A Review of Research Relating to the Form and Function of the Equine Foot

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Take home message

Soundness in the equine foot relies on the three functions of the foot—impact, movement, and stance—functioning concurrently. Recent investigations support anecdotal experience regarding the causes of hoof form, and the findings can assist both veterinarians and farriers in treating hoof pathology.

1. Introduction

Form follows function, and the function of the horse’s foot causes the shape and constitution of the hoof. The three functions of the hoof—movement, impact, and stance—all affect the health of the horse, and all three need to be considered concurrently in diagnosing and treating foot disease. Both veterinarians and farriers have observed that high stress and displacements of the hoof capsule, such as flares, dishes, rings, cracks, and imbalances, result in pain and discomfort. Findings of recent investigations offer improved understanding of the three functions of the hoof and can advance our treatment of horses as well as improve our ability to write prescriptions for farriers, who are often responsible for treatment of the diagnoses veterinarians make. This paper reviews and discusses recent research associated with each of the three functions of the foot.
2. Movement

The horse, as a prey animal, has a highly developed ability to move. Movement starts at the last moment in the stance phase, when the heels leave the ground and the entire hoof rotates around the toe. This motion is called breakover or hoof unrollment. The breakover location is the most dorsal location of the solar aspect of the hoof capsule (or the shoe) that contacts the ground and is the last part of the hoof capsule or shoe to leave the ground.1 A paradigm shift in understanding the effect of motion on breakover occurred when observations of the wild horse showed that in hard environments, the breakover was on the sole, just inside the white line at the toe pillars,2 whereas in soft environments, it was on the hoof wall and importantly, also at the toe pillars.3 This discovery started a new way of looking at the foot and spurred investigations to assess function of toe length in domestic horses.

The effect of the function of movement on the form of the hoof capsule was noted when semi-feral ponies went from little movement to foraging 100% of the time. The “self-trimming” which occurred only through movement caused a decrease in elongated hoof wall length and the removal of cracks, distortions, and tears.3 In domestic horses, when the form of the hoof capsule is changed through trimming, a statistically significant change occurs in the hoof/pastern axis. At mid-stance, when the metacarpus is at a 90-degree vertical angle to the ground and the breakover location is trimmed on the solar surface to be .6 cm from the tip of PIII (identified radiographically), improvement in a low hoof/pastern axis and re-positioning of the navicular bone proximally results.4 A long breakover will lower the hoof/pastern axis, leading to a dorsal distension of the hoof wall and associated sensory pain in hoof wall laminae.5 During an 8-week shoeing
period in sound horses shod with metal shoes, a 3.3% decrease occurred in the hoof/pastern axis,\(^6\) lowering the hoof/pastern axis. The forces in the DDFT have been shown to increase around the navicular bone when an increase occurs in flexor angle or in a low hoof/pastern axis, because of the greater curvature of the DDFT. An in vitro study of contact stress in bones of the DIP joint as a function of flexion angle indicates that the load on the navicular bone and its associated joints is highest between the navicular bone and PIII and between the navicular bone and the second phalanx (PII) during dorsiflexion. Considerable stress occurs in the region of the DIP joint between PIII and the navicular bone in both the articular cartilage and ligamentous attachments, as well as in the subchondral bone. The resulting pathophysiology is increased contact load between the navicular bone and PIII and between the navicular bone and PII, which negatively affects the numerous nerve fibers located at the insertion of the DSIL and DDFT. In addition to its effect on nerves, the hoof/pastern alignment has an effect on the vasodilatory mechanism controlling blood flow through the DLIS/DDFT insertion and the dorsal hoof wall.\(^7\) Raising the heels decreases the tension in the DDFT by decreasing the moment of force on the DIP joint.\(^8\) Finite element analysis demonstrates that a 5-degree heel wedge decreases stress and displacement in the caudal aspect of the foot compared to a flat shoe or a 5-degree toe wedge.\(^9\)

Although some investigators have expressed concern that the shorter toe length will affect stride characteristics, in a comparison of sound horses on a hard surface rocker-toed shoes vs. flat shoes did not show any differences in the stride characteristics during the gait phase.\(^{10}\)
In summary, movement around the DIP joint against a surface creates the location and amount of force within the hoof, and the breakover point is created by the function of movement around the center of articulation against a surface. Toe length affects the hoof/pastern axis, and a low hoof/pastern axis affects the tension and pressures on the DDFT, navicular bone, and caudal aspect of PIII. A low hoof/pastern axis can be treated with toe length and/or heel wedges.

