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Diseases of the front feet are the most common cause of lameness in horses. A survey of 43,500 lame horses in general veterinary practice in the UK in the early sixties, found the foot to be the cause of the lameness in over 30% of horses. A more recent study estimated that the navicular bone alone was responsible for approximately one-third of chronic lameness in horses. Lameness associated with the fetlock region is also extremely common in horses. In a recent survey of causes of lameness in different horse breeds, synovitis or osteoarthritis of the metacarpophalangeal joint was consistently listed as one of the 10 most common causes of lameness in all categories of Sport Horses surveyed. The diagnosis of lameness depends primarily on a detailed clinical evaluation, including careful analysis of response to regional analgesia, but it is then necessary to choose the most appropriate imaging modality (or modalities) to use to make a final diagnosis.

Clinical Examination
A methodical approach to clinical examination of the distal portion of a horse’s limb should include step-by-step careful visual evaluation, digital palpation, application of hoof testers, measurement of the response to physiological stress tests (i.e., flexion, extension, torque) and evaluation of the effect of different ground surfaces, flexion, circling, and direction-of-going on the degree of lameness.

The foot is an intricate organ with specialised epidermal and dermal structures, 3 synovial cavities, 2 tendons, 6 ligaments and 3 bones as well as many other related structures. A thorough appreciation of the anatomical detail of this organ is an absolute requirement for understanding and interpreting the clinical and imaging observations made during the course of an examination.

The astute clinician hopes that he can gain insights from a detailed examination into the exact location and cause of the horse’s lameness, and this is to be encouraged. Even though clinical signs can be highly
indicative of some foot diseases, however, it is worth remembering that many foot problems share similar clinical signs.

**Visual inspection**
The human eye finds symmetry esthetically more pleasing, and therefore, asymmetry is often readily detected. Anatomical symmetry is generally taken as a measure of soundness. Symmetry is disturbed by swelling, atrophy, deformation, and changes caused by stresses of asymmetrical loading. Visual evaluation of the distal portion of the limb relies heavily, therefore, on recognition of asymmetry between the lateral and medial aspects of the same limb and between contralateral limbs. Asymmetrical morphology of the feet is usually acquired as a consequence of chronic lameness resulting in decreased weight-bearing in the lame limb. The relatively overloaded (i.e., sound) foot acquires a more shallow toe angle, as well as a larger circumference of the solar margin and a larger width of the hoof. The relatively underloaded (i.e., lame) foot becomes more upright (i.e., steeper angle of the toe and heel) and narrow (i.e., smaller width and smaller circumference of the solar margin). This asymmetry, once acquired, remains present for a long time, even after the original lameness has resolved.

A subjective visual impression of swelling is often best validated by including objective measurements in the examination protocol. A simple measuring tape can produce objective figures that can be compared to the contralateral limb or used as reference values for comparison during follow-up examinations. It can be surprising how measurements of perceived swelling compare poorly to the subjective clinical observation. The distal portion of the limb is visually inspected with the horse standing squarely and bearing weight evenly on both front limbs. Subsequently, the limb is lifted, the foot cleaned, and the integrity of the palmar structures of the foot evaluated. Visual highlights and external deformities that should be detected during this part of the examination include dorsopalmar and lateromedial foot imbalances, traumatic or surgical scarring of the skin, bony exostoses, suspensory ligament branch injuries, bowed tendon (i.e., SDFT at the fetlock, SDFT branches or DDFT in the pastern), desmitis of the annular ligaments, joint and digital flexor tendon sheath swelling, hoof wall defects and deformities (e.g., growth rings, false quarters, grooves, hoof cracks, pyramidal deformation), infections of the sole, frog and frog clefts, and quitter
Digital palpation
To appreciate any deviation from the normal anatomy by careful digital palpation of the anatomical landmarks of the distal portion of the limb, the examiner has to be thoroughly familiar with the normal anatomical features and their incidental variations. When a finding is suspicious, the limb in question should be compared with the contralateral limb.

A methodical digital examination of the distal limb proceeds from distal to proximal, first with the limb weight-bearing, then with the limb lifted, always looking for swellings, defects, temperature changes, and other irregularities. It starts with assessment of the temperature of the hoof wall, the coronary band and the heel bulbs with the palm or the back of the hand. Be aware that the hand can detect temperature differences of 1.5° C and above.

The coronary band is evaluated for its consistency, presence of focal softening or depressions. The amount of filling of the dorsal joint pouch of the DIP joint is estimated from its fluctuation under digital pressure. The palpable elevation at the origin of the collateral ligaments of the DIP joints, which are situated approximately at 10 and 2 o’clock around the circumference of the coronary band (with 12 o’clock being at the dorsal aspect of the sagittal plane of the foot), should be symmetrical. The elasticity of the collateral cartilages is compared between lateral and medial and between left and right feet. The skin over the dorsal aspect of the pastern joint should be freely mobile over underlying structures (i.e., joint capsule and periosteum).

There should be an obvious, palpable, proximodistal concave groove between the palmarolateral (medial) margin of the proximal phalanx and the lateral (medial) border of the digital flexor tendons between the level of the base of the proximal sesamoid bones and the middle scutum. Disappearance of this groove due to soft tissue filling may indicate the presence of distal sesamoidean desmitis or tendonitis of a branch of the SDFT. Horses should not resent focal percussion of the dorsal cortex of the proximal phalanx.

