Localization of Pain in the Equine Foot
Emphasizing the Physical Examination and Analgesic Techniques

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An astute clinician can gain insight into the location and cause of a horse’s lameness by carefully examining the feet. Even though many foot problems produce similar clinical signs, careful physical examination of the foot may provide clues as to which method of perineural or intrasynovial analgesia is likely to be the most helpful in localizing the source of pain. By using different techniques of digital analgesia, a clinician may be able to determine the structure within the foot that is the source of pain. As well as identifying a specific lesion that is the cause of pain and lameness, it is equally important to identify poor foot conformation that may precipitate foot pain. Authors’ addresses: Equine Sports Medicine Program (John Schumacher) and Department of Clinical Sciences (Taylor), College of Veterinary Medicine, Auburn University, Auburn, AL 36849; Equine Clinic, National Veterinary School of Lyon, 69280 Marcy L'Etoile, France (Schramme); and Department of Large Animal Clinical Sciences, College of Veterinary Medicine, University of Tennessee, Knoxville, TN 37996 (James Schumacher); e-mail: schumjo@auburn.edu. *Corresponding author; †Presenting author. © 2012 AAEP.

1. Introduction
Although the incidence of various causes of equine lameness may vary with breed and use of the horse, abnormalities of the foot are the most common cause of lameness in horses, and if a foot abnormality is not a direct cause of lameness, the abnormality may initiate lameness elsewhere in the musculoskeletal system.1–7 Because hoof conformation is closely correlated to the forces applied to the equine foot, physical examination for lameness should begin by visually inspecting the foot.8 Visual examination is often followed by palpation of the hoof/digit, by applying a hoof tester, by examining the horse in motion, by administering flexion and extension tests, then localization of lameness via diagnostic analgesia.

2. Visual Inspection of the Foot
Because many horses not experiencing lameness have distorted hoof capsules, it is important to distinguish between functionally sound feet and feet with hoof capsule distortion that is often associated with lameness.9 Constant observation of abnormal hooves may blind the clinician to hoof abnormalities that may affect soundness.

NOTES
Symmetry
Visual evaluation of the distal portion of the limb relies heavily on recognition of asymmetry between the lateral and medial aspects of the same limb and between contralateral limbs. The human eye finds symmetry aesthetically more pleasing, and therefore, asymmetry is often readily detected. Digital asymmetry (laterality, high/low syndrome, mismatched feet, mild club foot) may be acquired as a consequence of decreased weight bearing caused by asymmetrical movement,\textsuperscript{3,10,11} asymmetrical tension of tendons,\textsuperscript{9} and pain.\textsuperscript{12} The relatively overloaded (i.e., initially more sound) foot acquires a shallower angle of the dorsal hoof wall, low or under-run heel (Fig. 1) and lower palmar angle (angle of the solar margin of the distal phalanx relative to the ground surface), as well as a larger circumference of the solar margin and a wider hoof. In the relatively underloaded (i.e., lame or short-strided) limb, the foot becomes more upright and narrow (Fig. 1) with a higher palmar angle.\textsuperscript{9} Once acquired, this asymmetry may remain even after the original lameness has resolved. Resolving the asymmetry requires efforts toward restoring equality of load distribution between limbs. Although it is not always associated with lameness, asymmetry of the equine hoof should not be overlooked as an indication of previous, impending, or chronic lameness.\textsuperscript{13} In one study, mismatched hoof angles occurred with equal prevalence in sound and lame horses, indicating that this type of asymmetry is not always associated with current lameness.\textsuperscript{14} We are not aware of any studies that have assessed the consequences of mismatched feet of mature, sound horses.

Coronary Band
Hair on the coronary band should lie flat against the hoof capsule; hair projecting horizontally (Fig. 2) may indicate excessive ground-reaction force on the associated hoof wall and may be correlated to pain within the foot. When viewing the foot from the side, a healthy coronary band should be nearly straight with only a mild proximally directed arch (Fig. 3). The coronary band is dynamic, and its shape can be affected by chronic overloading.\textsuperscript{15} A coronary band with a proximally directed arch at the quarters is evidence of chronic overloading of the quarters (Fig. 4). A coronary band that bends distally in the heel to become nearly vertical (Fig. 5) is an indication that the foot has a poorly developed heel. Asymmetry of the height of the coronary band in the heel region on one side is commonly known as a “sheared heel”, which is defined as instability between medial and lateral bulbs of the heel\textsuperscript{15} and often a hoof capsule distortion resulting in proximal displacement of one quarter/heel bulb.
relative to the contralateral side of the foot. The medial heel bulb/quarter is more commonly displaced proximally because it is more common for the foot to be offset laterally. This asymmetry of the heel region is important to note because it often indicates medial-lateral imbalance during loading and predisposes the horse to a spontaneous quarter crack on the side of the foot that has been displaced proximally. Sheared heels often have a "fissure" between the heel bulbs in which a chronically moist environment favors the development of thrush. Sheared heels can be present without causing lameness.

The angle of the coronary band can be used to estimate the position of the distal phalanx within the hoof capsule. One study described the angle of the coronary band of apparently normal front feet to be $23.5 \pm 3$ degrees. We believe that the angle of a normal coronary band is probably about 20 to 25 degrees relative to the ground (Fig. 3). If the coronary band angle is $>30$ degrees, the horse is likely to have a negative palmar/plantar angle (Fig. 6), and if the angle of the coronary band is $>45$ degrees, the horse undoubtedly has a negative palmar angle.

