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Diagnostic Imaging of the Equine Digit Part 1: Radiography and Ultrasound

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The truth inherent in the age-old adage, “no foot, no horse” has remained unchanged over the centuries. The understanding of foot-related lameness, its underlying pathology, and the ability to identify it have, however, undergone a revolution that has accelerated over the past decade. When faced with a horse whose lameness is alleviated by palmar digital (PD) nerve blocks, the clinician must make a series of decisions about the preferred case management. The decision-making process has become more difficult with the advent of new and “better” diagnostic modalities, such as nuclear medicine tests, magnetic resonance imaging (MRI), and computed tomography (CT). The purpose of this 2-part series of *Large Animal Veterinary Rounds* is to provide information regarding the use and interpretation of diagnostic imaging modalities in the horse. Due to the breadth of information available about imaging of the foot, the focus of both parts will be on diseases of the podotrochlear apparatus and the distal interphalangeal joint (DIP).

At one time, navicular disease or podotrochleosis (ie, navicular syndrome, heel pain, palmar foot pain, or caudal heel syndrome, with a positive reaction to PD block) was recognized as a lameness condition primarily affecting Thoroughbred and Quarterhorse breeds, resulting in chronic progressive degeneration of the navicular bone.^{1,2} Many physical examination findings associated with the condition have been reported, including small upright feet, a positive hoof-tester examination, landing toe first, shortening of the caudal phase of the stride, and a positive result with PD perineural anesthesia. Historically, once the clinical suspicion of navicular disease was confirmed with a PD nerve block, radiographs were made. The “navicular skyline” projection greatly aided bone evaluation and increased a clinician’s ability to make the diagnosis.³ The skyline view is still considered a mainstay of the radiographic examination.

Unfortunately, not all horses with lameness in the foot fit into this diagnosis. Some have foot pain that is localized with a PD nerve block, but relatively unremarkable in radiographs. Currently, in addition to navicular degeneration, it is accepted that a host of other structures may have pathologies resulting in clinical lameness indicated with a PD nerve block.⁴ Anatomic structures of clinical importance lying within the hoof capsule include the middle (P2) and distal (P3) phalanges comprising the DIP joint, along with the collateral ligaments of this joint. The podotrochlear apparatus includes the deep digital flexor tendon (DDFT), the navicular or podotrochlear bursa, the distal sesamoid (navicular) bone, the distal sesamoidean impar ligament, and the collateral sesamoidean ligament (CSL) or suspensory ligament of the navicular bone. The distal portion of the digital sheath is also housed within the hoof capsule. Recently, the distal digital annular ligament has also been implicated in lameness.⁵⁻¹⁴

Diagnostic imaging

It is imperative to re-visit the goals of diagnostic imaging at the outset of any discussion on lameness diagnosis in the horse. Ideally, diagnostic imaging will provide an accurate and complete description of the pathology, which should be consistent with the degree and localization of the lameness found on clinical examination. With imaging, clinicians can accurately determine the prognosis and develop a directed treatment plan, the importance of which becomes more evident as the number and expense of available treatment options increase.

However, understanding the limitations of diagnostic imaging can help clinicians determine the amount of missing information. For example, a horse with bone lysis on the palmar aspect of the flexor cortex of the navicular bone as shown on radiographs will almost certainly have disease of both the navicular bursa and DDFT. Although the soft tissue structures cannot be directly evaluated on radiographs, the clinician should be able to deduce the presence of pathology in these structures and the clinical relevance of any abnormalities,



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which should correlate with the degree and localization of the lameness. A moderate-to-severe lameness should have representative pathology and, if a similar degree of pathology is not identified, it should indicate that information is missing and additional imaging may be indicated.

For most anatomic regions, radiography and ultrasound act as complementary tools. As in the previous example of flexor cortical bone loss, the proximal reflection of the navicular bursa and the distal portion of the DDDT can be evaluated using ultrasound. Thus, the findings of the 2 modalities complement each other, allowing the clinician to develop a more accurate prognosis by better defining the true extent of the pathology.