There should be no palpable swelling, either fluctuant or fibrous, of the metacarpophalangeal joint capsule. Swelling of the metacarpophalangeal joint is best assessed over the dorsal aspect of the joint, immediately proximal to the dorsoproximal margin of the proximal phalanx, and over the palmarolateral and palmaromedial joint pouches that are situated proximal to the apex of the sesamoid bones and dorsal to the insertion of the lateral and medial branches of the suspensory ligament. Similarly, there should be no palpable swelling of the digital flexor tendon sheath.
The landmarks for palpation of the presence of fluctuant filling of the digital flexor tendon sheath are its palmarolateral and palmaromedial pouches proximal to the sesamoid bones, palmar to the insertion of the branches of the suspensory ligament and dorsal to the lateral and medial margins of the flexor tendons. In addition, the palmarodistal pouch should be evaluated over the distal palmar aspect of the pastern, immediately proximal to the heel bulbs. The palmar silhouette of the pastern and fetlock regions is outlined by the annular ligaments and should be smooth and free of swellings or indentations. The lateral and medial branches of the suspensory ligament should be smooth, symmetrical in thickness, pain-free on digital pressure, and the overlying skin should be freely mobile. Focal digital pressure over bony prominences of the margins the metacarpophalangeal joint or over the proximal sesamoid bones should not elicit pain. The presence of digital pulses should be assessed at the level of the proximal sesamoid bones and over the medial palmar artery in the proximal to middle third of the metacarpal region. Digital arteries can be enlarged without pulsation, or pulsation can be present with varying degrees of enlargement. An increased digital pulse is a good indication of the presence of inflammation in the distal portion of the limb.

With the limb lifted, the stability of heel bulbs should be assessed by grasping each heel bulb with the left and right hands and determining whether movement occurs between the two. The neurovascular bundle should be palpated on either side of the DDFT in the distal palmar aspect of the pastern. The skin should be freely mobile in the distal palmar aspect of the pastern, the palmar surface of the DDFT should be flat, smooth, and pain-free when focal pressure is applied. There should be no palpable synovial fluid present in the palmar distal pouch of the digital flexor tendon sheath. The normal angle of flexion of the fetlock is approximately 110° to 120° and should be identical in both forelimbs. Forced flexion of the metacarpophalangeal joint should not be resented.

**Hoof testers**

The use of hoof testers enables the examiner to rule out the presence of peripheral foot pain associated with the hoof wall, sole, dermal tissues, and digital cushion. The knowledge of abnormal sensitivity in the dorsal or palmar aspect of the sole of the foot is especially important when considering the differential diagnosis of structures desensitised by various diagnostic anaesthetic techniques in the foot. The use of hoof testers for identification of navicular pain is controversial, but
generally considered to be unreliable. Examination using a hoof tester is conducted in a methodical fashion, applying focal pressure to the sole and wall in a circumferential movement from the lateral heel across the toe to the medial heel. After exploring the sole, the testers are placed across each side of the frog and the opposite hoof wall. Both hands should be on the testers, and the foot should be immobilized between the knees. The degree of response to application of hoof testers is determined by the size of the testers, the size of the foot, the thickness of the sole, the demeanour of the horse, the amount of pressure applied by the examiner, and finally, the presence of disease. It is important to develop a sense for what is normal variation between horses and for a particular horse and responses between contralateral feet should be carefully compared. In one study, the hoof tester examination had a sensitivity of 45%, a specificity of 50%, a positive predictive value of 50% and an accuracy of 48% for the identification of navicular pain.4

**Physiological stress tests**

Distal limb flexion tests have been used for many years to localize pain to the region of the fetlock. Even though flexion tests result in exacerbated lameness in most horses with intra-articular disease of the metacarpophalangeal joint, lameness caused by many diseases of the foot and the pastern will be equally exacerbated. In addition, the response to a fetlock flexion test is dependent on the force and time used to perform this test.5,6 Flexion tests can and should be standardized for time and force (Flextest®).5 One study found the optimal force for a flexion test to be 100 N for a duration of 1 minute.5 A slightly positive flexion response (100 N/1 min) in a horse with no other clinical signs or radiographic abnormalities had no clinical significance.5 Other investigators showed that most clinically sound horses have a (slightly) positive flexion test of the distal portion of the limb and that the results of the flexion test increased significantly with age.7 This observation and the lack of long-term consistency of the test cast doubt on the presumption that a positive flexion test may be an indication for the presence of subclinical joint disorders and question the possible value of the test as a predictor of future joint-related problems.7 Lameness following a fetlock flexion test is more likely to be clinically significant if the response is markedly different between contralateral limbs.

Extension and flexion tests of the DIP joint and navicular apparatus are performed by placing a 15-20° wooden wedge under the foot resulting in either toe elevation or heel elevation for a period of 1 minute.
Alternatively the foot can be placed on one side of a plank, the other side of which is gradually elevated by the examiner to produce the similar effect. Toe elevation increases strain in the DDFT, navicular suspensory ligaments and impar ligament, and elevates the compressive force on the navicular bone. Nevertheless, toe elevation tests only have a sensitivity of 55% and a specificity of 42% for the presence of navicular pain. Heel elevation reduces strain in the DDFT, impar ligament and navicular suspensory ligament but increases direct impact pressure on the heels. In spite of this, Turner found that heel elevation has a sensitivity of 76% and a specificity of 26% for the presence of navicular pain. It has been my observation that many horses with lesions of the DDFT (as identified on MRI), experience worsening of lameness after heel elevation.