At the other extreme, a coronary band parallel to ground (as viewed from the side) is indicative of a high palmar angle, which is often associated with a club foot or distal rotation of the distal phalanx (Fig. 7). The coronary band angle and the solar angle of the distal phalanx (palmar angle) are correlated with the distal interphalangeal joint moment arm (DIP MA) (DIP MA is alternate terminology for DIP torque) and the force exerted by the deep digital flexor tendon (DDFT) on the navicular bone. The calculation of internal distal limb forces during stance phase has been described. The force applied to the navicular bone before and after corrective shoeing is calculated and depicted by the red arrows of different size in Fig. 8. As the coronary band angle increases or the solar angle of the distal phalanx (palmar angle) decreases, both the DIP MA and the force exerted by the deep digital flexor tendon on the navicular bone increase. In our opinion, assessing solar angle of the distal phalanx by examining the coronary band is easier in hind feet than in front feet. A hind foot with a negative solar angle (plantar angle) will have a growth ring pattern that is wider at the toe than at the heel and a line imagined along the coronary band slope and extended forward will strike the front leg above the carpus or even the chest or abdomen rather that at the carpus or below. A distally directed arch in the coronary band in the dorsal portion of the foot may indicate remodeling of the distal phalanx (Fig. 9).

**Hoof Wall**

The normal healthy hoof wall should be smooth, have a light sheen, and be free of flares, cracks, and prominent growth rings. Formation of growth rings has been reviewed by Rooney. Growth rings are horizontal ridges of the hoof capsule that are formed by tubular horn distortion that occurs when perfusion of the coronary corium is altered by
changes in diet, exercise, or by systemic disease. Wall growth is generally inversely related to hoof loading.\(^{15,23}\) When growth of the wall becomes retarded as the result of uneven circulation, alterations in growth ring width are evident at the proximal margin of the hoof capsule (Fig. 10). We believe that narrow growth rings in some areas indicate that circulation of the coronary corium has been decreased in that region (Fig. 11). A region of the hoof with narrowed growth rings (suggesting altered/uneven circulation) has most likely been receiving nonuniform or excessive ground-reaction force because wall growth is generally inversely related to load.\(^{23}\) A hoof that exhibits growth rings that are narrower in some regions (Fig. 11) probably has chronic overload of the hoof wall in the region of narrow rings. Narrow growth rings are commonly seen in the toe region of horses with chronic laminitis because the dorsal region of the corium is usually the area most poorly perfused, a result of compression of dorsal coronary corium, solar plexus, and dorsal laminar vessels caused by rotation of the distal phalanx.\(^{24}\) In our experience, narrow growth rings are often found in the medial quarter of the forefeet of athletic horses presented for lameness evaluation. The coronary band of these horses is usually displaced proximally similar to the coronary band of horses with sheared heels and is probably caused by similar unequal distribution of vertical forces,\(^{17}\) which may be accentuated by conformation or mediolateral imbalance. For horses with proximal displacement of the coronary band in either region, lameness may resolve after administering only the medial portion of an abaxial sesamoid nerve block, suggesting that abnormally localized forces on the hoof wall may be a source of pain.

The presence of hoof wall flares or cracks is often caused by chronic, excessive overloading of the hoof wall in the region where these defects are found.\(^{16,19,25}\) Cracks in the quarter are more likely to be a cause of lameness than cracks in other regions because the quarter is thinner than other regions, making a quarter crack more likely to involve the dermal layers of the hoof.\(^{25}\) Horizontal cracks (Fig. 12) are usually the result of a disruption of production of horn caused by coronary band trauma or when subsolar infection opens (“graves out”) at the coronary band. These cracks are seldom a cause of lameness.\(^{25}\)

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Fig. 6. Observation of the steep coronary band angle (29 degrees) of this horse correctly predicted that the plantar angle would be zero or negative in his right rear foot. Also note the broken hoof/pastern axis that is frequently associated with this conformation. The third image is an overlay of the radiograph over the photo of the distal limb created using Adobe Photoshop® software.

Fig. 7. Observation of a coronary band nearly parallel with the ground prompted a correct prediction that the palmar angle of this horse’s front foot would be relatively high [i.e., 14 degrees (middle image)]. The third image is an overlay of the radiograph over the photo of the distal limb created using Adobe Photoshop® software.
Frog

The frog is highly dynamic, and its morphology changes relative to current hoof demands and terrain. The width of a healthy frog should equal 50% to 66% of its length. The frog of a healthy hoof has sufficient depth at its dorsal aspect to reach the bearing surface. If this portion of the frog does not engage the ground, fibrocartilage in the palmar portion of the foot develops poorly or atrophies. The central sulcus should be wide and shallow so that the index finger or ring finger fits easily into it. Contracture of the central sulcus is commonly observed. Contraction of the central sulcus can create an anaerobic environ-

Fig. 8. These images represent radiographic overlay of the same foot before (A) and after (B) a shoeing change/reset. Note that the coronary band angle has decreased from 24 to 20 degrees, the palmar angle has increased from 1 to 8 degrees, and the pastern-distal phalanx axis has been straightened by 8 degrees by the reset. The force exerted by the DDFT on the navicular bone as represented by the size of the red arrows has also decreased in magnitude after the change/reset. These images were created using Adobe Photoshop® software by Dewey R. Wilhite from original images supplied by DRT; technical assistance on calculations was provided by Randy Luikart, CJF.

