The Biomechanical Effect of Wedged, Eggbar and Extension Shoes in Sound and Lame Horses

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Horses with navicular disease, laminitis, and bone spavin redistribute weight to unload the painful aspect of the foot/limb. Wedges aided this redistribution but shoe extensions did not. It is not appropriate to undertake studies into the mechanics of corrective farriery on sound horses of good conformation and then extrapolate these results to predict the effect of corrective shoeing on a lame horse. Authors' address: The Royal Veterinary College, North Mymms, Hatfield, Herts, AL9 7TA England. © 2001 AAEP.

1. Introduction

Equine limbs, particularly the forelimb, have a much more limited range of movement than human and carnivore limbs: they are largely confined to movement in a sagittal plane. This design has the advantage that the limb structure can become specialized for movement in a single plane, with the reduction of muscular tissue and enhancement of tendinous structures, which act as springs, storing elastic energy. The tendons of the distal limb are strained (storing elastic energy) during the early part of stance when the limb is loaded, and then recoil when the limb is unloaded in the second half of stance, releasing the energy back to the system and initiating the flight phase.1 A horse's limbs support its body weight so the average limb vertical force over time is equal to its body weight. As a horse goes faster it spends less time with its feet on the ground so the peak force on its limbs has to be higher. This is why high speed locomotion is more likely to result in injury. This is discussed in more detail in Wilson et al.2

2. Mechanics of Equine Locomotion

The relatively simple anatomical arrangement of the distal limb and the lack of muscle means that the horse has only limited scope to alter the mechanics of the system thus, its gait—for instance, in response to pain. It also means that limb movement is very repeatable from stride to stride, which makes gait analysis easy to perform and analyze. The simplicity of the mechanical system also means that the outcome of changes in foot balance and corrective shoeing are relatively predictable and similar in different horses.

3. Methods in Gait Analysis

We used a combination of forceplate measurement of limb forces (Model 9287AB)a and automated 3D video motion analysis (ProReflex)b to generate the data that forms the basis of this article. With these systems it is possible to determine the load transmitted through individual limbs, the limb positions with millimeter accuracy, and, via calculation of joint moments, calculate the forces in the...
tendons and on the bones of the distal limb. In this type of study it is often useful to look at the position of a point called the point of force or point of zero moment (PZM). Imagine that the horse’s weight acts at a single point under the foot, that is, an imaginary point of balance for the load transferred from the foot to the ground. This is the point of zero moment and its location relative to the foot can be determined with a forceplate and motion analysis equipment. If corrective farriery alters the weight distribution in the foot, then the effect should be apparent as a displacement of the PZM during stance. The distance between the PZM and the center of rotation of a joint is termed the moment arm for the ground reaction force (GRF). The product of the GRF (in Newtons) and the moment arm (in meters) gives the moment (torque) acting on a joint which will be balanced by opposite moments generated by muscles, tendons, and ligaments.

In the studies reported here the data were collected during trot locomotion from groups of 6–17 horses with 6–10 stance phases analyses for each state. Comparisons between groups were carried out using paired t-tests, ANOVA, and principal component analysis. A p < .05 was taken as indicating statistical significance in comparisons. For detailed protocols and results see Wilson et al (2001) and other papers cited in the text and reference list. In these two presentations, the data from a number of experiments are combined to provide an overview of the relationship between corrective farriery and limb loading in sound and diseased horses. These data enable us to investigate the mechanical basis of equine locomotion and develop our understanding of how the horse adapts its locomotion to pain, corrective farriery, and treatment.

