Proceedings of the American Association of Equine Practitioners

Focus Meeting on the Foot
Fort Collins, CO, USA – Sep. 5-7, 2013

Next Meeting:

Annual Convention
Dec. 7-11, 2013 - Nashville, TN, USA

Resort Symposium
Feb. 6-8, 2014 - Rio Grande, Puerto Rico, USA

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Routine Imaging of the Equine Foot

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Take Home Message—Any thorough examination of the foot requires imaging. Radiography is the most commonly performed. A complete examination requires multiple views. Although there are limitations to radiography, contrast radiography and ultrasonography can add sufficient new information to justify their use. Despite the increased popularity of magnetic resonance imaging (MRI), advanced imaging techniques like scintigraphy and thermography continue to add valuable information that MRI cannot.

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I. INTRODUCTION

Radiographic examination of the digit is the most common radiographic study performed by the equine practitioner. The practitioner should strive to obtain good quality radiographic equipment and develop good radiographic technique. In addition, an accurate diagnosis requires an understanding of good working knowledge of anatomy and pathophysiology of disease. The practitioner needs to understand the complex anatomy of the foot and recognize that there is a range of normal variations seen in many of the anatomical structures in the foot. Good radiographic technique necessitates an understanding of the relationship of limb position, cassette position and x-ray tube angle. It is also important to recognize that inadequate foot preparation, inappropriate projections and motion (of the animal and examiner) can create artifacts. Errors in interpretation often occur due to correctable technical problems.

A detailed clinical exam should be performed before a specific radiographic study can be recommended. The clinical examination should include a complete lameness evaluation with specific manipulative test, flexion tests, and hoof tester application. Ancillary diagnostics such as palmar digital nerve block, distal interphalangeal joint block, navicular bursa block and digital flexor tendon sheath block may further direct the clinical examination. The response to each one of these blocks may direct the clinician to include more definitive radiographic projections. Advanced imaging techniques such as thermography, diagnostic ultrasound, and nuclear scintigraphy can direct the clinician to perform a specific study or to include specific projection to further elaborate an area of interest. In the future, magnetic resonance imaging will become more common but will not preclude the radiographic exam. It is hoped that MRI will validate certain radiographic changes seen on the standard foot examination. Radiographic examination of the digit will remain the common imaging technique between the field practitioner and the referral hospital in lameness and prepurchase examinations of the horse.

II. EQUIPMENT

The equine practitioner should develop a working knowledge of the equipment that is currently available. There are a limited number of systems available that meet the requirements of an ambulatory practitioner. Many manufacturers produce lightweight high frequency units that have greater exposure capabilities. Cost and physical characteristics (weight) of the equipment may influence the suitability of a system for a specific practice. It is preferable to purchase a system with a light collimator or laser pointer and a line voltage measuring unit included.

Digital radiography (DR) has become common place in the equine veterinary market. There are several systems available and these systems can be utilized with the high frequency radiographic systems already in use with current radiographic imaging systems. The major advantage of these systems is that the images have more exposure latitude (more shades of grey) which makes it possible to see both bone and soft tissue detail in the same image. Systems have the added benefit of software that allows the image to be manipulated (magnification, contrast, brightness, cropping, edge enhancement) as well as allowing the image to be measured and enhanced with drawings.

III. PREPARATION OF THE FOOT

It is essential to clean the foot of dirt and debris before performing a radiographic examination. The bottom of the foot is not the only area that needs to be cleaned but should include the heels and wall. In most instances shoe(s) removal will be necessary to adequately examine the navicular bone and P3 as well as to minimize scatter radiation (which can
diminish detail of the radiograph). Skill and the appropriate equipment are necessary to remove the shoes without damaging the foot. Loose flakes of horn from the sole and frog should be pared away and particular attention should be paid to trimming the clefts of the frog sufficiently to allow removal of dirt and debris. Packing the sole and sulci of the frog with a material like Play-do decreases gas artifacts from the trapped air. This packing is especially important for the navicular and P3 examinations. Unfortunately, packing may decrease detail because it adds soft tissue density. Once the foot is prepared it should be placed on paper or canvas to reduce contamination of the packing material with dirt/debris. After the radiographic examination, the foot should be covered with an elastic tape has to prevent the walls from being damaged when traveling from the area of the study to the stall and later to the farrier.