Torque = 500 kg × 0.06 cm × sine 35° = 17.1 m.kg

\[ F_{nav} = 2|F_{DDFT} \times \cos (\alpha/2)|; \text{where } \alpha = 123 \]

\[ F_{nav} = 2[10 \text{ N/kg} \times \cos (123/2)] \]

\[ F_{nav} = 2[10 \text{ N/kg} \times 0.477] \]

\[ F_{nav} = 9.54 \text{ N/kg} \]

Fig. 9. The photo on the left shows a coronary band “dipping” lower at the dorsal hoof wall (black arrow) than in the quarters (red arrow) in a horse with chronic laminitis. The radiograph of the same foot shows substantial bone remodeling. The solar margin of P3 has acquired the shape of a “banana,” and there is a “ski tip” at the dorsal rim.

Torque = 500 kg × 0.06 cm × sine 27° = 13.5 m.kg

\[ F_{nav} = 2|F_{DDFT} \times \cos (\alpha/2)|; \text{where } \alpha = 125 \]

\[ F_{nav} = 2[10 \text{ N/kg} \times \cos (125/2)] \]

\[ F_{nav} = 2[10 \text{ N/kg} \times 0.462] \]

\[ F_{nav} = 9.24 \text{ N/kg} \]
ment that is ideal for development of thrush (Figs. 14A–F). When the frog tissue entrapped by the contracted sulcus becomes infected, the dermis at the deepest aspect of the sulcus often becomes eroded. The horse may exhibit lameness and show significant signs of pain when the sulcus is cleaned with a hoof pick. The pain caused by thrush in the central sulcus may cause some horses to land toe first to avoid loading the inflamed soft tissues of the heel. Landing toe-first may cause the heel to contract and atrophy more, perpetuating the infection and lameness.

The relationship of the untrimmed frog to the sole indicates the position of the distal phalanx within the hoof capsule (i.e., the palmar angle). For instance, if the apex of the frog is deeply recessed and the frog appears to be angling toward the coronary band at the toe, the distal phalanx is probably similarly positioned, having a negative palmar angle.

Fig. 10. Examination of the hoof surface can give an indication of its overall health and growth rate during previous weeks to months. In the image on the left, the dry and scaly hoof surface can be an indication of retarded hoof growth. Note that the dorsal aspect of this hoof (black arrow) has a slightly wider growth ring and a more normal, smooth surface. The narrower growth ring (red arrow) is associated with the dry and scaly side of the hoof.

Fig. 11. Note the divergent growth rings, in the foot in the image on the left, that are commonly found in horses with chronic laminitis. The middle image shows narrow growth rings in the medial quarter of a horse with chronic laminitis. The image on the right shows smooth new growth that resembles an “earthworm” (black bracket) proximal to an invaginated growth ring (black open arrow). The red bracket shows a region that was previously thinned to help stimulate the upper new growth. The upper new growth (black bracket) is a positive prognostic sign of improved hoof perfusion compared with the recent past.

Fig. 12. A horizontal hoof crack is usually the result of disruption of the production of horn caused by coronary band trauma or when a subsolar infection opens (“gravels out”) at the coronary band.
Collateral Grooves or Sulci

The depth of the collateral grooves may provide an accurate anatomical reference for predicting the relationship between the internal and external structures of the foot and the bearing surface because the depth of the collateral grooves is not altered by any method of hoof care, whereas the plane of the frog can be altered by a hoof knife. Foot structure that can be predicted based on characteristics of the collateral grooves includes depth of sole, distance of the distal phalanx from the bearing surface, and the palmar/plantar angle. Based on dissection studies of the foot, there appears to be a constant relationship between the collateral grooves and hoof conformation/structure. The collateral grooves apparently run parallel to and a fixed distance (10 to 11 mm) from the solar surface of the distal phalanx in the dorsal half of the foot and the same...
distance from the collateral cartilages in the palmar half of the foot. In the healthy foot with adequate depth of sole, the collateral groove at the apex of the frog is 10 to 20 mm from the ground. This indicates that the distal phalanx is positioned an adequate distance from the ground, because the concave aspect of the distal phalanx is positioned 10 to 11 mm proximal to the deepest part of the collateral groove (point A, Figs. 15 and 16). We are currently conducting studies to validate these observations.

The orientation of the dorsal aspect (front half) of the collateral groove in relation to the ground plane parallels the position of the distal phalanx in the hoof capsule. Collateral grooves of some horses have a stair-step or undulating shape where the groove dips or curves to become substantially deeper in the heel region (Fig. 17). We believe that collateral grooves that exhibit this type of conformation are an indication of poor development of the internal structures of the heel. A foot that has collateral grooves with this deep curvature in the heel region should be examined radiographically to confirm digital alignment and orientation of the distal phalanx to the ground (palmar angle). Horses with a negative palmar/plantar angle typically have a long to low heel conformation and a shallow digital cushion. For horses with this type of conformation, the combined thickness of the frog and digital cushion is less than 2 inches and the heel bulbs can be easily distracted. Many lame horses with negative plantar angles do not block sound to the foot because this conformation may be associated with pain in the hock, suspensory ligament, and lumbar region.