3. Impact

Impact is defined as the first milliseconds after initial contact, when the foot decelerates rapidly to reduce its vertical and horizontal velocity to zero. While the vibrations that occur are damped by the ground surface and the structures contacting the ground, the forces generated range from 120% of the horse’s body weight at the trot to an estimated 170% at the gallop.\textsuperscript{11} Attenuation of shock is related to the bones and interphalangeal joints\textsuperscript{12} and their relationships as well as through the soft tissues of the hoof, which attenuate shock waves of impact and amplitude.

Toe-first landing is generally equated with heel pain in horses. Further, reports of impact generally describe landing as flat\textsuperscript{13} or lateral flat.\textsuperscript{14} However, the desirability of heel-first landing in the horse—as occurs in humans, mammals, and birds—is supported by the following data.

Anatomically, the laminae are more dense in the area of the heel spike, or heel pillar.\textsuperscript{5} Internally, a large venous plexus is located at the heel portion of the foot,\textsuperscript{15} and the majority of perkinje fibers are located at the palmar/plantar heel.\textsuperscript{5} Pathology in the navicular ligaments has been demonstrated when vertical forces through the center of the foot cause consistent motions between the navicular bone and PIII.\textsuperscript{16}
Hemodynamic forces support a heel-first landing. Anatomically, elastic and fibrocartilaginous fibers make up the digital cushion, which occupies the heel portion of the foot and is softer and more yielding than the bony tissue of the mid portion of the foot. Although this construction suggests a heel-first landing, Bowker hypothesized a damping effect if impact was heel first through activation of special hemodynamics in the heel portion of the foot. He theorized that the high transient energy forces produced within the horse’s foot can be dissipated via the ungual cartilage if these tissues are activated through heel-first landing. Research on hydraulic fluid theory has shown that the greatest absorber of shock is moving liquid, and that greater forces are absorbed when resistance is higher. In the equine foot, the moving liquid is the flow of blood while the veno-venous anatomoses are in a high resistance because they are interspersed in dense cartilage. A heel-first landing with frog contact either to the ground or to a hard pad causes a bellows effect of the ungual cartilages, effectively increasing the pressure in the foot and pulling blood through the distal sesamoidean impar ligament (DSIL) and into the heel portion of the foot (Fig. 1).

**Figure 1.** Note the ungual cartilages shape of vertical and horizontal to the spine of the frog. Note vascularity in the ungual cartilages
Figure 1. Transverse section through heel pillars.

Vertical cartilaginous tissue of ungual cartilage. The vertical cartilage continues horizontally to the spine of the frog, assisting in outward movement of ungual cartilages during heel-first landing. Note vascular tissue surrounding and in ungual cartilage.

The vibrations of impact are better absorbed by ligamentous soft tissue than by harder bone tissue. A heel-first landing enables the structures along the back of the limb from the origin of the deep digital flexor muscle to the suspensory ligaments of the pastern to absorb the vibrations of impact. During a heel-first landing, the flat shape of the dorsal pastern, which is composed mostly of hard bone tissue, in concert with the round curve of the palmar/plantar proximal pastern, which is composed mostly of
ligamentous tissue, acts like a flying buttress. Architects in the 1600s, motivated to extend the height of buildings without covering openings and creating darkness, developed the flying buttress to allow greater mass to be supported by the same surface area foundation. The same type of structure is found in the digit of the horse. The upper straight surface of the dorsal pastern follows the line of thrust from the body mass, while the arched palmar/plantar surface of the pastern mitigates thrust from horizontal forces and serves for attachments of the sesamoidean ligaments, deep digital flexor tendon, and superficial flexor tendons. ¹⁸ Tendons and ligaments store elastic energy better than bone, and energy may be further absorbed proximally through the deep digital flexor muscle because of its extremely short fibers.¹⁹

In the human, a “heel-pad paradox” was the unexplainable 95% energy loss in vivo compared to 30% in vitro. This was not understood until the venous plexus in the heel was incorporated into measurements, resulting in greater consistency between in vitro and in vivo measurements.²⁰

When the foot leaves the ground during lift off, forces are also applied to the foot. The solar location of the toe pillar courses proximally through the horn tubules and terminates at the intersection of the dorsal aspect of the ungual cartilages and the collateral ligaments of the DIP joint (Fig. 2).
Figure 2. A coronal section through the coronary band.

