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BREAKOVER OF THE HOOF AND ITS EFFECT ON STRUCTURES AND FORCES WITHIN THE FOOT

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SUMMARY

The location of the breakover of the hoof capsule can be positioned through shoe placement, shoe shape, or trimming on barefoot horses. Placing the breakover in relation to the tip of PIII is a more dependable location than placing breakover guided only by visual evaluation of the hoof capsule. The hoof-pastern axis and the position of the navicular bone will be affected by the distance from the apex of the frog to breakover. The resulting decrease in strain of the deep digital flexor tendon while standing and during movement will decrease inflammation and disease in the equine digit.

INTRODUCTION

A straight alignment of the bones through their axis is considered optimal for physiologic function. Malalignment of the bones of the digit, also termed broken back hoof-pastern axis (HPA), is extremely common and has an incidence of 72.8%[1] in the forelimb of lame horses. Such malalignment will cause an increase in pressure on the navicular bone (NB) by the deep digital flexor tendon (DDFT).[2] Diseases associated with a low HPA include navicular disease, strained superficial digital flexor tendon (SDFT) and DDFT, and arthritis of the distal interphalangeal joint (DIP) joint.[3-5]

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Efforts to improve the alignment of the HPA have included trimming the toes and the heels.[6] Changing the location of the breakover, or shortening the breakover, has been advocated as a method of improving the alignment of the second phalanx to the third phalanx[7]; however, breakover locations vary from study to study. No work has assessed the specific location of breakover of the hoof capsule with respect to the third phalanx and its effect on alignment.

The purpose of this study was to document whether the specific location of breakover of the hoof capsule relative to the third phalanx would alter the alignment of the second phalanx to the third phalanx and the position of the navicular bone within the foot, as measured radiographically. The effect of such a change on the biomechanical forces of the DDFT at its insertion were determined.

MATERIALS AND METHODS

Horses (N = 11) ranging in age from 3 to 18 years and weighing from 188 kg (413 lb) to 550 kg (1,210 lb) were included in this study. All horses had no previous history of lameness and had been without shoes or farrier care for at least 6 weeks. When trotted on a cement surface, they were clinically sound and landed heel first on each foot.

Definitions Used in This Study

Breakover is the most dorsal location of the solar aspect of the hoof capsule that contacts the ground. This is the last part of the hoof capsule to leave the ground during the caudal phase of the stride. The sole plane is the keratinized sole composed of a superficial exfoliating epidermis and a deeper but firmer nonexfoliating epidermal tissue. The sole plane refers to the boundary between these 2 layers of epidermal tissue and can be

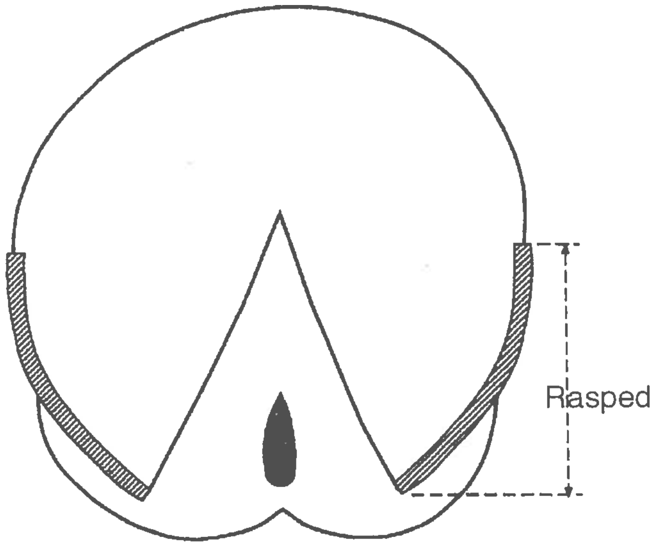

Figure 1. The hoof wall was rasped starting at the widest part of the hoof capsule and moving palmarly.

identified on removal of the flaky, white superficial layer. The true apex of the frog is the softer tissue at the apex of the frog that can be seen blending with the hard sole. This transitional zone is marked by a color difference with the frog being dark and the sole lighter in color. Other definitions used in this study include the widest part of the hoof capsule, which is the longest distance between the medial and lateral hoof walls, and the center of articulation of DIP joint, which is located as the sagittal midpoint of the distal articulation of the second phalanx, between the joint capsule attachments, as seen on lateral-medial radiographs.