**Heels**

During examination of the foot, the “heel base” of the hoof capsule, the collateral cartilages, and the digital cushion should be evaluated. The “heel base” of the hoof capsule includes the hoof wall, the buttress, angle of the sole, and the bars. The heel tubules should be straight and have an angle of incidence with the weight-bearing surface similar to the tubules in the toe region. Ideally, the most palmar extent of the bearing surface of the heel tubules would be at the base of the frog and very near a vertical line drawn thru the middle of the third

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**Fig. 15.** This image was rendered in Autodesk ® 3dsMax®. Original 3D data were derived from dicom images using Materialise Mimics Software®. The hoof capsule is partially translucent in this image so that internal structures can be visualized. Point A indicates the deepest aspect of the collateral grooves at the apex of the frog. Point B indicates the point on the solar surface of the distal phalanx that is directly proximal to the deepest aspect of the collateral grooves at the apex of the frog (point A). The consistent distance (10 to 11 mm) between these two points allows the clinician to predict distal phalanx orientation. The collateral groove depth (point A to the ground plane) in this foot is sufficient to allow space for adequate sole depth in the toe region. If one imagines moving the ground plane proximally so that the distance from the ground plane to point A is zero mm, it becomes clear that sole depth decreases as collateral groove depth decreases. Image created by Dr. Ray Wilhite, Department of Anatomy and Physiology, CVM, Auburn University.
metacarpal/metatarsal bones. Many podiatrists describe under-run heels as those that are \( \geq 5 \) degrees lower than the toe angle.\(^{18}\) O'Grady, however, emphasized the relationship of the foot to the metacarpal/metatarsal bones when determining if the heels are under-run.\(^{33}\) He considered heels positioned well forward of the line drawn through the middle of the third metacarpal/metatarsal bones to be under-run.\(^{33}\) Under-run heels that grow forward toward the widest part of the foot often collapse under the weight of the horse, causing heel tubules to run nearly ground parallel. The bars and the angle of the sole may be crushed and deformed as a consequence of the severely under-run heel. One author (D.R.T.) has observed that horses with under-run or collapsed heels generally have thin (less than 2 inches\(^{\text{3}}\)) digital cushions that are easily deformed with finger pressure.

**Solar Proportionality**

When viewing the solar aspect of a healthy hoof, the ground surface should be approximately as wide as it is long (Fig. 18).\(^{28}\) This creates a relative proportion from the front of the foot to the palmar aspect that is related to alignment of the center of articulation (of the distal interphalangeal joint) in the middle of the foot, or when shod, the middle of the shoe.\(^{35}\) The normal solar surface of the foot may be wider laterally than medially.\(^{28,32}\)

![Fig. 16](image1.png)

Fig. 16. The image on the left depicts point A as the deepest point of the collateral grooves at the apex of the frog. The hoof capsule has been made partially translucent in the image on the right so that point B can be visualized on the solar surface of the distal phalanx. Image created by Dr. Ray Wilhite, Department of Anatomy and Physiology, CVM, Auburn University.

![Fig. 17](image2.png)

Fig. 17. Note that the collateral groove of this hind foot of a 4 year-old Thoroughbred racehorse is deeper at the apex of the frog (red arrow) than it is at mid frog (white arrow), which indicates that the position of the palmar aspect of the palmar processes of the distal phalanx is lower than the dorsal rim (i.e., the foot has a negative plantar angle). Also note that the collateral groove curves inward to be deepest under the heel region (blue arrow). This conformation of the collateral groove indicates a “weak” or “underdeveloped heel.” Horses with this collateral groove conformation usually have thin digital cushions and heel bulbs that are easily distracted. The lateral radiograph of the same foot confirms the presence of a negative plantar angle and a broken hoof/pastern axis (even though the slight obliquity in this radiograph makes it difficult to determine the exact plantar angle, the plantar angle is definitely less than zero). Photos courtesy of HoofSolutions™.
The healthy sole tends to be callused and between 10 to 15 mm thick\textsuperscript{33} beneath the distal rim or tip of the distal phalanx. The sole must be at least 10 mm thick to protect the distal phalanx from trauma associated with impact.\textsuperscript{9,33} A ruler calibrated in millimeters can be placed within the collateral groove to measure the distance between the deepest part of the groove and the plane of the outer perimeter of the sole (Fig. 19). We believe this measurement predicts the height at which the distal phalanx is suspended above the bearing surface of the foot and can be used to predict solar depth. It is not uncommon to find horses in which the depth of the collateral grooves measured at the apex of the frog is essentially zero millimeters from the ground (i.e., no space). This may indicate that at the apex of the frog (which is normally about 2 cm behind the tip or distal rim of the distal phalanx in the nonlaminitic foot), the bone on the midline is only 10 mm proximal to the bearing surface. Considering that the distal phalanx is concave, the sole of these horses becomes thinner from the apex of the frog peripherally toward the tip or distal rim of the distal phalanx. As an example of this, one of the authors (D.R.T.) has observed that flat-soled horses that have zero collateral groove depth at the apex of the frog, generally have less than 7 mm of solar depth at the tip or distal rim of the distal phalanx (Fig. 19A).\textsuperscript{33a} The distal rim of the distal phalanx is predisposed to trauma when the sole is less than 10 mm.\textsuperscript{9,33} Over time, the traumatized distal phalanx remodels and takes on a rounded appearance on the lateral radiographic projection (Fig. 20B). After this happens, solar depth may appear to be closer to normal when measured, but this is due to bone resorption. Feet with shallow collateral grooves are predisposed to solar bruising, subsolar infection, remodeling of the distal phalanx, and even rim fractures of the distal phalanx due to lack of solar depth and/or concavity of the sole. The opposite situation is true of feet with deep collateral grooves at the apex of the frog. These feet have sufficient solar depth and/or solar concavity to elevate and protect the distal phalanx from the trauma associated with impact.