The unique and complicated anatomic configuration of the equine foot provides one of the biggest challenges for diagnostic imaging. The hoof capsule houses all the components of the musculoskeletal system, as well as the laminae, vasculature, and neural tissue (Figure 1). The clinical importance of many of these soft tissue structures was likely underestimated or at least under-recognized until the use of advanced imaging modalities such as MRI^{15,16} and CT.¹⁷

Advanced diagnostic imaging techniques increase the understanding of heel pain and assist in providing a complete and accurate diagnosis. The knowledge gained from these techniques enables clinicians to use the more routinely available diagnostics – radiography and ultrasound – to greater advantage. It is now known that a close inspection of specific anatomic regions, such as the ligament attachment sites, should be performed, in addition to more traditional evaluations of the osseous structures. A discussion of the capabilities and weaknesses of nuclear scintigraphy, MRI, and CT scanning will be presented in Part 2 of this article in an upcoming issue of *Large Animal Veterinary Rounds*.

Radiography

Diagnostic techniques withstanding the test of time have done so because they add critically important information that remains valuable to clinicians. Even in centres with advanced

Figure 1: A. Parasagittal section with the hoof capsule removed. B. Transverse section. a. middle phalanx b. navicular bone c. distal phalanx d. deep digital flexor tendon e. distal sesamoidean impar ligament f. distal articular border of the navicular bone g. navicular bursa h. collateral sesamoidean ligament i. distal interphalangeal joint space j. digital sheath



Figure 2: Digital navicular skyline projections from two different horses.

A. The image on the left demonstrates clipping artifact whereby structures of low density, the heel bulb and wings of the distal phalanx, have been completely 'clipped' out of the image (*). Compare to the radiograph (B) where the heel bulb is still visible. The radiograph does demonstrate a round lucency with a sclerotic rim superimposed over the medulla of the navicular bone.

B. The image on the right is of a foot with the sulci of the frog packed. Digital processing can amplify artifacts that in this case create a lucent line crossing the navicular bone (small arrows). The crescent shaped lucency within the palmar cortex on midline (large arrow) is a normal finding.



diagnostic imaging tests, radiography remains a first-line test for horses with heel pain. Although limited in its ability to identify pathology in soft tissue structures, many major bone-related problems can be either diagnosed or ruled-out using radiography.¹⁸

Accurate radiographic interpretation is dependent on a high-quality study and a good working knowledge of the regional radiographic anatomy. The production of a high-quality study depends on several key factors, including patient preparation, positioning, adequate equipment, adequate numbers of radiographic projections, and a knowledge of the topographical anatomy enabling appropriate beam angulations.

Patient preparation: The shoe should be removed and the foot cleaned and trimmed so that no areas of sole or frog overgrowth are present. Dirt, cornified tissue, and gas trapped within tissue can cause artifacts that superimpose on anatomic structures of clinical importance, particularly in the heel and frog regions. Gas within the sulci of the frog frequently causes artifacts that superimpose directly over the body of the navicular bone, compromising radiographic quality. To avoid this artifact, the frog sulci can be packed with radiolucent material such as Play-Doh™ or petroleum jelly. It is noteworthy that common digital image techniques such as edge enhancement can amplify the overall effect of this type of artifact (Figure 2).

Patient positioning: The anatomy of the foot is complex and multiple projections are necessary to produce radiographs where the x-ray beam is tangential to the surfaces of interest. Positioning devices should include a block to elevate the foot off the ground and a tunnel to house the cassette or digital detector where the horse can stand. Some clinicians advocate the use of a positioning device that holds the distal limb in a non-weight-bearing, mildly-flexed position.

