Introduction:
The subject of diagnostic imaging of the fore and hindlimb is broad and of course could fill a textbook. The goal of these proceedings is to discuss common areas of difficulty as well as novel approaches to common imaging exams. These proceedings will also discuss ways in which to improve basic radiographic interpretation, in part by comparing to advanced imaging.

Study parameters:
As we learn more about the limitations of diagnostic analgesia in localizing the lameness to a discrete region, the more we have learned that we need to expand our included imaging range as well as potentially the number of diagnostic blocks performed. Lameness localized to the foot is one of the most common causes of lameness, and therefore one of the most frequently imaged regions. In a patient whose lameness is markedly improved or abolished with a palmar digital (PDN) nerve block, the source of the lameness can range from the sole to the distal fetlock region. Imaging of the fetlock and pastern would be indicated for a horse that responds to an abaxial nerve block, and imaging of the fetlock and entire metacarpus/metatarsus (MC/MT3) would be indicated for a horse that improves with a low-four point nerve block. Of course, in horses that respond partially to one block and partially to another more proximal block, the imaging area expands. Including intra-articular and intra-thecal analgesia does help further refine the area to be imaged, although still often includes imaging of areas beyond the synovial structure of interest. Being aware of the variety of lesions that may occur beyond the traditionally accepted range of lesions can help decrease the likelihood of missing a clinically significant imaging abnormality. Obtaining additional radiographs and performing ultrasound outside the traditional range when no abnormalities are noted during a typical scan is recommended. For example if a patient’s lameness is improved with a low four-point nerve block and no abnormalities are noted in the fetlock and distal cannon region, including the proximal metatarsus/metacarpus is indicated to evaluate for proximal suspensory ligament disease or other more proximal abnormalities. Likewise, ideally, MRIs should be evaluated as being acquired so that additional scanning can be
performed if no significant lesions are noted, rather than risking having to repeat the MRI at a later date to include other anatomic structures.

Diagnostic Imaging of the Forelimb:

Foot:
Similar to many other sources of lameness, lameness localized to the foot is generally initially evaluated using radiography. Radiography provides good bone detail and is a useful, readily available and relatively inexpensive screening tool. However, the more that we learn about pathologic processes in the foot, the more we know that there are significant limitations to what can be diagnosed with radiographs. Normal radiographs do not rule out the presence of disease, and similarly, abnormal radiographs may only show “the tip of the iceberg” in terms of the pathologic processes that are occurring. Any time advanced imaging of the foot is performed, it is useful to compare those findings to the radiographs and/or ultrasound findings. Regularly comparing modalities can markedly improve radiographic and ultrasound interpretation skills. This may mean repeating the study after the exam to see if additional views can help identify the pathologic finding identified with advanced imaging.

A standard radiographic study of the foot should include a horizontal DP, lateral, dorsal 60° palmar (D60P) and skyline view of the navicular bone. Proper positioning is essential for the skyline view, and malpositioning is one of the most commonly made mistakes. Poor positioning can easily create the appearance of medullary sclerosis and loss of corticomedullary distinction. A good way to determine whether a navicular skyline view is properly positioned is to examine the articulation of the dorsal margin of the navicular bone and the palmar aspect of the middle phalanx. If this joint space is clearly defined, then the radiograph is generally correctly positioned. (Figure 1). Additionally, the foot should be adequately cleaned and prepared to limit debris and gas artifact. The lateral view is often overlooked for evaluation of the navicular bone. While less sensitive to changes in the corticomedullary distinction than the skyline view, it is useful to correlate the findings on the two projections. If there is the appearance of sclerosis on the skyline view, but excellent corticomedullary distinction on the lateral view, then there is a greater likelihood that obliquity artifact is affecting the skyline view.

It is important to keep in mind that the flexor cortex of the navicular bone is a curved structure. This means that it is not possible to be completely tangential to all components of the cortex with a single skyline image. Knowing this helps explain why a horse can have a flexor cortex erosion visualized on MRI that is not well visualized radiographically. However, even when the defect itself is not seen, there should be other radiographic indicators of disease, particularly medullary sclerosis and a loss of corticomedullary distinction. (Figure 2) If a flexor cortical erosion is suspected, repeating the image while varying the angle of the beam slightly can change which portion of the cortex is highlighted by the radiograph.