3. Digital Palpation of the Foot
The examiner should be thoroughly familiar with the normal anatomical features of the digit and incidental variations to appreciate any deviation from the normal as determined by digital palpation. When a finding is suspicious, the region of the limb in question should be compared with that of the contralateral limb. A methodical digital examination of the distal portion of the limb proceeds from distal to proximal, first with the limb weight-bearing, then with the limb lifted, always looking for swellings, defects, variations in temperature, and other irregularities. Examination by palpation starts with assessment of the temperature of the hoof wall, the coronary band and the heel bulbs by using the palm or the back of the hand. The hand can detect temperature differences in tissue of 1°\textsuperscript{36} to 1.5°C. Elevated temperature of a foot may indicate the presence of inflammation, subsolar infection, or the prodromal stages of laminitis. Decreased temperature of the coronary band may indicate poor perfusion of the coronary corium as often occurs with subacute-chronic laminitis once the lamina have failed and coronary corium is being crushed by weight bearing against the unstable hoof capsule or severe, mediolateral imbalance in which case the corium will be cooler on the overloaded side of the foot. Some clinicians and hoof-care professionals use inexpensive infrared thermometers to increase their ability to objectively evaluate temperature of the hoof and coronary band, but efficacy of
prominent ledge or depression in the coronary band indicates that the distal phalanx is located deeper than normal within the hoof capsule. Horses with this palpable abnormality at the dorsal aspect of the coronary band usually have excessive distance between the coronary band and the extensor process. In our experience, a palpable depression in the coronary band is usually accompanied by other digital abnormalities that can be found during physical examination, such as a thin, flat, sole with a shallow collateral groove at the apex of the frog, a narrow, contracted frog (which may have a contracted central sulcus), a narrow heel, and a narrow distance between the collateral cartilages. The dorsal aspect of the coronary band and the region immediately proximal to it should be palpated for effusion in the dorsal pouch of the DIP joint. Effusion in the dorsal pouch is an indication of synovitis, which is claimed to be a significant cause of foot pain in some performance horses.4,37,38 Effusion in the DIP joint, however, can also be a nonspecific finding because it can be caused by mechanical stress/forces and often it is not associated with lameness. Distension of the DIP joint is also occasionally observed in horses with navicular disease.39

Heel

In recent years, inadequate development of fibrocartilage in the palmar/plantar portion of the foot has been recognized as a precursor to tissue injury and lameness.30,40 Horses with underdeveloped heels typically have poorly formed digital cushions and thin collateral cartilages. These structures determine the overall conformation of the palmar/plantar portion of the foot. It remains to be determined if heel development is a static state associated with genetically determined conformation or a conformation that can be altered by physical stimulation; possibly either or both factors may be involved. Clinicians should gain an appreciation for variation in the consistency and overall size of the digital cushion and collateral cartilages. The digital cushion can be palpated between a thumb placed between collateral cartilages and the fingertips placed on the frog (Fig. 22). A sense of “normal” can be learned by palpating the digital cushions of sound horses with “good feet” and comparing those findings with those of horses with poorly conformed feet.30,40,41 The depth of the combined tissues of normal digital cushion and frog should be 2 inches.9 Horses with underdeveloped digital cushions or “flimsy” collateral cartilages2 typically have underrun heels that can be easily moved up and down independently or they may have contracted heels and thin, non–weight-bearing frogs.30,33 The feet of the hind limbs are far less likely to have underdeveloped heels, and these feet can be compared with the front feet to get a sense of heel development.33 The authors and others4,6 have observed that horses that have been chronically stalled, how-

Fig. 20. (A), This foot has near zero collateral groove depth at the apex of the frog (point A). Note that inadequate sole depth (6 mm) is found under the rim of the distal phalanx. (Anatomical location of points A and B are also shown in Figs. 15 and 16.) Also note the gas shadows that the collateral grooves create in the heel area (red arrows). This is the radiographic appearance of a foot with the “stair-step” or undulating shape of the collateral grooves that we believe to be associated with a “weak” or “underdeveloped heel.” The heel bulbs of this horse were easily distracted with digital pressure and the digital cushion when palpated was soft and thin. Also compare this foot with the foot in Fig. 17, which also has “undulating” collateral grooves, yet to a greater extent, whereby the shallowest point is at mid-frog, indicating that the distal phalanx of that foot has a negative plantar angle. Horses with negative plantar angles usually have adequate sole depth under the dorsal rim of the distal phalanx but may have inadequate solar protection under the palmar processes. (B), The distal phalanx in this radiograph has severe bone remodeling as the result of chronic laminitis and thin soles. If the distal phalanx was normally shaped, it probably would penetrate the sole; instead, bone has been remodeled by the chronic trauma and suboptimal perfusion. Also note that the collateral groove depth of this horse is quite shallow (estimated to be less than 3 mm), and the gas shadow of the collateral grooves in the heel region is the similar to the foot in A.

these instruments used for this purpose has not been studied.