Lameness
As a general rule, pain originating in the distal portion of the limb causes a supporting limb lameness (or impact lameness), as opposed to a swinging limb lameness (or propulsion lameness), characterized by the exaggerated downward motion of the head and neck when the sound (i.e., contralateral) limb strikes the ground. Lameness caused by pain in the distal portion of the limb tends to be worse when the horse is trotted on hard ground than when the horse is trotted on soft ground and is often more noticeable when the horse trots in a circle. Lameness is usually worse when the lame limb is on the inside of a circle than when it is on the outside of a circle.

Specific foot diseases
Even though many foot problems share similar clinical signs, correct interpretation of clinical signs may be helpful in the location of some specific foot diseases.

Navicular bone disease can occur in all types of horses of all ages, but is more common in horses older than 7-9 years of age and uncommon in ponies. Clinical signs are often insidious at first. Lameness may first become apparent after a period of enforced rest or a change in management, shoeing or ownership of the horse. In the presence of navicular bone disease, horses may experience resting pain that leads to pointing of one front foot, sometimes alternating between feet. This may also be seen in horses with DDFT tendinopathy. Occasionally, horses with navicular pain are seen to pack bedding under the heel of the foot. A wide variety of foot shapes is seen in horses with navicular disease:
narrow, upright feet, feet with low and collapsed heels, or normal, well-balanced feet. If lameness is consistently worse in one foot, feet may become asymmetrical in shape though this is not typical for navicular disease. Digital vessels may be enlarged but this is also not specific. Response to hoof tester application to the sole and frog is usually negative. An increase in intra-articular pressure and distension of the coffin joint has been described in horses with navicular disease. Lameness associated with navicular bone disease varies from shortening and reduced lift of the stride to overt unilateral lameness. Stumbling is fairly typical. The earliest abnormalities experienced by the rider may be a loss of forelimb action before overt lameness becomes visible. Lameness may fluctuate and vary between examinations. Horses with navicular disease frequently move better on soft surfaces, even when trotting in circles. Lameness is typically accentuated on hard surfaces, especially when the horse is circled with the lame limb on the inside. Distal limb flexion usually causes a mild to moderate increase in lameness but marked pain on flexion or a marked exacerbation of lameness are not typical for navicular pain. Occasionally horses with navicular pain may be seen to become lame in the contralateral forelimb following a flexion test. This can also occur in horses with DDFT tendinopathy. Elevation of the toe with a wedge or a wooden board may accentuate lameness, but this test is neither highly sensitive nor specific for navicular bone pain.

Lameness caused by tendinopathy of the DDFT occurs predominantly in mature horses between 5 and 14 years of age. No breed predilection has been reported though some authors believe there to be an association with jumping. The duration of lameness prior to MRI evaluation varied from 1 month to 3 years. Approximately 50% of horses with DDFT tendinopathy are presented with an acute onset, moderate to severe lameness while the other 50% experience a more insidious progression of lameness. Some horses are presented for poor performance evaluation and may not show lameness when trotting in a straight line, particularly if they have been stall rested. There are generally no visual or palpable abnormalities that indicate the presence of an injury of the distal portion of the DDFT as the cause of lameness. Occasionally distension of the digital flexor tendon sheath is present in horses with a lesion that extends proximally to the level of the sheath. Even more rarely, a focal, firm soft tissue swelling can be appreciated on the palmar aspect of the DDFT in the palmarodistal aspect of the pastern in horses with a lesion that
extends proximally to the level of the digital flexor tendon sheath. Very occasionally pain can be elicited by applying firm, deep finger pressure to the palmar surface of the DDFT in the most distal aspect of the pastern between the heel bulbs. Flexion and extension tests of the digit produce variable results and the response is not specific for tendonopathy. Paradoxically, a heel-elevation test with a wooden wedge of 15-20° may result in marked exacerbation of lameness. Lameness in horses with DDFT tendinopathy in the foot may vary substantially in severity, both between horses and historically within individual horses. It is generally accentuated by hard work and improves with rest. Many horses experience intermittent episodes of severe lameness and some may be seen pointing the affected foot intermittently at rest. Lameness when trotting in a straight line has been graded between 0/10 and 6/10. However, all horses are lame when trotting in a circle on hard ground, especially when the affected limb is on the inside of the circle. Rarely lameness may be worse when the affected limb is on the outside, possibly because the medial lobe of the DDFT is affected rather than the lateral one. Paradoxically, some horses with DDFT injury appear to be more lame on soft ground with the affected limb on the outside of the circle, but this is uncommon. Approximately 70% of all horses with distal tendinopathy are only lame in one limb, while the remaining 30% are bilaterally lame. The presence of bilateral lameness may only be detected after regional analgesia of the lamer limb.

Collateral desmopathy of the coffin joint may occur in all breeds or disciplines but again horses used for jumping appear to be at an increased risk. Knowledge of an acute injury is rarely reported in the history. In one report, however, almost 20% of horses diagnosed with collateral desmopathy had a history of being treated for a foot abscess prior to referral for diagnosis. Most horses with collateral desmopathy or enthesopathy do not display any localizing signs. Distension of the dorsal pouch of the coffin joint may be present but is not a characteristic finding. A discrete, palpable swelling may occasionally be found at the level of the origin of a collateral ligament, immediately proximal to the dorsomedial or dorsolateral aspect of the coronary band. The medial collateral ligament is injured almost twice as often as the lateral collateral ligament. In a small proportion of horses, both the lateral and medial collateral ligaments are affected. Some authors report that pain cannot be induced by passive manipulation of the digit in horses with collateral desmopathy of the coffin joint. In the opinion of others however, horses
with collateral desmitis are prone to react painfully to digit flexion performed with the examiner pulling on the toe of the hoof capsule while facing caudally while horses with collateral enthesopathy are less likely to resent digit flexion. Although the heel wedge test and the reverse (toe) wedge test are not specific for collateral ligament injury, placement of the wedge under the foot in the lateromedial plane, so that the lateral or medial side of the foot is elevated tends to cause marked exacerbation of lameness associated with collateral desmopathy. When lameness is exacerbated by a transverse wedge test, desmopathy can be suspected on the side of the foot that was lowered by the wedge.