While the deep digital flexor tendon and impar ligament cannot be directly assessed radiographically, there can be osseous changes indicative of disease. Certainly flexor cortex lysis of the navicular bone is often associated with damage to the deep flexor tendon. Other osseous changes include focal lucencies on the distal phalanx, indicative of osseous resorption of the insertion of the impar or deep digital flexor
tendon. These are best appreciated adjacent to the DIP joint space on the D60P view. Additionally, osseous irregularity and sclerosis of the distal margin of the navicular bone can accompany enthesopathy of the impar ligament. Distal border fragments of the navicular bone are vastly underdiagnosed radiographically, but when visualized are often large enough with sufficient adjacent bone change that concurrent impar ligament abnormalities are likely.

Diagnosing osseous resorption of the insertion of the collateral ligaments of the distal phalanx is another radiographic challenge. Depending on the positioning of the image and conformation of the horse, the degree of definition of the fossa will vary. While not essential to good quality radiographs, an upright positioning block (such as wooden slatted block or a Redden navicular block) helps standardize the image positioning and decrease obliquity. Generally the D60P view is the best view for assessing changes to the fossa, although the margins of the fossa are also well visualized on the skyline view if the patient is not wearing shoes. Comparing medial to lateral as well as right to left can help identify changes in the fossa. (Figure 3) Usually horses that have severe collateral ligament injuries will have related swelling at the coronary band, but it is possible for horses to have damage confined to just the fossa, or to the fossa and distal collateral ligament, with no external swelling visible. One of the best ways to improve one’s ability to identify lesions at this site is to compare to MRI or CT findings. If an injury to the collateral ligament fossa is diagnosed with MRI or CT, re-review the radiographs to see if the change in the fossa is visible. Conversely, if a lesion at the fossa was suspected radiographically but is not present on advanced imaging, examine the radiograph carefully to try to determine what may have lead to that appearance. Over time, this will lead to improved ability to detect these changes as well as avoid false positive diagnoses.

Ultrasound is often not included in the work up of a horse that blocks to a PDN, because of the likelihood that the source of the injury is in the foot. Ultrasound can be used between the heel bulbs to evaluate the soft tissue structures in the foot such as the deep digital flexor tendon, navicular bursa and collateral sesamoidean ligament. Additionally, as we know, horses that block to a PDN can have pathologic changes in the pastern region resulting in lameness. Including ultrasonography of the pastern and foot can diagnose lesions in horses that otherwise might have undergone MRI evaluation. The caveat is that even with a skilled ultrasonographer, MRI will generally provide more detail and more complete picture, so that even if a lesion or lesions are identified with ultrasound, an MRI may still be elected. Ultrasounding a horse both before and after an MRI will help improve ultrasound skills and lesion detection.

Pastern:

One of most common reasons for performing ultrasonography of the pastern and distal metacarpu/tarsus is because of effusion of the digital sheath that improves to an intra-thecal block or local analgesia. Sometimes finding the lesion is quite straightforward, but can be elusive as well. Moving beyond the standard approach to the pastern to include oblique angles, on and off angle imaging and non-weight bearing studies improves the likelihood of lesion detection.

Using on and off angle imaging helps define the margins of the tendons and other soft tissue structures as well as characterize the nature of the lesion. Many deep digital
flexor tendon injuries in the pastern region are characterized by lobe enlargement and tearing of the abaxial dorsal margin. The margins of the deep digital flexor tendon should be evaluated from a palmar medial and palmar lateral approach as well as just from palmar to increase the likelihood of detecting the lesion. (Figure 4) Additionally, off angle imaging and non-weight bearing studies improve the ability to outline the tendon margin and detect changes in shape. Resting the horse’s limb on a farrier sling during the non-weight bearing exam works well because generally the horse remains relaxed in this position and it minimizes motion of the limb. (Figure 5). Including off angle and non-weightbearing studies also improves detection of tearing of the manica flexoria in the distal metacarpal/tarsal region. Again, any time it is possible, compare the ultrasound evaluation to advanced imaging findings and/or the results of tenoscopy.