4. The Response to Lameness
In this article lameness is defined as an assessment made by a clinician and asymmetry as a left–right difference in a parameter measured using motion analysis equipment. The lame horse will change its gait in an attempt to reduce pain, one assumes, by attempting to unload the painful tissues or the affected limb. The horse does, however, still have to support its body weight, which limits its ability to compensate for pain and redistribute its weight. Small animals like dogs and cats compensate very well for pain by reducing limb peak force or stance time, and indeed after limb amputation can ambulate on three limbs. The horse, however, due to its greater size, is much more constrained in its ability to redistribute body weight and the signs of lameness are more subtle. The 0.1-lame horse compensates by placing and loading the limbs more slowly/carefully (an audible difference) but does not reduce the limb peak force to any great extent. Head and/or hip movement (observed clinically) around impact is one mechanism used to achieve this reduction in limb loading rate. In addition, the limb is protracted in a more flexed orientation (i.e., the foot is higher), presumably to shorten protraction time.

One might expect that motion analysis would be valuable for diagnosing different clinical conditions, especially at high speed. There are differences in the locomotion of horses with different clinical conditions but the use of motion analysis for clinical diagnosis is limited because the horse will tend to respond to any painful condition in the manner reported above. When the load transferred through a limb is reduced, effects will be observed at all joints rather than at one specific painful joint (for instance). It is therefore not always easy to distinguish cause and effect.

5. Alterations in Limb Forces with Specific Conditions
Mechanics of Caudal Foot Pain/Navicular Disease
We have recently undertaken a study on horses with navicular region pain. We used a combination of forceplate analysis, motion analysis, and radiography to determine the limb forces, weight distribution under the foot, the force in the deep digital flexor tendon (DDFT), and on the compressive stress (force per unit area) on the navicular bone during the stance phase of trot. These data show that in normal horses the force on the navicular bone rises through stance to a peak around 85% of stance, just before the heels leave the ground. This force profile is due to passive loading of the DDFT via the accessory ligament: as the distal interphalangeal joint (DIP) extends in late stance, the tendon is stretched (like a spring balance), increasing the force in the tendon, hence the compressive force it exerts on the navicular bone.

In horses with navicular disease, the force on the navicular bone peaks early in stance and again just before the heels leave the ground. The late peak is similar in magnitude in normal and diseased animals, but the early peak, only present in the horses with navicular disease, results in a much higher loading rate on the bone which may be responsible for the pathological remodeling observed in horses with the disease. When we desensitized the heels of these horses with a palmar digital nerve block, the tendon force, hence the force on the navicular bone, drops in early and mid stance. Our proposed explanation for these data is as follows.

The horse perceives general pain in the navicular/heel region rather than pain specific to the navicular bone. This pain could be the result of a variety of foot pathologies. The horse compensates for this pain in the heel region by unloading the heels, especially at the beginning of stance, to reduce concussion. It does this by contracting the deep digital flexor muscle, hence increasing the force in the DDFT. This flexes the DIP joint so the horse lands toe first. After landing, the weight is born further forward on the foot, increasing the moment arm on the DIP joint and increasing the force exerted on the navicular bone. Palmar digital nerve block re-
versed this response, to some extent, and the load on the navicular bone is actually reduced. These data suggest that there may be a positive feedback mechanism in which navicular region pain elicits a compensatory mechanism that increases the compressive force on the navicular bone. This may explain why some horses with chronic heel pain develop radiographic changes in their navicular bones. Whether such an increase in loading would actually cause navicular disease is, however, unproven.

This mechanism can also provide an explanation for the reported susceptibility of the horses with a broken back hoof/pastern axis to navicular disease and the tendency of some horses with long standing navicular disease to develop boxy, upright feet. A horse with collapsed heels will tend to exert a higher force on its navicular bones (because the DDFT is stretched further—see above) so it will be more susceptible to develop navicular disease. If it has a long toe this will increase the moment arm on the DIP joint, hence the force on the navicular bone during toe first landing and possibly also at breakover (see below). Some horses that are attempting to unload their heels by DDF muscle contraction are presumably successful that they will develop contracted heels and an upright foot.