Horses with collateral desmopathy or enthesopathy are typically presented with mild to moderate foot lameness of more than 2 months duration that has all the hallmarks of palmar foot pain or ‘navicular syndrome without radiological abnormalities’. Occasionally a horse may be presented with an acute onset, moderate to severe lameness but this is rather atypical. Lameness is usually mild when the horse is trotted in a straight line but invariably worsened when trotting in a circle. Lameness is further worsened when circling is performed on hard ground, especially when the lame(r) limb is positioned on the inside of the circle. This set of circumstances results in severe valgus stress on the coffin joint of the inside limb and therefore compression of the lateral collateral ligament and elongation of the medial collateral ligament. This elongation has been proposed as the inciting mechanism for strain injury of the collateral ligament. As medial collateral desmopathy is reportedly more common than lateral collateral desmopathy, it follows that most horses will be more lame with the affected limb on the inside of the circle. Paradoxically however, at least one report reports lameness due to collateral desmopathy as being worse when circling in soft ground with the limb on the outside of the circle. Approximately 33% of all horses with collateral desmopathy are only lame in one limb. Another third of horses shows obvious signs of bilateral lameness while yet another third of horses only shows evidence of mild contralateral lameness when regional anaesthesia is performed on the lame(r) limb.

Primary coffin joint pain is often associated with unilateral or bilateral distension of the dorsal joint pouch. This dorsal outpouching can be palpated on the distal dorsal aspect of the pastern. Ballottement of joint fluid in the dorsal pouch may be possible, or the swelling may be firm and fibrous when chronic capsulitis is present. Pain is present on distal limb flexion, but the response is usually less marked than in horses with
metacarpophalangeal joint pain. All types of foot imbalance may be associated with primary coffin joint pain. Lameness may vary from low-grade stiffness with shortening of the stride in horses with bilateral synovitis, to severe lameness in horses with acute, unilateral sprain-type trauma or advanced osteoarthritis. As for other causes of foot lameness, lameness is usually worse on a circle, especially on a hard surface

**Suggested Readings:**

**Take home message:**
A careful examination of the distal limb can help to gain insight into the exact location and cause of a horse’s lameness. However, it is important to develop a sense for what is normal variation in anatomy and in response to stress tests and to compare responses between contralateral feet. In addition, it must be remembered that many foot problems share similar clinical signs.
Until recently, there was little scientific basis for interpreting response to various techniques of diagnostic analgesia of the digit. As a result, some diseases, such as navicular disease, were often over-diagnosed, and others over-looked. Recently, some clinicians began to question long-held beliefs concerning analgesic techniques of the foot, especially that analgesia of the DIP joint localized pain to that structure or that a palmar digital nerve block (PDNB) localized pain to the palmar half of the foot. Within recent years, many studies have examined the response to diagnostic analgesia of horses lame because of pain in a particular structure or region of the foot. Clinical observations, anatomical studies, magnetic resonance images of feet of horses with lameness caused by foot pain, and results of clinical trials that created pain in certain structures of the foot have helped to clarify interpretation of the results of regional, intra-articular, and intra-bursal analgesia of the foot of horses. These studies have also highlighted the limitations of diagnostic analgesia of the horse’s digit. In this paper, we present a summary of current knowledge of the use of analgesia to localize sites of pain within the digit of lame horses.

**Choice of local anesthetic**

Although many clients have an expectation that the source of pain causing lameness can be identified during a single examination, identification of the source of pain within a foot may involve using different techniques of perineural or intra-articular analgesia requiring multiple examinations. When multiple examinations are anticipated, the
choice of local anesthetic solution may be important. Use of 2% lidocaine in such cases may allow for more frequent examination because the analgesic effect of lidocaine is shorter than that of 2% mepivacaine. The length of analgesic effect of lidocaine or mepivacaine is not well documented perhaps because the length of analgesic effect may depend on the degree of pain causing lameness\textsuperscript{1}. The analgesic effect of lidocaine and mepivacaine is claimed to be 90 to 180 minutes and 120 to 180 minute, respectively, by some authors\textsuperscript{1,2}. According to Wyn-Jones (1988)\textsuperscript{3}, however, the analgesic effects of these drugs is less; lidocaine and mepivacaine, when administered perineurally, have an anaesthetic effect of only 30 to 45 minutes and 90 to 120 minutes, respectively. Andreen et al. (1994)\textsuperscript{4} found that the analgesic effect of mepivacaine lasted only 55 minutes when treating endotoxin-induced synovitis of the middle carpal joint. Lidocaine is more irritating to tissue than is mepivacaine which may make it less desirable for use in the lower portion of the limb\textsuperscript{5}. For the authors the inflammatory effects of lidocaine preclude its use in joints of the lower portion of the limb. Intra-articular use of 2% lidocaine may also be undesirable because it has been shown \textit{in vitro} to be significantly more chondrocytotoxic than 2% mepivacaine\textsuperscript{6}. Experimentally, perineural administration of 2% or 3% ketamine HCl in isotonic saline solution or bicarbonate solution at the base of the proximal sesamoid bones resulted in 15 to 25 minutes of analgesia\textsuperscript{7,8} indicating that this short-acting drug may prove useful for lameness examination when used as a local anesthetic when multiple techniques of local anesthesia are anticipated. The authors, however, are unaware of reports concerning the clinical value of ketamine HCL for regional anesthesia in the horse.