**Proximal Metacarpus and Metatarsus**

Lameness originating from the proximal metacarpus and metatarsus is common in sport horses and Western performance horses. Pathologic changes can be found both in the bone and in the suspensory ligament, and can occur individually, or, more often, in combination. Osseous abnormalities include bone production and resorption at the origin, avulsion fragmentation and bone bruising or osseous contusion. With moderate to severe bone proliferation, DP radiographs will often demonstrate an area of increased opacity of the proximal MC/MT3. In the hindlimb, this is more likely to be seen laterally. Avulsion fragments can sometimes be identified. Care must be taken to not mistake an irregular or coarse trabecular pattern, which can be seen with chronic stress remodeling, with an avulsion fragment. Ultrasound is the ideal method to confirm or evaluate the presence of an avulsion and can even be superior to MRI due to improved contrast between bone and ligament on ultrasound compared to MRI. (Figure 6) Once cortical bone changes have occurred, the bone never fully returns to a normal appearance, even when no longer clinically significant. Nuclear medicine can be used to help differentiate an active process from an old bone injury. MRI provides the advantage of providing excellent bone and soft tissue detail. MRI allows for evaluation of osseous contusions at the origin of the suspensory ligament. These injuries are not uncommon, particularly in Western performance horses, and can occur with minimal associated ligamentous pathologic change.

Due to the complexity of the make-up of the suspensory ligament, ultrasound of this structure can be challenging, in both the fore and hind limbs, although particularly the hind. The presence of fat and muscle fibers results in a heterogeneous appearance and areas of hypoechochogenicity. Making use of on and off angle imaging and including non-weight bearing studies is key to a complete exam. A traditional palmar approach to the fore proximal suspensory ligament does not allow for visualization of the abaxial margins and the true contour is not readily identified. Similarly, in the hindlimb, off-angle non-weight bearing ultrasound evaluation differentiates the margins and tissue types of the suspensory ligament in a way that cannot be fully achieved in the standard exam. In both the fore and hind limb, visualization of the interface between the origin of the ligament and palmar/plantar cortex of MC/MT3 is vastly enhanced with the non-weight bearing examination. (Figure 7). In the hindlimb, a non-weight bearing plantar approach reduces the distance between the probe and osseous margin and allows for the beam to be tangential to the bone. This is the most sensitive approach for detecting bone
resorption, proliferation and osseous fragmentation at the origin of the suspensory ligament. Suspected lesions noted on the long axis approach should be confirmed on transverse images and vice versa. The appearance of the ligament with off-angle ultrasound imaging much more closely resembles the appearance on MRI and allows for better comparison between modalities.

**Tarsus**

Tarsal osteoarthritis is common and often easily identified radiographically. However, it is common to focus on the changes on the dorsal aspect of the joint and on pathologic changes at the articulation of the central and third tarsal bones and third tarsal and third metatarsal bone. However, degenerative changes can occur elsewhere in the distal tarsus as well and should not be overlooked. In particular, degenerative changes between the third and second and between third and fourth tarsal bones can be a significant source of lameness that is often underappreciated radiographically. Similar to the theme throughout these proceeding, comparing tarsal radiographs to MRIs or CTs in which these changes are found can significantly improve radiographic detection of these injuries in the future. Additionally, keeping a collection of normal images is always helpful in improving detection of unusual pathologic changes as well as avoiding misdiagnosing superimposition artifacts as fractures or other abnormalities.

Biarticular slab fractures of the central tarsal bone often occur in a dorsomedial to plantar lateral oblique configuration. (Figure 8) Horses with these fractures may present with an acute onset of severe lameness that typically improves with rest to a grade 2 or 3/5. Tarsocrural joint effusion is often present, and the horse typically improves with analgesia of the distal intertarsal joint. Often there is moderate to severe sclerosis of the central tarsal bone, which may predispose the horse to fracture. The standard set of tarsal radiographs generally are not tangential to the fracture line and therefore these fractures are easy to miss radiographically. If such a fracture is suspected, obtaining a DMPLO image that is oblique approximately 60 degrees from lateral rather than 45 improves the likelihood of detection.

**Stifle**

Compared to the distal limb, imaging of the stifle is limited. Radiography and ultrasound remain the mainstay. CT arthrograms and in some cases MRI can be performed, but these options are still limited at this point in time.