Mechanics of the Digit in Founder

A change in foot mechanics is also apparent in ponies with chronic founder. These ponies land heel first, which is assumed to be to protect the painful dorsal laminae (laminar detachment occurs predominantly in the dorsal region of the foot). Laminar detachment destabilizes the distal phalanx and results in either rotation or sinking of the distal phalanx, depending on the extent of detachment with respect to the position of the PZM. Rotation occurs when there is weakening of the lamina in the dorsal region yet the lamina at the heels remains mechanically competent. The distal phalanx pivots about this point so that the toe moves caudally and distally. The DDFT is passively loaded via its accessory ligament during stance. Rotation of the distal phalanx causes shortening of the DDFT and, as tendon force is proportional to its length (see above), rotation will reduce the force in the DDFT. The reduction in DDFT force results in a reduced flexor moment in the DIP joint during stance. Since the moments on the DIP joint must balance (stance is a quasi static equilibrium of joint moments), this will reduce the extensor moment created by the GRF. This reduction in moment is reflected in the PZM moving towards the heels. This unloads the dorsal laminae and increases the proportion of the load transferred through the intact palmar laminae.

Rotation can thus be regarded as a self limiting event, the magnitude (angle) of which depends on the degree of laminae detachment. If very extensive laminar detachment occurs, then the forces exerted on the remaining laminae will exceed their mechanical capacity and the distal phalanx will sink rather than rotate further.

Weight Distribution in Horses with Bone Spavin

Horses with osteoarthritis of the small tarsal joint (bone spavin) are described as having a characteristic gait. The clinical literature describes this gait having a shortened cranial phase of the stride: the leg is moved medially during the flight phase and then swung laterally just prior to ground impact (“stabbing”). This gait is believed to be the result of the horse attempting to reduce the load on the painful medial aspect of the tarsus. However, this supposition was based on clinical observations and had not been quantified until recently. In a study we determined the position of the PZM in the hind feet of normal horses and horses with bone spavin. We found that in horses with spavin the PZM is more caudal and lateral than in normal horses, confirming that they change their gait to unload the painful medial aspect of the tarsus.

6. The Effect of Corrective Shoeing on Equine Locomotion

Medio-Lateral Imbalance

Many authors describe the equine limb as acting as a column. This is certainly useful when considering mediolateral foot balance. As clinicians we attempt to balance or realign this column by foot trimming or addition of extensions. We have investigated the mechanical outcome of such treatments in sound horses and in horses with bone spavin (diagnosed by radiography and intra-articular TMTJ analgesia). In one study we applied a 6-mm thick wedge shoe to alter mediolateral foot balance in sound horses and in horses with bone spavin. These extensions had no apparent effect on the position of the PZM. This lack of an effect may however demonstrate that “if it ain’t broke you can’t mend it.” We also applied lateral extensions and trailer shoes to the hind feet of horses with bone spavin. These horses attempt to unload the dorsomedial aspect of their small tarsal joints by redistributing their weight to the caudal–lateral aspect of the foot. The lateral extensions (20-mm wide) and trailers (20-mm long on lateral heel) are assumed to act by helping the horse to redistribute its weight in a more comfortable manner either by rotating the foot or by helping the horse bear weight on the lateral side of the foot. An alternative explanation is that the corrective farriery forces the horse to move “normally” and prevents it from unloading the painful tissues. We do not know which is the case but have found that both extension and trailer shoes have little consistent...
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Effect on the position of the PZM through stance or on the clinical lameness score of these horses questioning their efficacy as a treatment technique.14

Heel Wedges

Dorsopalmar alterations in foot balance are somewhat more complex to understand. First, consider a simple heel wedge. This has three effects:

1. During stance, the wedge will flex the DIP joint. This unloads the DDFT (which acts as a passive elastic link resisting extension of the DIP and metacarpophalangeal joints). The DDFT acts as a spring (imagine a spring balance) so if it is allowed to shorten it will exert less force. The DDFT passes around the navicular bone and exerts a compressive force on the navicular bone. When the DIP joint is extended, the angle of tendon deviation around the bone is reduced. This and the reduced force in the tendon (because it has shortened) means that the compressive force on the bone is reduced. The actual reduction in force on the navicular bone is in the order of 24% for a 6° heel wedge (and somewhat less in the tendon) and approximately double that for a 21° wedge.15,16

2. The heel wedge will tend to increase the weight transferred through the heels because the PZM has moved towards the heels.