IV. POSITIONING THE FOOT FOR THE EXAMINATION

Blocks are needed to elevate the off the ground allowing the foot to be centered in the cassette and the x-ray beam to pass horizontally through the specific area of interest (i.e. solar surface of the foot, DIP joint, navicular, etc.). The size of the block is dictated by the size of the radiograph machine. The appropriate size block can be determined by measuring from the floor to the center of the collimator and subtract ¾ inch. Two blocks of equal height are needed to allow the horse to bear weight evenly on both feet while performing the radiographic examination. It is important to position the feet on the blocks in a natural position with the cannon bone vertical to the ground, axis of the limb directly under the horse and the foot in line with the conformation of the horse (i.e. if the horse toes in the blocks should be placed in line with the foot direction). The foot should be placed as close as possible. The x-ray beam should be directed at this site. Typically, the x-ray beam position determines the position of the true apex of the frog with respect to the distal aspect of the hoof wall.

Radiopaque markers can be used to assess the exterior surface of the dorsal hoof wall in the radiographic study. Barium paste, wire, or a metallic marker can be placed on the dorsal hoof wall from coronary band toward the distal margin of P3 (DR has made this less necessary) to assess the hoof wall in the lateral view of the foot. A thumbtack can be placed in the apex of frog after it has been pared appropriately to determine the position of the true apex of the frog with respect to the distal margin of P3.

V. POSITIONING THE X-RAY BEAM

To appropriately position the x-ray beam the veterinarian or technician must have a keen knowledge of the anatomy in the area and a specific area of interest. For instance, to produce the lateral view of the foot, the x-ray beam should be parallel to the bulbs of the heel and centered on the specific area of interest. The navicular bone examination should have the x-ray beam centered below the coronary band midway between the dorsal hoof wall and the heels. The solar surface of P3 will be imaged best by centering the beam ¼” above the distal aspect of the hoof wall at the quarter midway between the heels and the toe.

X-rays obey the inverse square law, which means a small change in focal-film distance (distance between the x-ray machine and the cassette or FFD) can have a significant effect on the exposure (diminishes number of x-rays with distance). Because a small change in FFD can have a significant effect on exposure, it is imperative that this distance be consistent and should be measured on every exposure. This distance can be measured indirectly in systems with a collimator. The examiner should establish the correct FFD between the machine and cassette and then setting the collimator to the appropriate cassette size. It is also possible to place to laser pointers on the x-ray machine that are focused together at the FFD.

Subject-film distance is also an important variable that should be consistently evaluated and minimized. In most instances, the cassette can be placed as close to the subject as possible. If the plate cannot be placed close to the subject it creates magnification of the subject which reduces image sharpness. Beam angle should be 90 degrees to the cassette whenever possible. When the beam angle varies from perpendicular subject distortion can be a consequence. The subject should also be parallel to the plate to minimize distortion. Remember that the central beam position dictates the area seen with most clarity.

VI. STANDARD RADIOGRAPHIC STUDY OF THE FOOT

Lateromedial

Dorso 65 degree proximal-Palmarodistal Oblique (D45Pr-PaDiO)
Palmaro 45 degree proximal-Palmarodistal Oblique (Pa45Pr-PaDiO navicular skyline)
Dorso 0 degree palmar (D0Pr)