Trimming Procedure. After an evaluation for soundness, all feet were trimmed before the first radiographs were obtained. The sole was prepared by the removal of only flaky tissue covering the sole. Sole tissue was not trimmed away; the frog was not trimmed. The hoof wall was rasped starting at the widest part of the hoof capsule and moving palmarly so that when viewed from the sole, the height of the hoof wall was 0.3 cm higher than the level of the sole plane (Fig 1).

Radiographic Method

Radiopaque markers were placed by inserting a thumbtack at the apex of the frog. Along the dorsal hoof wall, a metallic wire was taped to the hoof capsule with the proximal end of the wire is placed at the coronet. This location is palpated as the junction between the skin and the hoof capsule. Both front or hind feet were placed concurrently on wooden blocks imbedded with a horizontal radiopaque wire. Feet were positioned so that the third metacarpus or metatarsus was perpendicular to the ground. Efforts were made to have both forelimbs (or hind limbs) equally weighted. Lateral-medial radiographs were obtained with both bulbs of the heel being parallel to the radiograph beam and the radiographic cassette touching the hoof

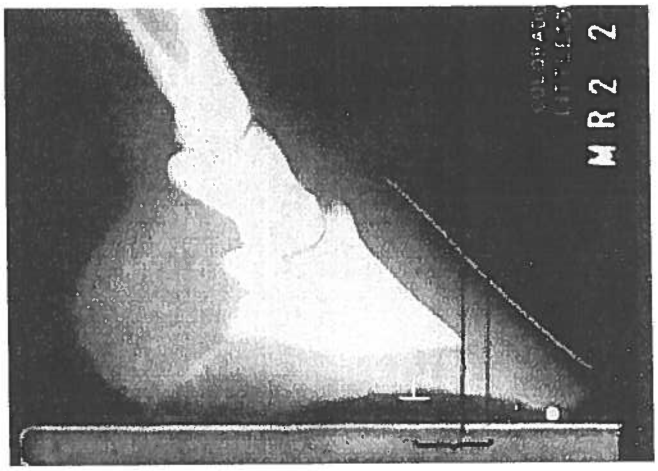

Figure 2. Radiograph showing the desired breakover distance.

capsule. Using this method, magnification was measured to be less than .075 cm.

Experimental Method

Using the first radiographs of each foot, a line was drawn on each radiograph from the tip of the third phalanx perpendicular to the ground. A second line dorsal and parallel to the first line was drawn at the following distances: 0.4 cm for horses 200 to 300 kg, 0.5 cm for horses 300 to 400 kg, 0.6 cm for horses 400 to 500 kg. The distance from the thumbtack to the most dorsal line was measured and called the desired breakover distance (Fig 2).

This same distance was measured on the solar aspect of the hoof capsule from the thumbtack dorsal toward the white line. A line was drawn perpendicular between the medial and lateral walls of the solar aspect of the hoof capsule at this distance. A rasp was used to roll the hoof wall and sole at this marked line at a 15° angle (Fig 3).

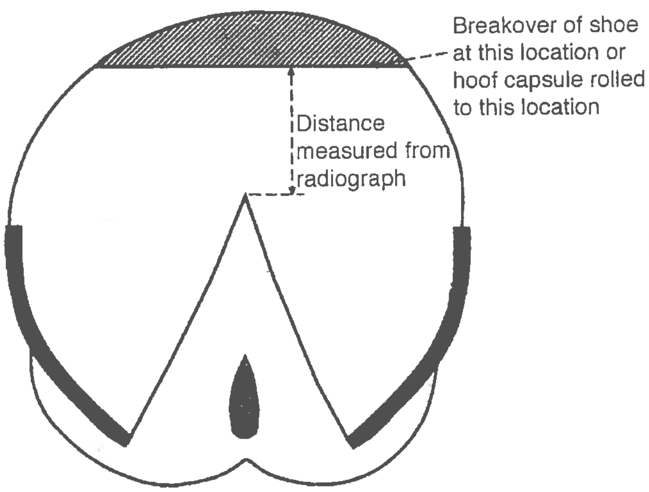

Figure 3. Diagram of breakover location on sole measured from radiograph.