This anatomic finding was consistent in horses in hard environments with the breakover location inside the hoof wall as well as for horses with the breakover location at the hoof wall. Three investigations in domestic horses found decrease in force during movement of sound horses. The use of rolled-toed shoes fitted just inside the white line compared to toe-clip shoes fitted at the hoof wall resulted in a decrease in the moment arm of ground reaction forces during breakover,\(^2\) the peak load during breakover is decreased 13.5% in a rolled-toe shoe compared to a flat shoe,\(^2\) and unrollment at the toe pillars produced the least change in forces when heel wedge, toe wedge, and flat sole levels were compared.\(^9\)

Two factors are at work to produce the decreases found in the work reported above. One is the change in length of the moment arm around the DIP joint, and the other is the tissue of the hoof which takes the forces of unrollment. Bowker has shown the same increase in laminar tissue density at the toe pillars as at the heel pillars, and farriers
see this same tissue from the solar surface, noticed as oval tissue at the medial and lateral dorsal toe which becomes visibly and palpably prominent when a hot shoe is applied to the solar surface. The use of the toe pillars in absorbing the forces of hoof unrollment needs further research.

4. Stance

During the mid-stance phase, the function of the foot is to support the mass of the horse. This may be the predominant stride phase for the domestic horse owing to stall or paddock confinement. Weight bearing forms the solar surface so that the widest part of the sole is at the center of pressure, which was found to move caudally in sound horses over an 8-week period. Toe length increased, and hoof angle decreased by 3.3%. During stance, the center of pressure will move caudally in a low hoof/pastern axis, but elevation of the heels will not move the center of pressure caudally. The change in center of pressure was attributed to a more upright position of the first and second phalanx. When the center of pressure moves caudally, an increase in contact stress occurs in the foot, but raising the heels does not affect the location of the center of pressure when the horse is standing. Thus, the pressures on the foot will remain the same, but the location of the pressures will vary. It is interesting to note that the vertical line through the widest part of the sole in the wild horse consistently transverses through the DIP joint at a more dorsal location compared to sound and foot-lame domestic horses, where the line transverses further caudal (Fig. 3).
Figure 3. Radiographs of widest part of the front foot, domestic horse on top row, wild horse on bottom row.
In 2001, Hood offered support for improved load bearing by incorporation of solar tissues in addition to the hoof wall. He noted a sole contact area almost three times greater on untrimmed horses measured on a deformable surface compared to hoof wall contact on a hard surface. Trimming almost doubled the surface area contact as hoof projections were removed, allowing greater portions of the wall to contact the surface. Shoeing did not increase the surface area from that of a trimmed foot. Hood concluded that allowing the peripheral region of the sole, the bars, and the frog to accept load decreased peak pressures applied across the foot and served to protect the foot. The
histologic structure of the epidermis shows less ability to support mass than the frog, although the laminae have shown adaptive responses to increased force (Fig. 4).

![Wild horse](image1)  ![Domestic horse](image2)

**Figure 4.** Histology of the laminae.

### 6. Conclusion

This paper examines recent investigations into the three functions of the foot and the resulting form to the hoof capsule. The findings offer deeper understanding of the needs of the domestic horse, as biologic imbalance and undue stress in any one of the three functions may lead to chronic disease. The breakover location and hoof wall length will affect the forces on the DDFT and navicular bone. These forces will be changed by toe length and/or heel wedges. The part of the foot which contacts the ground first during landing absorbs the shock of impact. Studies indicate that forces are better attenuated through tissues located in the caudal aspect of the foot. Research on impact is needed to compare flat-footed and heel-first landing. With respect to the function of stance, the location of the widest part of the foot and the amount of surface area in contact with the ground will offer insight regarding the health of the foot.

The data show that the hoof/pastern axis decreases when the horse does not forage for the majority of its food or when the horse wears a shoe, leading to a series of
consequences. There is an increase in strain to the ligaments and DDFT at the back of
the foot effecting the peripheral nerves and vascularity to the foot. The resulting pain
causes a flat or toe-first landing, and the center of pressure during stance moves caudally
placing weight bearing away from the bone and onto the soft tissues at the back of the
foot.

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References and Footnotes


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