Lateromedial

To obtain a lateromedial radiograph the foot should be positioned on a block of appropriate size (dictated by the x-ray machine). The foot should be centered in the middle of the cassette. The cassette should be placed as close to the foot as possible. The x-ray beam should be directed parallel to floor centered. If a specific region of interest (previously determined by the clinical exam or advanced imaging techniques) has been determined then the x-ray beam should be directed at this site. Typically, the x-ray beam position varies between the solar surfaces of P3 (⅓ to ½ inch above bearing surface of the foot for podiatry and laminitis studies) to more proximally at the coffin joint/navicular bone (beam centered at the middle of the coronary band). The beam angle should pass parallel to the bulbs of the heel. The radiograph demonstrates the dorsal and palmar aspect of P3 and the end on view of the navicular bone. With appropriate technique the dorsal hoof wall should be apparent with most normal horses.
having a thickness 15-18 mm (for most breeds). The proximal and distal border as well as the contour of the flexor surface of the navicular should be easy to discern when the projection is centered at this area.

**Dorso 65 Degree Proximal-Palmarodistal Oblique**

The dorso 65 degree proximal-palmarodistal oblique can be obtained with the foot in a weight-bearing position or with the foot on a navicular block (upright pedal). For the weight-bearing technique the foot is placed on a tunnel to the front of the cassette and the beam is directed 65 degree to the floor. With this technique the beam is directed 2 cm proximal to the coronary band. For the upright pedal the foot is placed on a block that holds the cassette while allowing the foot to be placed such that the toe is 85 degrees to the ground surface. This allows the x-ray beam to be directed horizontal with the ground centered 2-3 cm proximal to the coronal band on midline. The cassette is placed as close to the solar surface of the foot. The upright pedal view creates less distortion than the weight-bearing technique. This oblique is utilized because of good visualization of the body, solar margin and palmar processes of the distal phalanx. This same projection can be used to evaluate the navicular bone.

**Palmaro 45 Degree Proximal-Palmarodistal Oblique**

The foot is placed on a tunnel which is placed behind the opposite limb. The foot positioned as far caudally on the tunnel as possible. The horse should have the majority of its weight placed on the front limb. The x-ray machine should be placed above the foot close to the thorax of the horse. The x-ray beam should make an angle parallel with the flexor cortex of the navicular bone (approximately 45 degrees). Foot conformation can influence the beam angle by affecting the flexor surface angle. Some clinicians take and develop the lateral view first to determine the correct angle. It is important to not superimpose the fetlock over the heels. The beam should be centered on the bulbs of the heel. This oblique projection of the navicular bone allows assessment of the flexor cortex, medullary cavity and flexor surface of the navicular bone as well as the palmar/plantar processes of the distal phalanx.

**Dorso 0 Degree Palmar**

The foot should be placed on the appropriate sized block to allow the correct beam position. When performing the podiatry examination the DP projection should have the beam horizontal (parallel) and centered ½ to ¾ inch above the bearing surface of the foot. The plate should be placed as close to the bulbs of the heels as possible. The beam should be raised if the navicular region is the primary area of interest bone (coffin joint, navicular) in the DP plane.

**Interpretation**

There are two schools of thought on how the radiographs should be interpreted. Most of the time, radiographs are examined for signs consistent with the tentative diagnosis, such as evaluating for signs of navicular disease. In this case, the radiographs are evaluated for changes such as enlarged synovial fossa (lollipop formation along the distal border), enthesophyte formation along the proximal or distal border, flexor cortex changes, cyst-like formation within the bone, or medullary sclerosis.\(^3\)\(^4\) Unfortunately, research has shown that these changes occur in the non lame population with the same frequency as horses with navicular disease.\(^4\) Further, each of these views must be assessed for any significant changes in any of the bone surfaces.