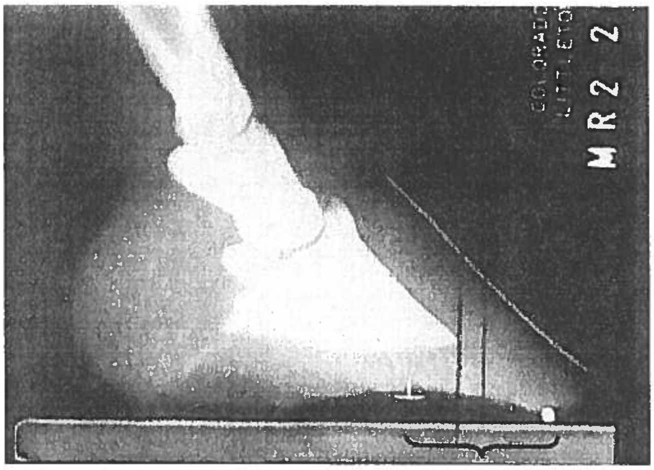

Figure **4.** Radiograph showing the original breakover distance.

A second set of radiographs using the same method were taken and the following measurements were made from the two sets of radiographs: (1) the distance from the thumbtack at the apex of the frog to breakover was measured, (Figs 2 and 4) to determine how much the breakover distance was reduced, (2) the angle between the second phalanx bisected sagittally and the dorsal aspect of the third phalanx (Fig 5) to determine the alignment between PII-PIII, (3) the distance between a line connecting the dorsal and palmar joint capsule attachments on the distal aspect of the second phalanx to proximal aspect of the navicular bone, (Fig 6) to measure the proximal/distal position of the NB, (4) the distance from a perpendicular line at the most distal insertion of DDFT called opposite (Fig 7), (5) the distance from the most distal insertion of DDFT to breakover called hypotenuse (Fig 7), (6) the distance from the center of articulation of the DIP joint to breakover at the toe (Figs 8 and 9) to assist in the calculation of the moment of inertia.

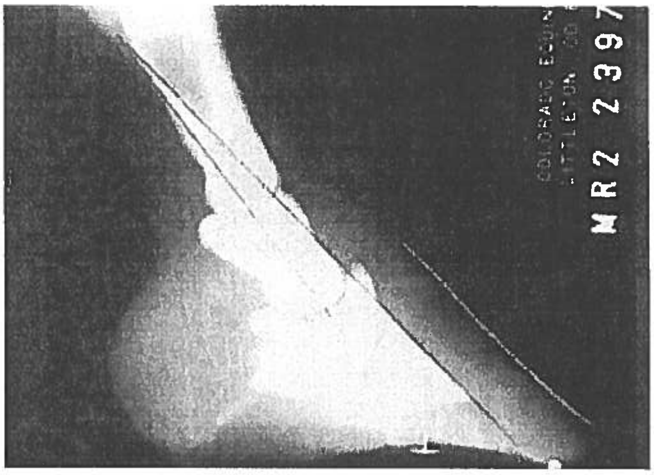

Figure **5.** Determination of the angle of the distal interphalangeal joint by drawing a line that sagittally bisects the second phalanx and one that traces the dorsal aspect of the third phalanx. The most desirable situation is when these 2 lines are parrallel.

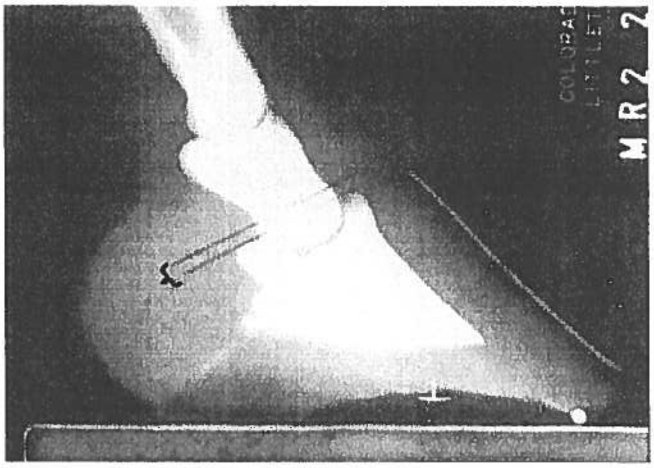

Figure **6.** The proximal/distal position of the navicular bone is determined by measuring the distance between a line connecting the dorsal and palmar joint capsule attachments on the distal aspect of the second phalanx to the proximal aspect of the navicular bone.