Adequate equipment: High-quality radiographs can be made using either traditional film screen cassettes or the newer digital detectors. Film screen systems should use a 200-400 speed or higher and be in good repair so that artifacts such as screen defects do not hinder image quality. While more attention should be paid to radiographic technique in terms of kilovolt peak (kVp) and miliampere seconds (mAs) when using traditional film screen, it is important to remember that these systems are more than adequate for most problems and still offer higher spatial resolu-

tion than most digital detectors.¹⁹ Detail can be increased by the addition of a grid. Most digital radiography systems offer visually accurate images; however, digital systems also offer another set of artifacts that the clinician must learn to decipher. Often artifacts such as overshoot or clipping significantly compromise digital radiographs of the equine foot (Figure 2).

Radiographic projections: A thorough examination of the foot requires multiple projections with the x-ray beam tangential to the anatomic structure of interest. This is particularly important when using radiographic findings to infer injury to or pathology of the associated synovial or soft tissue structures. A thorough discussion of radiographic projections is available in other sources.¹⁸

Lateromedial projection: Place the foot on a block, mark the coronary band and dorsal hoof wall with a radio-opaque marker. The cassette should be on the ground medial to the limb, and perpendicular to the ground and the x-ray beam. The x-ray beam is parallel to a line drawn from one heel bulb to the other, and the beam centered at the coronary band. Ensure that the toe is included in the shadow of the collimator light on the cassette (Figure 3). On this view, the beam is tangential to the dorsal and palmar surfaces and should be used to evaluate the joint margins, the cortical surfaces of the phalanges, and the navicular bone. Synovial invaginations in the distal border of the navicular bone, proximal border enthesiophytosis, and distal border fragmentation should be confirmed with this projection.

Dorsal 45° proximal to palmarodistal oblique projection (45° DP): The foot is on a block, with the cassette behind the pastern parallel to the angle of the pastern. The beam is perpendicular to the cassette and centered above hairline. Ensure that the foot is near the back of the block so that it projects backwards and palmar onto the cassette (Figure 4). On this view, the beam is perpendicular to the pastern and tangential to the proximal border of the navicular bone and the medial and lateral surfaces of the phalanges. This projection should be used to evaluate these surfaces, in addition to the joints and subchondral bone of the fetlock and the proximal and distal interphalangeal joints. Normal joints decrease in width from proximal to distal, ie, the metacarpophalangeal (fetlock) joint is the most narrow, followed by the proximal interphalangeal (PIP) joint, and then the DIP joint. If joint-space narrowing is suspected to be positional

Figure 3: A. Well positioned lateromedial radiograph. Palmar processes of the distal phalanx (*) and condyles of the middle phalanx (+) are superimposed almost directly over each other. B. Abnormalities can be seen as dorsal periarticular osteophytes and distal interphalangeal joint effusion (arrow) C. Palmar periarticular osteophyte production on the middle phalanx and navicular bone (small arrow) and irregular margination with mottled opacity of the distal flexor cortex of the navicular bone (arrowhead). This horse has chronic osteoarthritis of the distal interphalangeal joint.



Figure 4: A 45° DP radiograph. The distal interphalangeal joint is slightly wider than the proximal interphalangeal joint. There are enthesophytes in the distal attachment of the collateral sesamoidean (navicular suspensory) ligament (arrows).



(ie, the horse is leaning), the same side of all 3 joint spaces should appear narrow.

Dorsopalmar projection (0° DP): Foot is on the block, and the cassette is behind the foot and block perpendicular to the beam, with the beam parallel to the ground, and centered at hairline (Figure 5). With this view, there is superimposition of the navicular bone on the DIP joint; however, it gives a clearer evaluation of the extensor process of the third phalanx. It can be very useful in the evaluation of the distal attachments of the collateral ligaments of the DIP joint (lysis with chronic injury), hoof balance, and laminitis. If the horse has a toe-in or toe-out conformation, great care should be taken to align the beam with the horse's anatomy. Without alignment of the beam and the distal phalanx, there will be a false impression of hoof imbalance with respect to sole depth.