It is the author’s opinion that the radiographs should be assessed for change and what the change means from a pathologic sense. Once the basic films have been examined, it may be necessary to take additional oblique views to completely appreciate any pathologic change. The author evaluates each of the views for various changes, the dorso palpalarm projection is used to assess the joint surfaces and joint alignment, assessment for osseous change within the bones, assessed for hoof capsule - bony column orientation and medial to lateral hoof balance. The lateral projection can be used to assess joint surfaces, osseous changes within the bones, navicular bone changes, hoof pastern axis deviation, and hoof capsule bony column orientation. The dorsosolar view of the third phalanx can be used to assess the weight bearing margin of the bone, assess the size and symmetry of the vascular channels and third phalanx bony architecture. The navicular bone should be evaluated along the proximal and distal borders, assessment of the distal border to determine presence or enlargement of synovial fossa, and for changes within the navicular bone architecture. The flexor view is assessed for changes along the flexor surface of the navicular bone. This view is also important to assess the medullary cavity of the navicular bone, and it is the best view for assessment of the wings of the third phalanx. Evaluation of the radiographs along these parameters allows a thorough assessment of the bones of the foot to determine changes that may have occurred as a result of pathology, or as a result of occupational stress both important factors for the potential buyer. If the radiographs show changes it may be warranted to do further imaging diagnostics to more accurately determine the pathological changes.

**VII. NAVICULAR BURSOGRAM**

One technique that can be very useful is the navicular bursogram. Injection into the bursa is made from the palmar surface with the limb flexed at the carpus. Aseptic injection techniques are used to inject a 3-ml mixture of 1:1 contrast material and local anesthetic or medication.\(^5\) The landmarks for needle insertion is a point just proximal to the central sulcus of the frog, with the needle directed towards the apex of the frog and in a direction parallel to the ground surface of the hoof. Needle insertion is made easier if regional analgesic injection of the medial and lateral palmar nerves is performed first or in the instance of “blocking” the bursa for diagnostic purposes a small bleb of local anesthetic over the site of insertion is very helpful. A 20 gauge, 3.5-in. (9 cm) needle is
used. The needle is inserted until resistance was encountered; this is usually at 2/3 the length of the needle. If the needle is inserted further before encountering resistance, it usually indicated incorrect placement. A lateral radiograph of the hoof is taken to confirm the position of the needle prior to injection. Ideally the needle tip is midway between the proximal and distal borders. Once the needle position is confirmed, the bursa is injected with the contrast mixture and a second lateral hoof radiograph is taken to confirm the filling of the bursa. If the bursa has been successfully injected, then a palmaroproximal–palmarodistal (PP-PD) oblique projection of the navicular bone is obtained. The contrast material seen from a lateral view normally had the shape of an apostrophe. The contrast, seen from the PP-PD projection, is a distinct line of contrast material juxtaposed to the deep digital flexor tendon which is normally separated from the navicular cortical bone by a layer of radiolucent fibrocartilage.

The bursograms are evaluated for several different changes: 1) normal flexor fibrocartilage seen as a uniform radiolucent area 1-2mm in thickness covering the flexor surface of the navicular bone; 2) thinning or erosions of the flexor fibrocartilage, seen as a loss of the thickness of the previously mentioned radiolucent line; (3) fibrillation or splits of the deep flexor tendon within the navicular bursa, which was noted as filling defects along the bursal surface of the deep flexor tendon; (4) presence of flexor subchondral bone cystic defects, which were noted as focal filling of the flexor cortical area with contrast; (5) communication of the navicular bursa with the distal interphalangeal joint, seen as leakage of the contrast from the bursa into distal interphalangeal joint; (6) complete focal loss of the dye column, which was thought to be a result of flexor tendon adhesion to the bone; (7) narrowing or enlargement of the proximal to distal borders of the bursa (bursa change) thought to represent inflammatory changes of the bursa; (8) leakage of contrast from the bursa suggesting a tear of the border of bursa; (9) marked widening of the contrast thickness thought to indicate loss of palmar support of the tendon by the distal annular ligament; (10) contrast within the body of the tendon thought to be a focal deep flexor tear; (11) contrast within the impar ligament assumed to be indicative of tearing or damage to the impar ligament and (12) contrast within or surrounding the proximal suspensory of the navicular bone indicative of ligament injury.