RESULTS

The results (Table 1) showed the following changes in the posttreatment measurements: (1) the distance from the apex of the frog to breakover decreased by a mean distance of 1.5 cm. ($P < .0001$), (2) the angle between the second and third phalanx decreased by 4.3° ($P < .0001$), (3) the distance from the joint capsule attachments of the DIP joint to the proximal aspect of the NB decreased by a mean difference of .21 cm ($P < .0001$), (4) the opposite decreased a mean of 1.4 cm ($P < .0001$), (5) the hypotenuse decreased a mean of 1.37 cm ($P < .0001$), (6) the distance from the center of articulation of the DIP joint to breakover decreased a mean of 1.4 cm ($P < .0001$), (7) the static strain of the DDFT on the third phalanx[8] decreased a mean 24.8 kg/cm ($P = .0003$), and (8) the moment of inertia[9] decreased by 13,266.5 kg/cm^2 ($P < .0001$).

DISCUSSION

The present study has shown that a decrease in breakover distance will (1) improve the alignment of the second phalanx to the third phalanx, (2) move the navicular bone proximally, and (3) decrease the calculated strain forces of the DDFT at its intersection at stance and motion.

Previously, breakover has been positioned relative to the hoof wall. Because the hoof wall is modified epidermis, there is the potential for distensability and variability to the hoof wall shape, as evidenced in club feet,[10] chronic laminitis,[11] and long

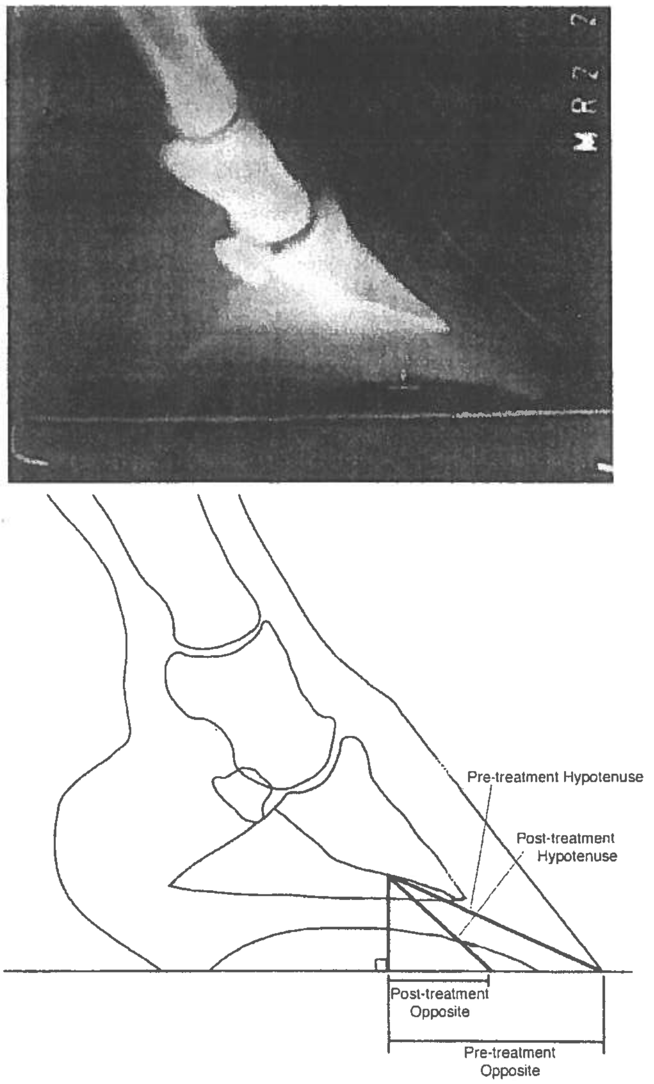

Figure **7.** The static strain forces of the DDFT is calculated with the following formula: strain = mass sin opposite/hpotenuse.

toe.[12] The breakover of the hoof capsule is the result of biomechanical forces from the internal forces in the foot coming through the tendinous attachments on the third phalanx against the external resistance from the outside environment. In addition, the position of the third phalanx can vary in relationship to the hoof capsule (Page BT, Ovnicek G, Erfle J, personal communication).