Dorsal 65° proximal to palmarodistal oblique projection (65° DP or navicular cone-down): Foot is on the cassette tunnel, and extended slightly forward of vertical limb position, with the cassette in tunnel, the beam angle should be between parallel to hoof surface and vertical, and centered at the hairline. For film screen systems, ensure that there is adequate radiographic technique to penetrate the foot, superimposed phalanges, and the navicular bone (Figure 6). On this projection, the beam is positioned so that the DIP joint space, the distal flexor border of the navicular bone, and the distal articular border of the navicular bone are separated. Close inspection of these surfaces should be

Figure 5: A 0° DP radiograph. There is a large round osseous fragment associated with the extensor process of the distal phalanx (arrows). Note that both the proximal and distal interphalangeal joints appear slightly narrow on the lateral aspect of the joint (arrowhead). This is most likely due to the patient leaning to that side.



Figure 6: 65° DP or navicular cone-down radiographs from two different horses. A. There are two separate distal navicular bone borders. 'a' represents the distal articular border and 'b' represents the distal aspect of the flexor cortical margin. There are several enlarged synovial invaginations arising from the distal articular border. The small arrows outline a rounded osseous fragment arising from the lateral, distal flexor border. This fragment is likely within the proximal attachment of the impar ligament. **B.** The navicular bone is slightly well defined but note the complete loss of joint space in the medial aspect of the distal interphalangeal joint (*) (small arrows).

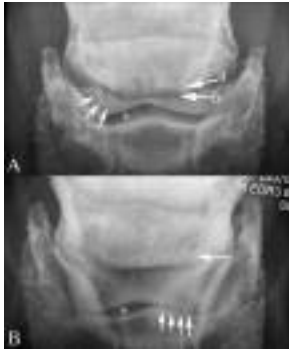


Figure 7: Lateromedial radiograph with lines to demonstrate beam angle for the three commonly used dorsal to palmar projections. Line 1 represents the 45 degree DP projection – note that the beam crosses directly across the proximal border of the navicular bone at the site of attachment of the collateral sesamoidean ligament. Line 2 represents the 65 degree DP projection – note that the beam crosses the distal border of the navicular bone so that the articular surface (black arrow) and the distal flexor cortex (black arrowhead) are separated. Line 3 represents the 0 degree DP projection. This view is useful to evaluate sole depth and the distal attachment sites of the collateral ligaments of the distal interphalangeal joint.



performed. With this projection, the classic synovial invaginations of the distal articular surface and fragmentation of the distal flexor border (impar ligament attachment) are visualized. With multiple DP projections, the important surfaces are highlighted since the x-ray beam is tangential to each surface. Figure 7 is a depiction of the differences in beam angle for each of the views.

Dorsal 65° proximal to palmarodistal oblique projection (solar margin view): The same positioning, beam angle, and beam centre are used for this projection as for the navicular cone-down view above; however, exposure factors are decreased to prevent overexposure of the peripheral margin of the distal phalanx. On this view, the central portions of the foot are generally underexposed, but the peripheral portions of the third phalanx are appropriately exposed, allowing evaluation of the vascular channels and foramina (enlarged with chronic inflammation) and identification of solar margin fragmentation.

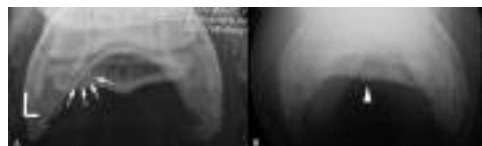
Palmar proximal 50°–65° to palmarodistal oblique projection (navicular skyline): The horse is standing on the cassette tunnel with the limb behind the vertical, the beam angle is approximately 50°–60° proximal, and the beam centre is between the heel bulbs. Beam angle will depend on hoof conformation and how far behind the vertical the distal limb is positioned. When the foot is further caudal, a “steeper” or more proximal angle is required. This radiograph is often difficult to obtain in horses with a clubfoot conformation or when they are very lame due to palmar heel pain (Figure 8). On this projection, the beam is tangential to the palmar or flexor cortex of the navicular bone, allowing evaluation of the bone surface and indirect evaluation of the fibrocartilage covering, navicular bursam, and the DDFT. This projection also allows for the evaluation and confirmation of lucencies identified on other views and evaluation of the corticomedullary distinction that may be obliterated by medullary sclerosis.