\textbf{The palmar digital nerve block}

A positive response to anesthesia of the palmar digital nerves of lame horses was once believed to localize pain to the palmar third or half of the foot, including the palmar aspect of the DIP joint\textsuperscript{9,10}. These beliefs were obviously the result of misinterpretation of desensitization of the palmar portion of the coronary band that occurs after a palmar digital nerve block and desensitization of the entire coronary band that occurs after anesthesia of the dorsal branches of the palmar digital nerve (that result from either an abaxial sesamoid nerve block or a pastern ring block). Many clinicians believed that the palmar digital nerves should be anesthetised near or distal to the proximal margin of the collateral cartilage to avoid anesthesia of the dorsal branches of the palmar digital
Easter et al. (2000) found, however, that anesthesia of the palmar digital nerves just proximal to the bulbs of the heel alleviated lameness caused by endotoxin-induced pain in the DIP joint, indicating that the palmar digital nerves innervate the entire DIP joint. According to this study and results of an earlier anatomic study, the dorsal branches of the palmar digital nerve are unlikely to contribute much more than sensory innervation to the dorsal aspect of the coronary band and dorsal laminae of the foot. A more important reason for depositing local anaesthetic solution as far distally in the pastern as possible when performing a PDNB is that more proximal deposition of local anesthetic solution increases the likelihood of causing analgesia of the pastern joint. When a 0.5- x 16-mm (25-ga, 5/8-in) needle is inserted over the palmar digital nerve one centimeter proximal to the proximal edge of the cartilage of the foot and directed distally local anesthetic solution is likely deposited at or slightly distal to the level of the palmar border of the pastern joint, because the height of the collateral cartilage in relation to the level of the palmar region of the pastern joint is probably similar for most horses. The likelihood of inadvertently desensitizing the pastern joint (and thus misinterpreting the result of a palmar digital nerve block) increases when reassessment of gait after the nerve block is delayed. The first re-evaluation of lameness can begin five minutes after administering regional analgesia in the distal portion of the limb. Wyn-Jones (1988) advised rapid assessment of gait after regional analgesia of the distal portion of the limb because rapid diffusion of anesthetic solution could anesthetise other nerve branches, thus confusing results of the examination. Radiopaque contrast medium deposited perineurally at the base of the proximal sesamoid bones was found to have travelled a significant distance proximally along the neurovascular bundle within 10 minutes after administration. Deposition of local anaesthetic solution outside the fascia surrounding the neurovascular bundle has been offered as an explanation for a delay in desensitization of a region. A clinician would likely have no idea as to whether or not a delay in resolution of lameness after a nerve block was due to proximal migration of local anesthetic solution with eventual inadvertent desensitization of more proximal structures or if delay in resolution of lameness was because of deposition of local anesthetic solution outside fascia surrounding the neurovascular bundle.

By performing unilateral anesthesia of the palmar digital nerve at different times it may be possible to localize pain to either the medial or
lateral aspect of the foot. In such cases, amelioration of lameness associated with navicular disease or disease of the DIP joint would be highly unlikely, lameness associated with a wing fracture of the distal phalanx or unilateral solar or hoof wall diseases would be more likely to improve significantly.

**Intra-articular analgesia of the DIP joint**

Similar to the palmar digital nerve block, intra-articular analgesia of the DIP joint using five to 10 ml of local anesthetic has limited value in localizing pain within the foot. Local anesthetic administered into the DIP joint desensitises that joint\(^15\), the navicular bursa\(^16\), the navicular bone\(^17,18,19\) and its suspensory ligaments\(^20\), the toe region of the sole\(^21,22\) and the distal portion oft he deep digital flexor tendon (DDFT) of most horses\(^23\). When a large volume of local anesthetic (e.g., 10 mL) is administered, the heel region of the sole may also be desensitized\(^22\). Not all horses lame because of DIP joint pain respond positively to intra-articular analgesia. Intra-articular analgesia may relieve pain caused by disease of periosteal and capsular soft tissue, but when joint disease involves subchondral bone, pain may not resolve with intra-articular analgesia\(^24,25\). Because subchondral bone is innervated by nerves that enter the bone marrow via the nutrient foramen, anaesthesia of nerves proximal to branches that enter the nutrient foramen may be necessary, in some cases, to resolve joint pain and lameness. Perineural anaesthesia of the palmar digital nerves proximal to the origin of the branches that enter the nutrient foramen of the middle phalanx may be necessary to resolve lameness caused by subchondral bone pain of the DIP joint.