Movements of the distal phalanx occur whenever the foot is loaded normally,[13] with metabolic insults to the fragile laminae, with excessive loads on the bony column, or removal of supportive structures within the foot (Ovnicek G, Page BT, personal communication, 1997). In the present study, the position of breakover was standardized relative to the tip of the third phalanx. By using this site and its relationship to the apex of the frog, a consistent location of breakover on the hoof capsule was achieved relative to the third phalanx. In addition,

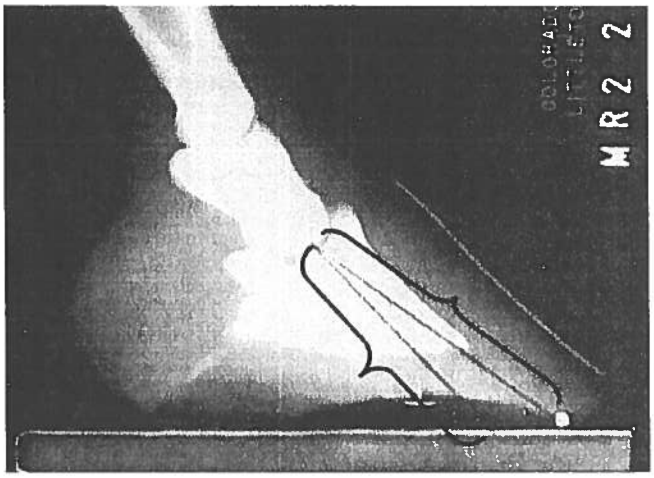

Figure **8.** The breakover distance influences the moment of inertia. Lines drawn from the center of the articulation between the second and third phalanges shows this change in distance.

the effects of these changes of this positioning of breakover, and their biomechanical results can then be compared more closely as the biomechanical forces now placed on the different foot structures appear to be relatively more constant from horse to horse. Although the position of the third phalanx was determined radiographically on a loaded limb, with experience the tip of the distal phalanx can be both visibly and palpably identified through the characteristics of the sole epidermis in most horses with minimal foot disease. In these instances, a raised epidermal callus (3-10 mm wide) can be observed on the sole immediately caudal to the white line along the dorsal hoof wall (Page BT, Ovnicek G, Bowker RM, personal communi-

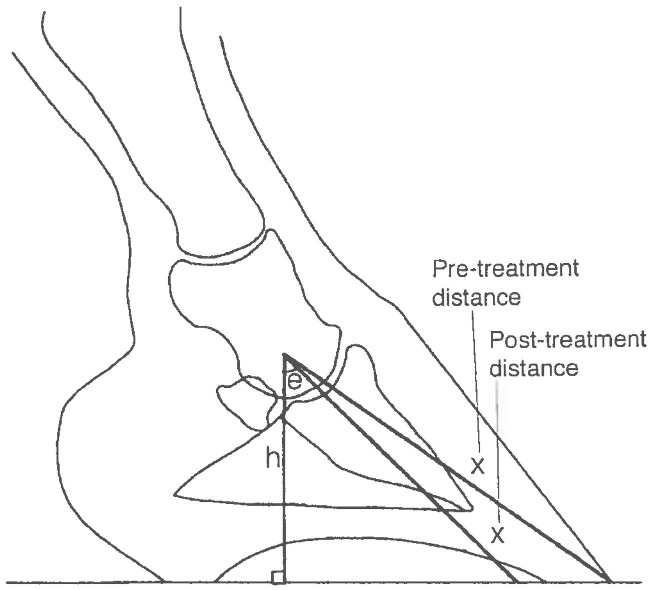

Figure **9.** The moment of inertia is calculated with the following formula: inertia = mass × distance^2 from center of articulation to breakover.

