Effects of industrial polystyrene foam insulation pads on the center of pressure and load distribution in the forefeet of clinically normal horses

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Abstract

Objective—To evaluate the ability of industrial polystyrene foam insulation pads to redistribute loads placed on clinically normal weight-bearing structures of the foot and shift the location of the center of pressure palmarly in horses.

Animals—25 nonlame mature horses.

Procedures—Both forefeet from each horse were evaluated. Center of pressure data and solar load distribution patterns were recorded during a 5-second trial by use of a commercial pressure measurement system prior to placement of foam sole support and at 0, 6, 12, 24, and 48 hours after placement. Total contact surface area, contact pressure, peak contact pressure, and center of pressure positions were compared by use of a linear mixed model with repeated measurements.

Results—Total contact surface area was increased significantly at all time points, whereas contact pressure and peak contact pressure were significantly decreased at all time points following application of foam sole supports. Immediately following application of sole support, the position of the center of pressure was significantly moved cranially. However, by 48 hours, the center of pressure was significantly positioned more palmarly than prior to application of the foam supports.

Conclusions and Clinical Relevance—Results indicated that the use of foam sole supports may be an effective, economical, and immediate treatment for acute laminitis.

Disciplines
Large or Food Animal and Equine Medicine | Other Kinesiology | Statistical Methodology | Veterinary Physiology

Comments
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Laminitis has afflicted the equine population for centuries and continues to be a substantial contributor to equine morbidity. It is believed that the cause of laminitis is likely multifactorial; therefore, it is difficult to identify a single mechanism of action. Many in vitro experiments have provided insight regarding potential pathways for the development of laminitis, but such pathways are difficult to confirm in vivo. The exact etiologies remain elusive, and the goals of treatment of acute laminitis are mainly supportive—relieve pain, halt or slow progression of the disease, and enhance recovery.

There is considerable controversy regarding the best way to treat laminitis in the acute phase. An ideal approach to management of acute laminitis should include treatment aimed at the physiologic and biomechanical mechanisms of the disease while providing the horse with appropriate analgesia. Mechanistically, this would include an intervention that decreases the stresses placed on the laminar junction. The options for accomplishing this are to decrease the force exerted by the deep digital flexor tendon on the third phalanx, decrease the force acting in a vertical manner on the lamina, and increase the surface area across which the vertical load is distributed. Additionally, an ideal treatment should be easy to administer and cost-effective for owners. Deep digital flexor tenotomy is an effective way of removing the strain in the deep digital flexor tendon, but because of surgical complications and a poor prognosis for athletic soundness, this surgical intervention is reserved for salvage cases. Raising the heels is a less aggressive method of reducing strain in the deep digital flexor tendon by shifting the center of pressure palmarly (or plantarly), but results of a study in which a 59% increase in lateral hoof wall strain resulted from a 15° to 20° heel elevation suggest that severe wedging may be detrimental to successful laminitis treatment. Increasing the weight-bearing surface area of the foot distributes the vertical load over a larger area, thereby

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decreasing the load placed on the normal weight-bearing structures—mainly the hoof wall.

A popular belief is that the support offered by applying industrial polystyrene foam insulation sheeting (known as blue foam) to the sole of the foot redistributes the weight of the horse, normally borne mainly by the hoof wall, to include the entire palmar surface of the foot. This would then decrease primary weight bearing by the hoof wall and presumably the laminar structures and redistribute weight to the sole and frog. In addition, it may provide support to the digital cushion and tissues between the distal phalanx and the sole. To this effect, prevention of laminar separation may be possible.

The purpose of the study reported here was to evaluate the ability of polystyrene foam sole supports to increase the weight-bearing surface area of the feet, decrease contact pressure, and move the center of pressure palmarly and validate its use as an effective means of minimizing load on hoof wall and presumably the laminar junction, with the long-term goal of providing an evidence-based approach to treatment of acute laminitis in horses. We hypothesized that the weight-bearing surface area in the forefeet of horses would be increased, the contact pressure decreased, and the center of pressure moved palmarly.