The coronary band of a healthy hoof should feel thick and spongy and should have no evidence of a “ledge” where a finger can be placed behind the proximal aspect of the hoof capsule (Fig. 21). A
ever, are likely to have poorly developed heels in the hind feet.

Horses with poorly developed heels may be predisposed to injury of the navicular bone and DDFT for several reasons: (1) they tend to have low palmar/plantar angles, which increases the force exerted by the deep flexor tendon on the navicular bone,\(^8\) (2) horses with poorly developed heels tend to land toe first, with the deep digital flexor tendon/muscle unit contracting as the heel descends causing abnormally high compressive forces on the navicular bone, which in turn causes disease of this structure and increased strain in the DDFT during locomotion,\(^4\) (3) poorly developed feet have 15 times fewer vascular channels in the collateral cartilages than are found in “good feet.”\(^2\) Feet with fewer vascular channels may contain less blood to act as a hemodynamic energy dissipation mechanism.

The palpable enlargements on the middle phalanx at the attachments of the medial and lateral collateral ligaments of the DIP joint, 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. Severe damage to these ligaments may result in soft tissue swelling, and palpation of these sites may elicit signs of pain from the horse, but evidence of disease of these collateral ligaments is often not palpable.\(^4\)

The thickness, density, and pliability of the collateral cartilages should be compared between lateral and medial cartilages and between cartilages of left and right feet.\(^2\) Poor quality of the collateral cartilages may indicate the heel as a source of pain, and palpation of this tissue also helps to determine the pliability of the hoof. Extremely stiff and inflexible collateral cartilages are often found in an upright foot, whereas “flimsy” cartilages are commonly found in feet with a collapsed heel and narrow convex frog.\(^2\) This distance between the cartilages should be assessed as well. One author (D.R.T.) has observed that horses with suboptimal heel development (especially Quarter Horses with narrow frogs, with/without heel pain) often have a very small distance between the cartilages (≤1 finger width).

Extensive ossification of one or both collateral cartilages may be observed in horses with disease of a collateral ligament of the DIP joint, trauma to the distal phalanx, trauma to the cartilage itself, or trauma to the ligaments that join the collateral cartilages to the middle (chondrocoronal ligament) and distal (chondroungular ligament) phalanges.

Fig. 21. The coronary bands in these pictures that have a prominent “ledge” due to excessive distance between the coronary band and the extensor process of the distal phalanx. Horses with these ledges are called “sinkers” when the ledge occurs because of laminitis (left image). The authors have observed that some sound horses can have excessive distance between the coronary band and extensor process and may have similar yet more subtle indications of “prominence” of the proximal aspect of the capsule as seen in the figure on the right where the top of the capsule can easily be palpated.

Fig. 22. The digital cushion should be palpated to become familiar with the variations in depth and density that exist between horses. The digital cushion should have a density similar to a tennis ball or a “well-done” steak. The frog and digital cushion should have a combined depth of approximately 2 inches. Photo courtesy of Pete Ramey.
or the navicular bone (chondrosesamoidean ligament).^{44}

4. Hoof Testers
The use of hoof testers may enable the examiner to find or rule out the presence of pain associated with the hoof wall, sole, dermal tissues, and digital cushion, but false-negative and false-positive findings obtained using the hoof tester are common. Deformability of the sole as the hoof tester is applied may give an indication of sole thickness. Causes of false-positive findings with the hoof tester are reflexes that occur when the horse is startled or annoyed by the pressure applied to the foot. Many horses with chronic foot pain do not react to testers because the hoof capsule has deformed to protect the painful region. In the authors’ experience, many horses with severe foot pain do not react to application of a hoof tester such as those with a subsolar abscess, laminitis, or fracture of the distal phalanx, perhaps because pain is already near maximal. 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 desensitized by various diagnostic anesthetic techniques in the foot. The use of hoof testers for identification of navicular pain is controversial but is generally considered to be unreliable.^{14,45} 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 demeanor of the horse, the amount of pressure applied by the examiner, and finally, by the presence of disease. It is important to develop a sense for what are normal variations between horses. Responses should be compared carefully between contralateral feet. In one study, examination using a hoof tester 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. In another study, only 11% of horses with navicular disease reacted to hoof testers applied over the middle third of the frog. Another important use of hoof testers is to assess the deformability or integrity of the structures of the hoof capsule; for example, sole depth can readily be evaluated by how much it deforms with application of hoof testers.