Table **1**.

All Data	N	Premeasurement pre-Mean	pre-Std	Posttreatment post-Mean	post-Std	Absolute Change abs diff Mean	Std	% Change Mean	Std	2-tailed Paired Test t	*P* Value
Frog-breakover (cm)*	21	4.1	0.9	2.6	0.7	−1.5	0.7	−35.8	12.3	−10.21	.0001
Angle PII-PIII (degrees)†	21	11.5	6.9	7.2	7.6	4.3	3.9	2.6	2.4	5.00	.0001
Joint capsule PII-proxNB‡	21	0.41	0.33	0.20	0.36	−0.22	0.21	−24.6	93.6	−4.75	.0001
Opposite (cm)§	21	5.46	.85	4.0	.59	−1.4	.72	−26	10.3	−9.3	.0001
Hypotenuse (cm)‖	21	6.17	.96	4.8	.65	−1.37	.72	−21	8.3	−8.8	.0001
Articulation to breakover (cm)¶	21	10.5	1.2	9.1	0.9	−1.4	0.8	−12.6	6.6	−7.66	.0001
Static DDFT strain (kg cm)#	21	4126	86.4	387.7	84.7	−24.8	25.7	−5.9	5.8	−4.4	.0003
Moment of inertia (kg/cm^2)**	21	53661.8	17349.6	40395.3	13188.4	−13266.5	8857.3	−23.3	11.4	−6.86	.0001

*Distance from apex of frog to breakover (cm).
†Angle between PII-PIII (°).
‡Distance from joint capsule attachment at distal PII to proximal dorsal navicular bone (cm).
§Distance from perpendicular and dorsal insertion of DDFT to breakover (opposite).
‖Distance from dorsal insertion of DDFT to breakover (hypotenuse).
¶Distance from center of articulation to breakover (cm).
#Static strain of DDFT onto PIII. Calculation: Strain = mass × sin opposite/hypotenuse.
**Moment of inertia (kg/cm^2). Calculation: Moment of inertia (kg/cm^2) = mass × distance from center of articulation to breakover.[2]

cation). Together these 2 methods compliment each other in verifying the location of the distal phalanx within the hoof capsule and the site of breakover.

Alignment of the hoof angle and pastern angle has been an objective of farriers and veterinarians for centuries[7] to minimize the internal stresses being imposed on the foot. The angle formed by the bony column of the phalanges with the hoof wall is referred to as the HPA and is ideal when the dorsal and palmar surfaces of the hoof are parallel to alignment of the digital bones.[14] Previously, evaluation of the HPA has been done through visual appraisal, which is nebulous and subjective. Individual variations of horses and various conformations of breeds may cause confusion when assessing the HPA[15] and a limb positioned behind or in front of the shoulder will change the pastern angle. Some researchers have preferred to use the angle of the shoulder as more dependable for HPA because of variability of soft-tissue thickness at the pastern.[16] That technique also lacks consistency because the spine of the shoulder is often obscured by muscle and horses often have shoulder angles, which are different from pastern angles.[15] The present work assesses the HPA using direct measurements of the digital bones, which is a more objective method than previously used to determine HPA.

This study showed an improved alignment between the second and third phalanges when the breakover was shortened in relation to the third phalanx. Various other methods have been used to align the second and third phalanges such as shortening the toe,[7] raising the heels,[17] or both.[18] Shortening the toe length by rolling or rockering the toe has been recommended to aid breakover.[18] Clinical responses were positive with this method, but there was not qualification of the amount breakover was decreased or the location of breakover to the bony column. One study showed radiographically, an improved alignment between the second and third phalanx by raising the heels.[17] Raising the heels will cause a secondary negative and unwanted biomechanical effect by decreasing the surface area of the hoof.[6]