The author has performed 350 bursograms. Normal fibrocartilage was seen in 29% of examinations. Thinning or erosion of the flexor fibrocartilage was seen in 62% of the bursograms. Fibrillation of the deep flexor tendon was recognized in 24% of the bursograms. Subchondral defects were seen in only 2 cases. Communication between the navicular bursa and the distal interphalangeal joint was noted in 11% of the contrast studies. Bursal tears were seen in 18% of the bursograms. Bursa changes were noted in 24%. Proximal suspensory tears were noted on 5%. Four of the changes were only seen in horses with unilateral lameness, (1) Adhesions (loss of the dye column) were noted in 8% of the horses. (2) Loss of distal annular ligament support was found in 1% of the horses examined. (3) Contrast filled areas of the deep flexor in 3% of the horse. (4) The impar ligament was involved in 1% of horses.

Evaluation of bilateral bursograms revealed two populations: 43% of the horses with bilateral examinations had similar changes on both feet but 57% of the horses had completely different changes. The changes were more numerous on the more lame leg in all cases. Four horses had repeat bursograms. In 2 of the horses the changes noted were worse on subsequent bursograms; while in the other 2, the abnormalities seen in the repeat bursograms were unchanged.

Since the original description of navicular bursography in 1998, the author has noted 6 other changes that have not been previously described on bursograms: (1) Tears in the core of the deep flexor tendon extending from the bursa up the pastern; (2) Tears in the bursa seen as leakage from the bursa; (3) Displacement of the deep flexor tendon from its normal position behind the navicular bone; (4) Contrast within the impar ligament; (5) Contrast within and around the proximal navicular ligament; and (6) Changes in the normal shape of the navicular bursa.

VIII. ULTRASONOGRAPHIC EXAMINATION OF THE FOOT

This imaging modality is extremely operator dependent, and imaging of the distal limb is technically challenging. In addition, it is not possible to visualize all the soft tissue structures within in the foot. Structure visualization varies by case and it is dependent on the foot conformation, and frog shape and condition. The shape of the heel bulbs and foot conformation dictates the window for imaging the structures proximal to the navicular bone. Penetration of the sound beam and therefore image quality with transcuneal examination is dependent on the condition of the frog. Paring of the frog until it is soft is absolutely necessary. In dry climates soaking of the foot is required for transcuneal examination. Mild depression of the frog with digital pressure is usually an indication that the sound beam can penetrate the frog well.

Techniques have been developed for imaging structures proximal and distal to the navicular bone including: deep digital flexor tendon, navicular bursa, collateral sesamoidean ligament, impar ligament. The proximal and distal margins of the navicular bone can be evaluated, the extent of which is partially dependent on the conformation of the foot. The proximal aspect of the collateral ligaments of the distal interphalangeal joint and associated bony attachments as well as the dorsal aspect of the joint can be evaluated. All structures should be evaluated in two imaging planes.

Examination of the deep digital flexor tendon includes evaluation of the tendon lobes which should be symmetrical in size and shape. The opposite limb should be used for comparison. Evaluation of the deep digital flexor tendon in the foot is limited by beam angle. The curvature of the tendon often prevents the sound beam from striking the tendon fibers at 90 degrees which creates the normal echogenic appearance
present in the other areas, such as the pastern and metacarpus. Therefore assessment of the fiber pattern can be challenging and at times not possible. The mesotendon is echogenic regardless of beam angle, therefore changes in size, shape and margins in the deep digital flexor tendon are most easily detected. Normal tendon fibers proximal to the navicular bone are commonly dark gray to black, depending on gain settings. Mal-aligned fibers can often be identified in this region because they are echogenic in contrast to normal tendon fibers. Normal tendon fibers are dark and therefore only malaligned fibers can be at 90 degrees to the sound beam and produce an echogenic pattern. Other causes of echogenic or hyperechogenic regions in the deep digital flexor tendon at this level include fibrosis and mineralization, the echogenicity of these tissue types is not dependent on beam angle. Fibrosis can result in complete shadowing like calcification, and therefore should not be ruled out based on that criterion. Identification of fluid in the deep digital flexor tendon without other abnormalities, such as size and margin changes, can be difficult or impossible to detect because it can have the same echogenicity as normal tendon fibers. The lobes of the deep digital flexor tendon may have to be evaluated individually in the transverse plane depending on their shape and the foot conformation. Changing the probe orientation and evaluating the lobes individually often helps.