Although local anaesthetic solution administered into the DIP joint has been shown to diffuse into the navicular bursa and bone\(^26,27\), we believe that the likely explanation for desensitization of the navicular bone and its supporting ligaments by local anesthetic solution administered into the DIP joint is the desensitization of sensory subsynovial nerves to he navicular bone and its ligaments\(^28\) and the desensitization of the palmar digital nerves where they lie in close proximity to the palmar pouch of the DIP joint\(^29,30\). Schumacher et al. found that anesthetic solution administered into the DIP joint causes desensitization of the toe region of the sole and, occasionally, desensitization of the palmar aspect of the coronary band, findings that support the theory that analgesia of the DIP joint causes desensitization of the palmar digital nerves\(^22,31\). However, if the theory that local anesthetic solution within the DIP joint anesthetizes the palmar digital nerves at a site proximal to the branches that supply
innervation to the navicular bone and its associated structures is correct, then it is hard to reconcile this theory with the finding that 21% of horses that failed to respond to intra-articular analgesia of the DIP joint improved significantly after analgesia of the navicular bursa, unless that subset represented horses with uncharacteristic neuroanatomy\textsuperscript{18}. Nevertheless, if the theory is correct for most horses, failure to ameliorate lameness after intra-articular anesthesia of the DIP joint can likely exclude disease of the navicular bone or bursa or toe region of the sole as a cause of lameness. Turner (1996) concluded that navicular disease can be excluded as a cause of lameness if gait is not improved after blocking the DIP joint\textsuperscript{19}. If a large volume (e.g. 10 mL) of local anaesthetic is administered into the DIP joint without amelioration of lameness then pain in the heel region of the sole can also likely be eliminated as a cause of lameness\textsuperscript{31}.

**Intra-bursal analgesia of the navicular bursa**

Significant amelioration of lameness after administration of local anaesthetic into the navicular bursa indicates disease of the bursa, the navicular bone, and/or its supporting ligaments\textsuperscript{18}, solar toe pain\textsuperscript{31}, or disease of the distal portion of the DDFT\textsuperscript{32}. Even though analgesia of the DIP joint results in analgesia of the navicular bone\textsuperscript{17} or bursa\textsuperscript{16}, analgesia of the navicular bursa does not result in analgesia of the DIP joint\textsuperscript{18,32,33}. Analgesia of the navicular bursa may help to differentiate pain associated with disease of the DIP joint from pain associated with disease of the navicular bone and associated structures. Clinical\textsuperscript{19,32} and experimental\textsuperscript{21,22} observations indicate that a positive response to intra-articular analgesia of the DIP joint and a negative response to intra-bursal analgesia of the navicular bursa localize pain within the DIP joint as the cause of lameness. This clinical observation is valid if solar pain as a cause of lameness can be eliminated with hoof testers\textsuperscript{21,22}.

One possible explanation for the observation that analgesia of the DIP joint causes analgesia of the navicular bursa but analgesia of the navicular bursa does not cause analgesia of the DIP joint is that the site of direct contact between the palmar pouch of the DIP joint and the palmar digital nerves is located proximal to the origin of the deep branches that innervate the DIP joint and the navicular bursa, whereas the site of direct contact between the navicular bursa and the palmar digital nerves is located distal to these branches.

Some clinicians once assumed that improvement in lameness observed within 10 minutes after injection of the DIP joint with local anaesthetic
solution indicates that lameness is caused by pain in the DIP joint alone and that improvement observed more than 10 minutes after injection is caused by diffusion of local anaesthetic solution into the navicular bursa or around the nerves providing sensory innervation to the navicular bone and its associated structures. This assumption appears to be invalid because a positive response to intra-articular analgesia of the DIP joint has been observed to occur within 5 to 8 minutes of injection in a majority of horses with navicular disease or experimentally-induced navicular bursal pain. Based on results of his neuroanatomical studies Bowker (2007) concluded that much of the navicular apparatus and the insertions of the distal sesamoidean impar ligament and deep flexor tendon will be anesthetized within seven to nine minutes of direct analgesia of the DIP joint.

Results of experimental studies indicate that the effect of intra-articular analgesia of the DIP joint or of intrabursal analgesia of the navicular bursa on lameness should be assessed soon after injection (i.e., within 5 to 10 min) because after this time, the structures that become desensitized by diffusion of the anaesthetic solution become uncertain.

**Analgesia of the digital flexor tendon sheath (DFTS)**

Pain induced in the toe and heel regions of the sole, pain associated with synovitis of the DIP joint, and pain associated with synovitis of the navicular bursa are not significantly attenuated by intrathecal analgesia of the DFTS. It is logical, therefore, to assume that direct analgesia of the DFTS does not anesthetize the palmar digital nerves, but rather desensitizes only structures that are contained within or border on the sheath itself (i.e., the superficial and deep digital flexor tendons, the straight and oblique distal sesamoidean ligaments, the annular ligaments of the fetlock and pastern, and the portion of the DDFT that lies within the foot).

An ASNB abolished or improved lameness localized to the foot in all of 46 horses found to have a significant lesion in the digital portion of the DDFT using MRI. A PDNB, analgesia of the DIP joint, or analgesia of the navicular bursa, however, each ameliorated lameness in about two-thirds of these horses. Because lameness caused by disease of the DDFT within the foot may fail to improve significantly after analgesia of the palmar digital nerves, the DIP joint, or the navicular bursa, we believe that a portion of the DDFT within the foot and distal to the DFTS receives its sensory supply from more proximal deep branches of the medial and lateral palmar digital nerves that enter the DFTS.
Improvement of lameness in horses with lesions of the DDFT within the foot after intrathecal analgesia of the DFTS has been described\textsuperscript{37}. Because the palmar digital nerves are not anesthetized by blocking the DFTS\textsuperscript{36,38}, blocking the DFTS directly may be a technique that can be used to diagnose digital flexor tendinitis without the use of magnetic resonance imaging\textsuperscript{38}. Performing intrathecal analgesia of the DFTS in horses with lameness that is unchanged after anesthesia of the palmar digital nerves but resolves after an ASNB, may be useful. Resolution of lameness after intrathecal analgesia of the DFTS justifies suspicion of a lesion within the digital portion of the DDFT or within structures contained within the DFTS.