5. Physiological Stress Tests
Flexion tests of the distal portion of the lower limb have been used for many years to attempt to localize pain in the distal portion of the limb. Flexion tests of the distal portion of the lower limb exacerbate lameness of horses with disease of the proximal and distal interphalangeal joints, proximal and distal sesamoid bones, disease of a digital flexor tendon or suspensory ligament, as well as the metacarpophalangeal joint, which cannot be excluded from the test.^{13} In addition, the response to a flexion test of the distal portion of the lower limb is subjective because response depends on the force and time applied.^{46,47} One study found the optimal force for a flexion test to be 100 N for 1 minute.^{46} A slightly positive response to flexion (100 N/1 min) in horses with no other clinical signs or clinical or radiographic signs of disease of the distal portion of the limb had no clinical significance.^{46} Other investigators showed that most clinically sound horses react slightly to a flexion test of the distal portion of the limb and that a positive response to the flexion test increased significantly with age.^{48} This observation and the lack of long-term consistency of the test cast doubt on the presumption that a positive flexion test indicates subclinical joint disease and question the possible value of the test as a predictor of future, joint-related problems. Temporary lameness that occurs after flexing the distal portion of the lower limb is more likely to be clinically significant if the response differs markedly between contralateral limbs.

An extension/flexion test of the DIP joint and navicular apparatus is performed by placing a 15- to 20-degree wooden wedge beneath the foot so that either the toe or heel is elevated for a period of 1 minute or more. Alternatively, the foot can be placed on one end of a plank, the other end of which is gradually elevated by the examiner to produce a similar effect. Elevation of the toe increases strain in the DDFT, navicular suspensory ligaments, and the impar ligament, and increases the compressive force on the navicular bone. Nevertheless, in one study, toe elevation tests had a sensitivity of only 55% and a specificity of only 42% for the presence of navicular pain. Elevation of the heel reduces strain in the DDFT, impar ligament, and navicular suspensory ligaments but directly increases impact pressure on the heels. Despite this, Turner found that the heel elevation test had a sensitivity of 76% and a specificity of 26% for the presence of navicular pain. One author (M.S.) has observed that many horses with lesions of the DDFT (as identified on MRI) experience worsening of lameness after the heel is elevated.

6. Surface for Observing 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. Lameness caused by pain in the distal portion of the limb is often more noticeable when the horse trots in a circle, especially when the lame limb is on the inside.
7. Significance of Physical Examination of the Hoof
Many of the observations described above are those of the authors and other clinicians and have not been validated by scientific investigation. We hope that these observations will be subjected to scientific scrutiny to determine their predictive value in determining disease of the foot.

8. Localizing Pain Within the Foot Using Nerve and Joint Blocks

Choice of Local Anesthetic
Although many clients expect the source of pain causing lameness to be identified during a single examination, identifying the source of pain within a foot may require multiple examinations using a different technique of perineural or intra-articular analgesia at each examination. When multiple examinations are anticipated, the choice of local anesthetic solution may be important. Use of 2% lidocaine in such cases may allow for closer intervals between examinations because the analgesic effect of lidocaine is shorter than that of other commonly used local anesthetic agents, such as 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. Some authors claim the analgesic effect of perineurally administered lidocaine to last 90 to 180 minutes and that of mepivacaine to last 120 to 180 minutes.

According to Wyn-Jones, however, the length of analgesic effects of these drugs is less. Wyn-Jones claimed that lidocaine, when administered perineurally, has an analgesic effect of only 30 to 45 minutes and that lidocaine, when administered perineurally, has an analgesic effect of only 90 to 120 minutes. Andreen et al found that the analgesic effect of mepivacaine administered into the middle carpal joint of horses lasted only 55 minutes when treating horses for 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 distal portion of the limb. Because lidocaine is more inflammatory than is mepivacaine, the authors prefer to use mepivacaine when anesthetizing joints of the distal portion of the limb. Intrasynergial use of 2% lidocaine may also be undesirable because lidocaine has been shown in vitro to be significantly more chondrocytotoxic than is 2% mepivacaine.

Perineural administration of 2% or 3% ketamine HCl in isotonic saline solution or bicarbonate solution at the base of the proximal sesamoid bones produced 15 to 25 minutes of analgesia in an experimental model, indicating that this short-acting drug may prove useful as a local anesthetic agent for lameness examination when multiple techniques of local analgesia are anticipated. The authors, however, are unaware of reports concerning the clinical value of ketamine HCl for regional analgesia in the horse.

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, whereas the dorsal branches of the palmar digital nerves were thought to innervate the remainder of the foot. 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 an abaxial sesamoid nerve block or a pastern ring block, each of which anesthetizes the dorsal branches of the palmar digital nerve. Many clinicians believed that the palmar digital nerves should be anesthetized near or distal to the proximal margin of the collateral cartilages to avoid anesthesia of the dorsal branches of the palmar digital nerve and hence desensitization of the entire foot. Easter et al 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 alone innervate the entire DIP joint. According to the study by Easter and results of an earlier anatomical study by Sack, the dorsal branches of the palmar digital nerves 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 anesthetic solution as far distally in the pastern as possible when performing a palmar digital nerve block is that more proximal deposition of local anesthetic solution increases the likelihood of desensitizing the proximal interphalangeal (PIP) joint. When a 0.5 × 16-mm (25-gauge, five-eighths inch) needle is inserted over the palmar digital nerve one centimeter proximal to the proximal margin of the coronary band that occurs after a palmar digital nerve block and desensitization of the entire PIP joint, because the height of the collateral cartilage in relation to the level of the palmar region of the PIP joint is probably similar for most horses. The likelihood of inadvertently desensitizing the PIP 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 reevaluation of lameness can begin 5 minutes after administering regional analgesia in the distal portion of the limb. Wyn-Jones advised prompt assessment of gait after regional analgesia of the distal portion of the limb because rapid diffusion of anesthetic solution could anesthetize other nerve branches, thus confusing results of the examination. Nagy et al found that radiopaque contrast medium deposited perineurally in the lower portion of the limb traveled a substantial distance...
proximally along the neurovascular bundle within
10 minutes after administration (Fig. 23). Deposi-
tion of local anesthetic solution outside the fascia
(Fig. 23) surrounding the neurovascular bundle
has been offered as an explanation for the delay in de-
sensitization of a region that sometimes occurs
after administration of regional analgesia. A clinician
probably would have no idea if a delay in resolution
of lameness after a nerve block was due to proximal
migration of local anesthetic solution with eventual
inadvertent desensitization of a more proximal,
painful lesion or, instead due to deposition of local
anesthetic solution outside fascia surrounding the
neurovascular bundle.