Most commonly osteoarthritis of the medial femoral tibial joint is noted by the presence of periarticular tibial osteophytes. However, osteophytosis commonly affects the medial femoral condyle as well. These abaxially located periarticular osteophytes are often more easily appreciated with ultrasound rather than radiography. However, by regularly comparing ultrasound and radiography findings, radiographic detection of femoral condylar osteophytes improves. Additionally, periarticular osteophytes of the medial femoral condyle can occur axially as well, in the intercondylar fossa. These osteophytes are well-visualized with arthroscopy, and again, by continually comparing arthroscopic findings to radiographic evaluation, detection rates will improve.

Ultrasonography of the stifle allows for excellent assessment of the intra- and periarticular soft tissues. Not all portions of the medial meniscus can be visualized arthroscopically; therefore, ultrasound is an important partner to arthroscopy to provide
the most complete diagnostic visualization of the joint. In particular, tears of the medial meniscus located in the mid body may not be seen arthroscopically unless the tearing radiates to the cranial or caudal horn. It is important to realize that failure to visualize meniscal damage arthroscopically does not preclude the presence of a tear. Conversely, visualization of articular cartilage defects without adjacent subchondral damage, including thin fissures or diffuse fibrillation is poor with ultrasound in comparison to arthroscopy. This further emphasizes the need for a multi-modality approach to imaging the stifle.

Summary

In conclusion, the accuracy of diagnostic imaging improves with a dynamic, “think outside the box” approach. Expanding the normal range of a scan, including multiple approaches to ultrasound examinations and utilizing multiple radiographic projections increases the likelihood of lesion detection as well as a more complete clinical picture. Comparing multiple modalities, including other diagnostic imaging modalities, surgical results and post mortem findings is one of the best ways to continue to improve imaging skill.
Figure 1:
A well positioned navicular skyline view. The articulation of the navicular bone and middle phalanx is distinct (red arrow). The cortex and medulla of the navicular bone are well-defined and there is minimal superimposition of debris or gas artifact. There is normal curvilinear lucency within the mid-central eminence. A laterality marker is in place.
Figure 2: A) Skyline view of the navicular bone. There is marked trabecular sclerosis with decreased corticomedullary distinction. An ill-defined lucency is present in the mid-central eminence, but discrete cortical disruption cannot be seen. B) Sagittal PD weighted MRI image. The navicular bone is severely sclerotic and contains a large cyst-like flexor cortical lesion on the distal aspect. The more distal location of this lesion likely is the reason that the complete cortical disruption is not captured radiographically.
Figure 3: D60P radiograph of the right forefoot. There is increased lucency with a surrounding rim of sclerosis in the area of the lateral collateral ligament fossa of the distal phalanx when compared to the medial. On MRI the patient had resorption of the fossa as well as severe damage to the distal aspect of the collateral ligament.

Figure 4: Palmar lateral (left-hand image) and palmar medial (right) transverse ultrasound images at the level of P1A in the pastern. A focal dorsal margin abaxial tear is noted on the lateral aspect of the deep digital flexor tendon. This tear was difficult to see on the standard palmar images.
Figure 5: A farrier stand helps stabilize the limb for the non-weight bearing exam
Figure 6: Transverse non-weight bearing ultrasound and PD-weighted MR images of the proximal hind suspensory ligament at the same level. A focal chronic osseous body is well visualized as an area of hyperechogenicity in the dorsal lateral aspect of the proximal suspensory ligament on the ultrasound. This structure is difficult to appreciate.
on MRI because both the osseous fragment and ligament are of relatively low signal intensity, resulting in poor contrast between the tissue types.

Figure 7: Transverse non-weight bearing images of the proximal suspensory ligament. Image A is the lame right forelimb and image B is the left forelimb for comparison. Note the marked osseous irregularity and focal avulsion fragmentation of the palmar cortex of MC3 in image A (long arrow) versus the smooth bone margin in image B. Both of the suspensory ligaments are moderately enlarged with palmar displacement of the fat and muscle bundles (short arrow).
Figure 8: Transverse PD MR image of the tarsus. An obliquely oriented slab fracture extends through the central tarsal bone. The central tarsal bone is sclerotic.