**Suggested readings:**


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**Take home message:**

It may be possible to determine which structure within the foot is the site of pain responsible for lameness by using various techniques of perineural or intra-articular analgesia at different times.
Introduction

During the last years, tremendous advances in veterinary radiography have been performed, not in terms of diagnostic capability, but in terms of radiographic technology. Since the introduction of the first clinical computed radiography (CR) system in 1983 by Fuji Medical Corporation, the use of digital radiography has grown rapidly in equine veterinary medicine since 2000. During the first years of this numerical revolution (2000-2003), digital radiography was mainly represented by either expensive high quality systems coming from the human medicine or by lower cost equipments from the veterinary field. After 2005, higher performance CR systems were introduced in equine imaging at a more reasonable price. During the last years, equine radiography has seen the introduction of the first Direct Digital Radiography (DDR = DR) systems. Despite their higher cost, these last systems have attracted veterinarians due to the possibility of seeing immediately the radiographic image. Today, either Computed Radiography (CR) or Digital Radiography (DR) replaces conventional radiography in most equine practices. If numerous books and papers present the technical aspects of conventional imaging, only few studies describe the technical and practical use of CR and DR systems and their settings for optimizing the diagnostic quality of radiographs. Thus the purposes of this paper are 1. to present the different types of digital radiographic equipments available; 2. to describe the quality parameters of digital radiographs compared to those used for assessing conventional radiographs and 3. to discuss the practical use of these systems. Because evaluation of the foot is the most frequent radiographic examination in the horse, this region
will be used as a typical example. Nevertheless, comparison with other body parts will also be discussed to improve the understanding of the practical and optimized use of equine digital radiography.

1. Equipments available in equine digital radiography

Two main types of digital radiographic systems (Körner et al. 2007) are available today for equine imaging which differ mainly by the image acquisition process:

✓ Computed radiography (CR):

CR systems use flexible imaging plate (IP) containing photosensitive phosphors (typically barium fluorohalide crystals doped with europium) for image capture. This IP functions like conventional film / rare-earth screen combinations and are placed in a rigid custom cassette for protection.

→ CR image processing stages

During the X-ray exposure, the photostimulable phosphors of the IP absorb and store the X-ray energy without emitting light. Thus, a latent image is formed in the IP (Fig 1).

![Fig 1: General principle of CR imaging. PM tube = Photomultiplier tube.](image)

This latent image is then revealed by placing it manually or automatically in an IP reader. In the reader, the IP is scanned with a helium-neon laser. Due to the additional energy of the laser beam, the energy stored in the IP is released in the form of visible light. The emitted light is collected through a light guide and gathered by a photomultiplier tube. At this stage, this light is an analog signal representing the number of X-rays received by the photostimulable phosphors. After amplification, this analog signal is converted into digital data by an analog-to-digital converter and finally, a digital image is obtained. For instance, an image with a matrix of 1576 x 1976 pixels storing 12 bits (= 4096 grey levels) per pixel is obtained for a 24 x 30 cm cassette. But this raw image is not
the **radiographic image** sent to be either displayed on a computer or printed on a film (Fig 1).

The main advantage of CR is to be a multispeed system. This allows CR systems to correct for overexposure or underexposure of the IP. The sensitivity of the IP reading is determined at this stage either automatically (**Auto Mode**) or manually (**Fixed Mode**). This **sensitivity of reading** is characterised by a number, called for instance as “S” number in Fuji systems or “Exposition class” in Agfa ones. In the Auto Mode, an algorithm compares automatically the exposure of the IP to the ideal exposure of the IP to X-rays. The IP reader compensates for the differences by changing its sensitivity in order to obtain an image with a correct density. The amount of compensation applied is given by the value of the reading sensitivity. In the Fixed Mode, the reading sensitivity is set manually by the operator depending of the body part radiographed and of exposure parameters (kV – mAs). If the Fixed Mode is used, programs dedicated to the body part to be examined are generally implemented in the IP reader.

Once the sensitivity value determined, the raw image is transformed into an image with a lower size. For instance, the raw image storing 12 bits (4096 grey levels) per pixel is converted into an image storing 10 bits (1024 grey levels) per pixel. Consequently, some data are lost at this stage. Nevertheless, most recent CR IP readers store during a few days the raw image extracted from the IP. Thus, a new processing algorithm can be applied to the raw image if the first algorithm was inadequate. In other words, the reading sensitivity of the system can be modified to obtain an image with a correct density.

Before sending the image to the computer or to the printer, other processing algorithms are generally applied to optimize major image parameters such as contrast adjustments and degree of edge enhancement. In contrast to the reading sensitivity which can be changed only in the IP reader, this postprocessing can be modified on the diagnostic workstation.

The final step in the IP reader is to erase the IP for reuse. This is accomplished by scanning the IP with an intense white light to release any residual energy stored in the IP. The IPs can be reused up to 10 000 times without loss of image quality.