Recommended views: At the University of California, Davis School of Veterinary Medicine, a minimum of 5 views are taken to evaluate the foot, including the lateromedial, the 45° DP, the navicular cone-down, the solar margin, and the navicular skyline projections. Other views are added on an “as-needed” basis.

Anatomic knowledge: Variation, present in all horses, precludes the specific prescription of beam angle. Hooves are variable and toe-in or toe-out conformations require radiographers to adjust their approach. Lateral hoof imbalance, underrun heels, and clubfoot conformations also mandate individualized beam angulation. Even the most experienced radiographers will need to repeat views to correct for errors in positioning and beam angle.

Radiographic evaluation: The interpretation of radiographs should be done in a systematic fashion, in an appropriate viewing environment with reduced ambient lighting. Digital radiographs should be viewed on an adequate monitor with digital image review tools such as zoom, window, and level.²⁰ Once the radiographs are available, the overall

Figure 8: Navicular skyline projections from two different horses. A. From the horse shown in Figure 6A. The enlarged synovial invaginations are identified and have a slightly sclerotic margin. The round, osseous fragment arising from the distal flexor surface of the navicular bone is superimposed over the medullary space (arrows). **B.** Navicular skyline projection demonstrates irregularly margined lysis of the flexor cortex of the navicular bone (arrowhead). There is poor corticomedullary definition.



quality should be assessed. Are the views adequate? Are more necessary?

If the study is complete, identification and interpretation of radiographic findings can be performed. This is done very rapidly through pattern recognition by an experienced examiner.²⁰ For the inexperienced observer or an experienced observer searching for new findings, radiographic abnormalities are defined as alterations in size, shape, margination, opacity, and number of anatomic structures of interest. To accurately identify abnormalities, a systematic approach is necessary and the evaluation should include the soft tissues, periosteum, entheses and protuberances, cortices, endosteum, and medullary space of the distal extremity. The evaluation should also include the joint margins and capsular attachment sites and the subchondral bone shelf. Recognizing that radiography is limited in the evaluation of soft tissues and that soft tissue injury commonly occurs within the hoof capsule, particular attention should be paid to the sites of ligament and tendon attachment.

Ultrasound

Ultrasound is a complementary diagnostic imaging test to radiography. While radiographs do not image soft tissues well, ultrasound cannot penetrate tissues with high acoustic impedance such as bone and hoof wall. Ultrasound is a readily available, relatively inexpensive, and invaluable tool in the hands of a patient, trained operator. Ultrasound can be used to evaluate the foot through several acoustic windows, the distal pastern/heel bulb region,²¹ the transcuneal (frog) window,²⁰ and through the dorsal approach to the DIP joint.^{7,22} The dorsal aspect of the DIP joint can be evaluated, including the periarticular bone margins, the proximal portions of the collateral ligaments of the DIP joint, the distal DDFT, the navicular bursa, the collateral sesamoidean ligaments, and the distal sesamoidean impar ligament. Considerations include patient preparation, equipment, and knowledge of topographical anatomy.

Patient preparation: The skin surfaces should be clipped or shaved free of hair. The skin should then be thoroughly cleaned with either soap and water or a solvent such as rubbing alcohol to remove debris and dead skin cells. Ultrasound coupling gel should be applied and worked into the skin surface to remove any gas that is trapped in the outer layers of the skin and remaining hair. In order to use the transcuneal approach, the foot must be prepared in advance by paring the frog down to a thin layer and soaking the foot in water. In California, where the ground is hard and dry, the frog is pared as much as possible and the feet left to soak overnight when a transcuneal ultrasound is indicated.