3. When the heels are unloaded towards the end of stance, the body weight acts at the toe, producing leverage on the DIP joint, hence the deep digital flexor tendon and the navicular bone. When the heels are elevated with a wedge they are supported until later in the stride and the vertical force on the limb is lower when this forward displacement occurs. The moment on the DIP joint should therefore be lower.3,15

If we consider a horse with collapsed heels then the opposite process will exist. The DDFT will wrap further around the navicular bone and because the heels are lower the DDFT will be stretched longer so tendon force will be higher.

Eggbar Shoes

Eggbar shoes have no effect on the force on the navicular bone in sound horses15 but we have observed a significant unloading effect in some horses with navicular disease, particularly those with collapsed heels.6 This would concur with clinical experience on their efficacy in some horses. The mechanism of action is unclear but may relate to redistribution of the load over a larger area of the heels or reinforcement/coupling of the flexible palmar regions of the foot. The above mechanism suggests that redistribution of load to make the horse more comfortable would result in a reduced force on the navicular bone. Why eggbar shoes help some horses more than others is unclear but may relate to the location of pain or the degree of heel collapse.

Toe Position

When the heels leave the ground the body weight acts at the toe producing a long lever arm on the DIP joint, hence loading the DDFT and the navicular bone (see above). Attempts to reduce the length of this lever arm have been made by fitting a shoe with quarter clips rather than a toe clip and fitting a shoe designed along the lines of the four-point trim (natural balance shoe). We have applied toe clip, quarter clip, and natural balance shoes at three-week intervals to 9 horses (Latin square design) and assessed the horses one week post shoeing. Pulling the toe back made breakover (heel off to toe off) start earlier and shortened the duration of breakover. The moment arm of the GRF on the DIP joint during breakover was reduced but because breakover started earlier, hence at a higher GRF, the peak moment and force on the navicular bone was similar in the three shoe types.17

7. The Effect of Shoe Material on Foot Slip and the Energy Attenuated at Impact

There is anecdotal evidence that some horses are more “comfortable/go better” in plastic or rubber shoes. This has been attributed to reduction of “jarring” after impact. Shoe grip varies between shoe types, with plastic shoes sliding relatively easily and a variety of techniques being used to enhance shoe grip, for instance carbide studs, borium, and rubber shoes. The coefficient of dynamic friction between the shoe and the ground is reflected in the cranio-caudal impact forces and the time the foot breaks away at the end of stance. Shoes with a lower grip (especially those with a low grip at low limb forces) allow the foot to slide more after impact reducing the jarring experienced by the foot and possibly explaining why some horses are reported to be more comfortable in these shoes.18 Shoes with a low coefficient of friction with the ground break away earlier, shortening the caudal phase of the stride. The effect/benefit of this is unclear.

8. Conclusions

The mechanics of the equine distal limb and the effect of corrective farriery is governed by some simple mechanical principals. A good understanding of these principals aids the application of appropriate treatment rationales. Limb loading is also affected by the horse’s response to any source of lameness. It is not appropriate, therefore, to undertake studies into the mechanics of corrective farriery on sound horses of good conformation and then extrapolate these results to predict the effect of corrective shoeing on a lame horse. This may explain why some published studies show no clinical effect of corrective shoeing practices even though clinical experience would suggest that an effect does exist.
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References and Footnotes


*aKistler, Winterthur, Switzerland.
*bQualys AB, Svedalen, Sweden.

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