicular bursitis.

The advanced training required to perform comprehensive diagnostic ultrasound of the foot is available to general practitioners interested in becoming proficient at it.\(^1\) It is an extremely useful tool in diagnosing lameness in the foot and should be included as part of the work-up when indicated.

**Nuclear Scintigraphy**

Nuclear scintigraphy can be a very useful diagnostic tool for diagnosing lameness localized to the foot when used appropriately. It is important to remember when interpreting a bone scan that the images acquired reflect a physiologic process that is increased osteoblastic activity and blood flow in bone.\(^7\) The methylene diphenosphonate that is labeled with \(^{99m}\) technecium binds to exposed hydroxyapatite in active bone remodeling. Indications for performing a distal forelimb (carpus distally) bone scan include a lameness that blocks to the foot with no definitive diagnosis on radiographs or ultrasound or if there is suspicion of bony inflammation or injury based on the history and physical examination. Bone scans may also be useful as part of a prepurchase examination in sound horses to clarify questionable radiographic findings.

Nuclear scintigraphy is an early indicator of osseous inflammation. In the foot this is most commonly associated with navicular syndrome (inflammation, palmar cortex erosions, etc), pedal osteitis and coffin bone fractures (Fig. 4). Soft tissue injuries that affect a bony attachment such as at the insertion of the DDFT or insertion of the collateral ligaments of the DIPJ may also be identified on nuclear scintigraphy.\(^7\) It is a very sensitive diagnostic tool but is not highly specific, so it must be interpreted with the clinical examination and other diagnostic imaging findings in mind. Table 1 provides a brief comparison of the sensitivity and specificity of the imaging modalities discussed in this paper.

<table>
<thead>
<tr>
<th>Modality</th>
<th>Specificity</th>
<th>Sensitivity</th>
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</thead>
<tbody>
<tr>
<td>Radiographs</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Ultrasound</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>MRI</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Nuclear Scintigraphy</td>
<td>-</td>
<td>+</td>
</tr>
</tbody>
</table>

Table 1: Comparison of Specificity and Sensitivity of Imaging Modalities
Magnetic Resonance Imaging (MR)

MR provides an excellent view of the entire equine foot. The major advantage of MR over other imaging modalities is that it provides both anatomical and physiological information in multiple planes. However, it is important to remember that this modality is best used when appropriately indicated. A horse needing an MR is one who becomes sound with perineural anesthesia of the foot. Additionally, the horse would be an MR candidate if no definitive diagnosis can be established on radiographs or ultrasound. Other indications include: a severe lameness of greater than one month duration, a chronic lameness lasting greater than six months or less, and concern of soft tissue involvement that can only be entirely visualized by MR. These specific structures include the distal half of the collateral ligaments of the DIPJ and the distal attachment of the DDFT on the third phalanx.

When considering a patient for an MR, there are two choices: you can refer the patient to a facility that has high field or a low field magnet. There are pros and cons of each system. A complete understanding of these advantages and disadvantages will help you decide which system will be the best for each horse that you refer for an MR. The biggest difference for the patient is that the horse will have to be under general anesthesia for the high field magnet and will only need to be sedated for the low field magnet. Because the horse is still awake with the low field magnet, there is the factor of motion. If the horse sways, buckles at the knee, or becomes startled as he starts to wake from sedation, the magnet will detect this and the image

Figure 4: Nuclear scintigraphy of the foot showing increased radiopharmaceutical uptake in the navicular bone in the left front foot. The horse was diagnosed with a palmar cortical erosion on radiographs (above).
quality will be unacceptable. Therefore, the sequence will have to be run again. This generally means that the acquisition time for low field magnets is often greater than for high field magnets. However, if you consider the time for anesthesia and recovery when using the high field magnet, it is likely that it takes about the same amount of time (approximately 2-3 hours) to complete the MR from beginning to end regardless of which system you use. Another consideration is image quality. There is definitely more detail in the images that a high field magnet produces. However, the low field magnet produces images that are of diagnostic quality and there are few structures that cannot be evaluated in the low field that can be evaluated by high field. The final issue to consider is that it is significantly more expensive to use a high field magnet simply for the fact that the horse must undergo general anesthesia. On top of the cost, the standard risks of general anesthesia apply and must be considered especially if the horse has any significant anesthetic risks.

There are many different protocols used for MR of the foot. However, there are four main pulse sequences that the authors recommend. The sequences are as follows: T1 weighted, T2 weighted, short tau inversion recovery (STIR), and proton density weighted (PDW). Without getting into too much detail about how these sequences are different from one another, it is important to know what tissue density is highlighted for appropriate interpretation of the images. The T1 weighted sequence shows fat as the tissue that has the most signal. Simply, this means that in the T1 sequence, fat will show up bright white in color while fluid and bone will be darker and grey in color. The T2 weighted sequence is just the opposite. In this sequence, fluid density will have the most signal and will appear white. The STIR sequence results in markedly decreased signal in fat and bone density compared to fluid density and the fluid signal is even more obvious and white than even the T2 sequence. Therefore, this sequence is ideal for evaluation of the dorsal and palmar pouches of the distal interphalangeal joint, navicular bursa, and evaluating edema within in the bone. The PDW sequence has a mixture of weighting between T1 and T2. Therefore, there is not a specific tissue density that stands out more than another, but it provides excellent anatomic detail. With the use of these four sequences in multiple slices as well as sagittal, frontal, and transverse planes, a complete and thorough examination consisting of approximately 400-500 images, is accomplished.
Conclusions

The relative cost and time associated with each modality is another factor to consider when developing a diagnostic plan for your patient (Table 2). These numbers include all related time and expenses including office call and sedation.

<table>
<thead>
<tr>
<th>Diagnostic</th>
<th>Time</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clinical Exam</td>
<td>30 min exam</td>
<td>$</td>
</tr>
<tr>
<td></td>
<td>20 min per block</td>
<td>(including 2 blocks)</td>
</tr>
<tr>
<td>Radiographs- 8 views (includes pulling shoes and preparing the foot)</td>
<td>30 minutes</td>
<td>$</td>
</tr>
<tr>
<td>Ultrasound</td>
<td>30 minutes</td>
<td>$</td>
</tr>
<tr>
<td>MRI</td>
<td>2-3 hour procedures</td>
<td>$$$$</td>
</tr>
<tr>
<td></td>
<td>1 hour interpretation</td>
<td></td>
</tr>
<tr>
<td>Nuclear Scintigraphy (carpus distally)</td>
<td>30 minutes</td>
<td>$$</td>
</tr>
</tbody>
</table>

It cannot be overstated the importance a complete history, thorough clinical examination, and diagnostic anesthesia techniques have in localizing and diagnosing lameness in the foot. Radiology will always remain the primary imaging modality to employ when investigating a lameness which has blocked to the foot. Although MR is an excellent modality, for cost effectiveness, ultrasonography should be used prior to an MRI. The authors no longer recommend a palmar digital neurectomy without a MR or ultrasound. Nuclear scintigraphy is tremendously sensitive to evaluate osseous inflammatory changes in the foot. In particular, it is the best diagnostic tool to diagnose occult P3 fractures and early navicular disease. When diagnostic imaging is utilized appropriately and its limitations are understood, a definitive diagnosis can almost always be made and the most effective treatment plan can be implemented to give the patient the best possible outcome.

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