Equipment: The distal pastern can be evaluated using a linear tendon probe (7.5–10 MHz), with or without a stand-off pad; however, in most horses, the distal portions of the pastern and heel bulb region must be evaluated with a microconvex or curvilinear probe. The probe shape allows the operator to evaluate through the heel bulbs. Most often the probe is oriented distally, since it is difficult or impossible to maintain it perpendicular to the DDFT fibres. In this instance, the operator must use other indicators of a lesion, such as alterations in the size and shape of the tendon rather than changes in echogenicity (Figure 9). With

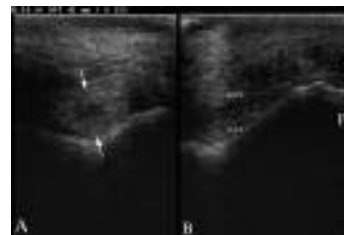
Figure 9: Ultrasound images of the DDFT in the distal pastern region from two different horses. The images are oriented so that medial is to the left and lateral is to the right. ML = medial lobe, LL = lateral lobe of the DDFT, NB = navicular bursa. **A.** The DDFT (arrows) is hypoechoic. The lobes are asymmetric and there is a hypoechoic lesion in the dorsal border of the medial lobe that causes alteration in size, shape and margination (arrowheads). **B.** The medial and lateral lobes are slightly asymmetric but moderate navicular bursa effusion is present dorsomedial and dorsolateral to the DDFT.



the transcuneal approach, a linear or curvilinear probe can be used if the frog is moist enough to allow penetration of cornified tissues. The distal navicular bone and bursa, the impar ligament, and the insertion of the DDFT can be variably evaluated with this approach. Occasionally, very thick or dry soles preclude the use of this window, independent of the preparation (this is often the case in dry climates). Either of the aforementioned probes are appropriate to evaluate the dorsal aspect of the DIP joint. Only the proximal portions of the collateral ligaments are accessible to ultrasound evaluation, particularly with a linear probe and, therefore, the curvilinear probe can prove useful in evaluating these structures (Figure 10).

Ultrasound evaluation: Similar to a radiographic evaluation, an ultrasound examination should be performed in a systematic fashion to ensure the production of high-quality images. Because ultrasound image evaluation is done in real-time, poor scanning technique may result in erroneous diagnoses. The operator should have a reasonable understanding of ultrasound physics, familiarity with probe manipulation, and knowledge of the anatomy before attempting an examination. Generally, tendon and ligament injury is diagnosed by identifying an enlargement of the structure, in addition to a decrease in echogenicity and altered fibre pattern. In the distal pastern/heel bulb region, the probe

Figure 10: Ultrasound images of the lateral collateral ligament of the DIP joint from one horse. **A.** The transverse image demonstrates a central hypoechoic lesion (arrows). **B.** Long axis view of the same ligament demonstrates fibre disruption in the hypoechoic lesion (arrowheads). Pr = proximal.



cannot be oriented perpendicular to the DDFT fibres. As a result, the parenchyma of the tendon is “off-incident” and is, therefore, expected to be uniformly hypoechoic. The ultrasonographer must then rely on other evidence of injury such as alteration in size, shape, margination, or a variation from its normal symmetric appearance. In the other described locations, the principles of soft tissue structure evaluation apply. Distal extremity evaluation should include the synovium and synovial fluid for quantity and quality, as well as alterations in size, shape, fibre alignment, and echogenicity of the other aforementioned ligaments. It is important to perform a detailed, thorough examination using comparisons with the contralateral limb when scanning unfamiliar anatomic regions.

Anatomy: Anatomy of the distal extremity is confusing. The narrow window provided by an ultrasound probe makes the anatomy even more confusing. The importance of using the contralateral limb for comparison and a good anatomy textbook cannot be overstated.

Summary

Diagnostic imaging is of paramount importance when evaluating a horse with lameness localized to the foot. Although limitations exist for both radiography and ultrasound, many abnormalities can be identified and characterized using these tools. These modalities are complementary and routinely used prior to advanced imaging. They have the ability to either identify or estimate the extent of pathology such that, in the absence of advanced imaging, a rational treatment plan and a relatively accurate prognosis can be made. In some cases, other imaging modalities (eg, MRI and CT) are warranted for a more accurate diagnosis, prognosis, and treatment plan.

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