The collateral sesamoidean ligament and navicular bursa are easily imaged and abnormalities in anatomy and echogenicity can be detected. The collateral sesamoidean ligament has a symmetrical shape, uniform echogenicity and well defined margins. Synovial proliferation in the proximal palmar recess of the distal interphalangeal joint can obscure the dorsal margin of the collateral sesamoidean ligament which on initial evaluation may cause the ligament to appear falsely enlarged. Close examination will usually allow detection of the true dorsal margin and allow assessment of the size of the ligament. Distention and synovial proliferation of the navicular bursa can be easily detected. However, determination of adhesions as opposed to synovial proliferation between structures such as the collateral sesamoidean ligament, navicular bursa, and deep digital flexor tendon is unlikely. Dynamic examination in this region has not proven helpful to confirm the presence of adhesions.

Transcuneal examination of the foot allows visualization of the deep digital flexor tendon, impar ligament and distal recess of the navicular bursa. Attenuation of the sound beam by the frog affects the image quality affecting the severity of the lesions which can be detected in this region. In contrast to examination of the deep digital flexor tendon proximal to the navicular bone, transcuneal examination often allows evaluation of fiber alignment and echogenicity. The fibers of the deep digital flexor tendon and impar ligament are often oriented such that the sound beam can strike them at 90 degrees producing a traditional echogenic pattern. Unfortunately, the window of visualization achieved with transcuneal examination is small and varies depending on foot conformation. Lesions which are not located close to midline often cannot be visualized. Bone margins are well visualized and entheses or bone resorption at the attachments of the deep digital flexor tendon and impar ligament can be demonstrated. Evaluation of the deep digital flexor tendon at the level of the navicular bone is difficult. Changes in size, shape and margins of severe lesions can still be detected. Abnormalities, depending on location, in the navicular bone flexor surface can also be identified.

The proximal aspect of the collateral ligaments of the distal interphalangeal joint can be evaluated at the level of the coronary band. Evaluation of soft tissue and osseous abnormalities is possible. The collateral ligaments of the distal interphalangeal usually have a uniform echogenic pattern with smooth margins. Abnormalities should be identified in transverse and long axis images. The bone margin of the second phalanx should be smooth and uniformly echogenic at the origin of the collateral ligaments of the distal interphalangeal joint. Cross-sectional areas of diseased ligaments varies widely, ranging from 0.75 to 1.04 cm2 (normal, 0.6-0.7 cm2). The ligaments will show various amounts of hypoechogenicity and parallel fiber malalignment.

Scintigraphy is a technique that measures gamma ray emission from a radioactive nuclide injected into the animal. The technique provides information on relative vascularity and rate of tissue metabolism. This is particularly useful in studying bone pathology and can help differentiate sites of injury in the foot.

Thermography provides information regarding skin temperature. It has been shown to be useful in assessing the relative blood flow to a region. This information is of particular interest when pre- and post exercise temperatures are determined. Exercise will normally cause a 0.5°C rise in skin temperature. Whenever, the skin temperature does not rise, poor blood flow should be considered a factor in the disease being assessed.

IX. CONCLUSIONS

The examination of the foot must imaging. Imaging not only gives insight into the nature of the injury it can identify important pathologic details. This allows the examiner to better determine treatment strategies but also prognosticate the outcome.

REFERENCES