In another study, the duration of the breakover was examined after decreasing the breakover distance and then comparing the time for the limb to leave the ground when shod in a flat shoe versus that in a rolled, rockered, or squared toe shoe.[19] No significant differences were observed between the 2 groups of shoes. However, in that study, no consistent measurement or quantitative assessment of the location of breakover was made, and as a result the subsequent changes in breakover distance was not determined. Also, no attempt was made to determine the relative position of breakover to any other foot structure, including the distal phalanx. Although the observations of the present study do not have any implications on the shortening of the breakover time at toe liftoff, the results do indicate that the forces generated at the flexor surface of the distal phalanx by the pull of the DDFT will be significantly reduced.

$$\text{Inertia} = \text{Mass} \times \text{Distance}^2$$

In the feral horse, the hoof wall is eroded by the constant movement of these horses over rough terrain to obtain a daily supply of food and water. The barefoot domestic horse is also influenced by the same external and internal forces on the foot during its movement across the ground surface, but because the domestic horse is restricted in its movements and often wears a shoe, insufficient erosion of the hoof capsule occurs, resulting in excessive growth of the epidermal hoof wall. This lengthening of the hoof wall will gradually increase the distance between the center of articulation of the DIP joint and the breakover at the dorsal hoof wall margin. By increasing the distance from the center of articulation of the DIP joint to the breakover, a low HPA will result. In addition, this low HPA will produce greater stress at the insertion of the DDFT onto the distal phalanx, as was determined mathematically by the moment of inertia forces generated at this site.

This insertion site onto the distal phalanx represents a region undergoing considerable stress, which can be observed histologically in the morphologic changes seen in the DDFT and the distal suspensory ligament of the navicular bone (distal sesamoidean impar ligament).[20] By decreasing this breakover distance, the stresses within the region, we hypothesize, should be reduced, resulting in reduced histologic signs of stress at the insertions of the DDFT and the distal suspensory ligament of the navicular bone. This can be supported mathematical because the change in angle between the second and third phalanx equals the change in the breakover distance times a constant. The constant is a radian measure and equals 180° divided by pi. This number equals 57°, which is the average angle of the hoof capsule measured in feral horses.[21]

$$\Delta\tau = \frac{180}{\pi} \frac{h\Delta x}{x\sqrt{x^2}} - h^2$$

When the breakover is moved closer to the tip of the third phalanx, the mass of the horse concurrently moves toward the palmar aspect of the hoof. This supports other work showing that a longer toe length causes an increase in flatfooted or toe-first landing.[22]

In the efforts of veterinary medicine to treat navicular disease, biomechanical treatments have been as successful as medical or surgical treatments.[23] Successful outcomes have been thought to result from the reduction of compressive forces of the DDFT onto the navicular bone.[24] In the present study, the results show that the navicular bone moved more proximally after decreasing the breakover, thereby decreasing compressive pressure from the DDFT onto the flexor cortex of the NB. Such a position of the navicular bone will decrease the weight-bearing capacity of this bone. This will reduce the pressures of the DDFT on the palmar cortex of the navicular bone. It is to be noted that a more proximal position will also shorten the distance between the insertion and origins of the navicular ligaments and has been hypothesized to improve the blood supply to the NB.[24]

Strain gauges can be used to measure the tension in the DDFT at midcannon with the horse standing and at a walk.[25] Their work showed a decrease in tension when the hoof angle was increased. The present study also shows a decrease in tension of the DDFT calculated from biomechanical formulas. The equine digit is a third class lever, the purpose of which is to multiply power and motion. A third-class lever will increase the speed at which a load can be moved and can move a load a greater distance.[26] The load is the mass of the horse; the effort is the pull of the DDFT at its insertion on PIII; and the fulcrum is the point, which is rotated around, the point of breakover. In this study, the breakover was moved closer to the third phalanx, thus the decreasing distance between the location of the effort and the fulcrum. Because the distance from the center of articulation to breakover is decreased and this number is squared, there is an exponential decrease in inertia.

CONCLUSION

The location of the breakover of the hoof capsule can be positioned through trimming, shoe shape, or shoe placement. Placing the breakover in relation to the tip of PIII is a more dependable location than placing breakover only guided by visual evaluation of the hoof capsule. The HPA and the position of the navicular bone will be affected by the distance from the tip of the frog to breakover. The resulting decrease in strain of the DDFT at stance and during movement will decrease inflammation and disease in the equine digit.

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