Localization of pain to either the medial or lateral
aspect of the foot may be possible by anesthetizing
the medial and lateral palmar digital nerves at dif-
ferent times. Some causes of lameness, such as
navicular disease or disease of the DIP joint, would
be highly unlikely to be the cause of lameness if
desensitization of one side of the foot resolves lame-
ness, whereas uniaxial diseases such as a nonarticu-
lar palmar process fracture of the distal phalanx,
unilateral solar or hoof wall disease, and severe
sheared heels would be more likely causes of lame-
ness. Some uniaxial diseases such as desmitis of a
collateral ligament or a subsolar abscess, however,
may require analgesia of both palmar digital nerves
to significantly resolve lameness.

Intra-Articular Analgesia of the DIP Joint

Intra-articular analgesia of the DIP joint using 5 to
10 mL of local anesthetic solution, like the palmar
digital nerve block, has limited value in localizing
pain within the foot. Local anesthetic solution ad-
ministered into the DIP joint desensitizes that
joint, the navicular bursa, the navicular bone and its
suspending ligaments, the toe region of the sole, and,
for most horses, that portion of the deep digital flexor tendon that resides
within the foot. When a large volume of local
anesthetic solution (e.g., 10 mL) is administered, the
heel region of the sole is also desensitized.

Not all horses that are lame because of pain in the
DIP joint (or any joint) respond positively to intra-
articular analgesia. Intra-articular analgesia may
relieve pain caused by disease of periosteum and
capsular soft tissue, but when joint disease involves
subchondral bone, pain may not resolve with intra-
articular analgesia. Because subchondral bone
is innervated by nerves that enter the bone marrow via the
nutrient foramen, anesthesia of nerves proximal to branches
(needle A) that enter the nutrient foramen may be necessary to
resolve joint pain and lameness.

Although local anesthetic solution administered
into the DIP joint has been shown to diffuse to the
navicular bursa and navicular bone, we believe
that the most likely explanation for desensitization
of the navicular bone and its supporting ligaments
when local anesthetic solution is administered into
the DIP joint is anesthesia of subsynovial nerves
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Intra-Bursal Analgesia of the Navicular Bursa

Significant amelioration of lameness after administering local anesthetic solution into the navicular bursa indicates disease of the bursa, the navicular bone, and/or its supporting ligaments or disease of the portion of the DDFT in the foot. Even though analgesia of the DIP joint results in analgesia of the navicular bone or bursa, analgesia of the navicular bursa does not result in analgesia of the DIP joint. 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.

One possible explanation for the observation that analgesia of the DIP joint causes analgesia of the navicular bursa but analogesia 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 anesthetic 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 anesthetic 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 concluded that much of the navicular apparatus, the insertion of the distal sesamoidean impar ligament, and the insertion of the DDFT are anesthetized within 7 to 9 minutes of intra-synovial 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 minutes) because after this time, structures desensitized by diffusion of local anesthetic solution become uncertain.71,72,82

**Analgesia of the Digital Flexor Tendon Sheath**

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 DDFT sheath.85 It is logical, therefore, to assume that intra-synovial analgesia of the digital flexor tendon sheath does not anesthetize the palmar digital nerves but rather desensitizes only structures that are contained within or border on the sheath itself (e.g., the superficial and DDFTs, the straight and oblique distal sesamoidian ligaments, the annular ligaments of the fetlock and pastern). An abaxial sesamoid nerve block 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.73 A palmar digital nerve block (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 coffin joint, or the navicular bursa, we believe that a portion of the DDFT receives its sensory supply from more proximal deep branches of the medial and lateral palmar digital nerves that enter the digital flexor tendon sheath. Improvement of lameness in horses with lesions of the DDFT within the foot after intrathecal analgesia of the digital flexor tendon sheath has been described.86 Because the palmar digital nerves are not anesthetized by blocking the digital flexor tendon sheath,85,87 it has been suggested that blocking the digital flexor tendon sheath directly may be a technique that can be used to diagnose deep digital flexor tendonitis within the foot without the use of magnetic resonance imaging.87 Performing intrathecal analgesia of the digital flexor tendon sheath on horses with lameness that is unchanged after anesthesia of the palmar digital nerves but resolves after an abaxial sesamoid nerve block may be useful. Resolution of lameness after intrathecal analgesia of the digital flexor tendon sheath justifies suspicion of a lesion within the digital portion of the DDFT or other structures contained within the digital flexor tendon sheath.

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**References and Footnotes**