- **Digital radiography (DR):**
  Numerical radiography can also be performed using a flat-panel detector. This recent technology is also called direct digital radiography (**DDR**)
because the detector is connected by a cable, and more recently by Wi-Fi, to a computer. Thus, the radiographic image is obtained on the computer screen immediately after the X-ray exposure of the patient. Detectors can be classified in 2 types depending of the technology used to produce the radiographic image:

**direct converting detectors:** contain a photoconductive layer composed of amorphous selenium (a-Se) that directly converts X-rays to electrical charges. Thin film transistors (TFT) placed beneath the selenium photoconductive layer are then responsible for the read-out of these charges. The TFT array covers the entire detector surface in a matrix that corresponds to pixels viewed on the computer screen. These different layers are housed in a rigid cassette connected directly to the imaging computer hardware.

**indirect converting detectors:** contain a scintillator in the top layer of the flat panel which converts x-Rays into visible light (as rare-earth screens in conventional radiography). A diode layer made of amorphous silicon (a-Si) placed immediately beneath the scintillator transforms the energy of this visible light into electric charges. These charges are then send to the computer by a TFT array as previously described for the direct detectors.

Two main types of scintillator are used: either Gadolinium Oxide Sulfide (GOS or Gd2O2S) which is used in conventional x-ray intensifying screen or Cesium Iodide (CsI). The advantage of CsI-based scintillators is that the crystals can be shaped into 5–10 μm wide needles, which can be arranged perpendicular to the surface of the detector. This structured array of scintillator needles reduces the diffusion of light within the scintillator layer. As a result, thicker scintillator layers can be used with CsI compared to GOS, thereby increasing the strength of the emitted light and leading to better optical properties and higher quantum efficiency (DQE) without altering the spatial resolution of the system. The DQE (Detective Quantum Efficiency) is one of the main characteristic of digital radiographic systems in terms of image quality: this parameter representing the efficiency of a system in converting the incidental x-rays into an image signal.

**Digital chain concept:**

If CR and DR systems are the main part of an equine digital radiographic system, others components of the digital chain should also be considered because the diagnostic performance of one system is limited by its weakest element:
diagnostic workstations: radiology viewing software offers usually numerous tools to improve image reading such as controls for window level and width (analogous to contrast and brightness), pan and zoom, flip, rotate, measuring tools and different postprocessing methods. If these tools may correct for errors performed during the image acquisition (ie: exposure factors), the diagnostic performance of a system remains always strongly dependent of the raw radiographic image quality. High quality workstation monitors are also important to optimize the diagnostic performance and medical grade, gray scale monitors have increased resolution, bit depth, and luminance compared with color monitors (Puchalski 2008). Finally, high ambient lighting effectively decreases the luminance of the monitor through reflection, which in turn decreases the overall contrast ratio of the monitor, making low contrast details more difficult to see. This remark is particularly important to consider when veterinarians perform radiographic interpretation in the field with high ambient lighting. These poor reading conditions may affect significantly their diagnosis.

DICOM standard and PACS: the Digital Imaging and Communications in Medicine (DICOM) standard (today DICOM 3.0) describes both the structure of images and image data, and the communication mechanisms that two devices use to share this data and information. DICOM informations are important to consider when digital radiographs are sent by internet or CD/DVD to other veterinarians for second opinion consultations. DICOM data are also at the basis of archiving using PACS systems. Picture Archive and Communication System (PACS) are now more widely used in equine veterinary practices and their ability to electronically transmit data to an appropriate storage medium and to remote sites for consultation, review, or formal interpretation should be considered when purchasing such systems.

2. Quality assessment of digital radiographs and associated settings of digital equipments

The quality of a digital radiographic image is dependent of 2 main factors: the signal to noise ration (SNR) and its dynamic range.

- Diagnostic quality of digital radiographs:
The diagnostic quality of a digital radiograph depends mainly from the equipments used (power of the X-ray generator, intrinsic quality of the CR or DR system) but also from the settings used in these systems. Consequently, it is essential that veterinarians learn how to optimize their
digital systems in order to obtain the highest diagnostic performance. If numerous papers and books present the method for conventional radiography, only few studies describe the approach for digital radiography. Moreover, processing and postprocessing applied to digital radiographic images make the quality assessment more complicated compared to conventional radiography. Nevertheless, the 4 steps used in conventional radiography are also the basis for determining the best settings of a digital radiographic system: 1) opacity or signal to noise ratio (SNR) assessment; 2) contrast evaluation; 3) sharpness and spatial resolution assessment and 4) artifacts.

The **SNR** of a digital radiograph can be compared to its density in conventional radiography. The SNR represents the ratio between the useful signal (that is the incidental x-rays) and the noise of the image arising mainly from random variations in the number of x-rays inside the incident x-ray beam (quantum noise) and the electrical and electronic noises. The noise can be identified in a digital radiograph by the grainy appearance of the thicker or more dense parts, that is the bony parts. The noise will become more visible particularly for underexposed radiographs.

In conventional radiography, the **dynamic range** of screen-film is represented by a S shaped curve within a narrow exposure range for optimal film blackening (Fig 2). Thus, the film has a low tolerance for an exposure that is higher or lower than required, resulting in failed exposures or insufficient image quality.

![Fig 2: Relationship between exposure and density (blackening) for conventional film-screen and CR systems.](image)

The dotted line represents the characteristic curve of a conventional film-screen system: underexposure creates a white image et overexposure generates a dark image. The IP of CR systems has a greater dynamic range (continuous line). Thus, radiographic