### Materials and Methods

Twenty-five healthy, mature horses (mean age, 11 years [range, 3 to 25 years]; mean weight, 493 kg [range, 311 to 667 kg]) were used in this study. There were 10 American Quarter Horses, 3 American Paint Horses, 2 Thoroughbreds, 2 Arabians, 2 Appaloosas, 2 Friesian crossbreds, 1 Haflinger, 1 Morgan, 1 Thoroughbred crossbred, and 1 Arabian crossbred. Each horse was required to have a history of regular foot care, be at least 2 weeks from its most recent foot trim (range, 2 to 8 weeks), currently be unshod, and have no history of laminitis. Prior to inclusion in the study, each horse was determined to be healthy on the basis of results of physical examination, including attitude, rectal temperature, pulse rate, respiratory rate, digital pulses, and absence of lameness. Physical inspection of each foot was used to identify and exclude horses with divergent growth rings, prolapsed soles, and defects at the coronary band. Radiographs were obtained of each forefoot to confirm absence of laminitis (eg, displacement or remodeling of the third phalanx). Horses were housed in individual stalls with wood shaving bedding over rubber mats, allowed free access to water, and fed a grass-alfalfa mix hay twice daily. Daily monitoring of general attitude, feed intake, water intake, urination, and defecation was performed. This study was approved by Iowa State University’s Institutional Animal Care and Use Committee.

**Study design**—Because of the necessity for equal weight bearing on both forefeet during each study condition, it was necessary to use a block design. Each forelimb of all horses was subjected to 2 test conditions and served as its own control. In the first (control) condition, each forefoot was thoroughly cleaned with a hoof pick and wire brush and positioned on a high-resolution pressure mat on a smooth, level, concrete surface. Each horse was allowed time to stand calmly and evenly. Care was taken to ensure each horse was standing squarely. Center of pressure data and solar load distribution patterns were then recorded during a 3-second trial at a sampling frequency of 100 Hz. If the horse moved during the sampling time, that trial was terminated and a new trial initiated. Following data collection of the control condition, a foam sole support was placed on each forefoot, thereby initiating the treatment condition. The horse was then allowed to briefly bear weight on each foam support prior to positioning each foot again on the pressure mat for data collection at time 0. The horse was returned to its stall and data collection was repeated at time points 6, 12, 24, and 48 hours.

**Sole supports**—Each foot was placed on a section of 1.5-in-thick industrial foam closed-cell insulation sheeting to obtain an outline of the hoof. The foot was then removed and the foam cut to match the perimeter of the hoof. A foot bandage used to secure the foam to the sole was created from strips of duct tape approximately 35 cm in length placed perpendicularly to each other until the bandage was approximately 1.5 times the diameter of the foam cutout. The foam cutout was then placed on the center of the duct tape and positioned in contact with the sole of the foot. The duct tape was then folded proximally to provide adherence to the hoof wall, securing the foam. Wraps of tape placed circumferentially around the hoof wall were then used to further secure the duct tape. A layer of elastic tape was used proximally to prevent stall shavings from interfering with the adherence of the duct tape. If the horse did not bear weight squarely on the foam support as determined by visual inspection (ie, the support slipped during initial weight bearing), a new foam cutout was created and used.

**Solar load distribution and center of pressure measurements**—A high-resolution commercial pressure measuring system connected to a computer was used to record pressure distribution patterns for each foot. The thin-film (0.18-mm) tactile pressure mat sensor is composed of 8,448 evenly distributed pressure-sensing elements arranged in rows and columns across the sensor surface with a spatial resolution of 3.9 sensing elements/cm². The dimension of each sensing element is 0.508 × 0.508 cm with each element separated by 0.508 cm. A custom software package was used to calculate the total contact surface area, total contact pressure, and peak contact pressure for each frame of data. The position of each sensing element corresponds to an x- and y-coordinate system related to the dimensions of the grid with the grid origin located at the upper left corner of the mat. The center of pressure was output as an x- and y-coordinate on this pressure grid matrix. To allow accurate comparison between feet, the center of pressure location was standardized to a consistent coordinate system within each foot by 2 of the authors (JAS and TRD). The x-axis was defined by a line connecting the heels with the axis origin located at the medial heel of the right foot and lateral heel of the left foot. Each foot coordinate system was then rotated.
resulting in a horizontal x-axis (x') by use of the following formulas:

\[ x' = x \cos \alpha + y \sin \alpha \]
\[ y' = -x \sin \alpha + y \cos \alpha \]

where \( \alpha \) is the calculated angle of rotation. As a result, the x-axis defines the medial-lateral plane and the y-axis the cranial-caudal plane (Figure 1).

Center of pressure was defined as the mathematical location of the point of action of the ground reaction force on the foot. The standardized y-coordinate was used as the response in statistical analysis. Contact pressure was defined as the total pressure encountered by the loaded sensing elements. Peak contact pressure was defined as the pressure of the single sensing element that received the largest amount of load. Total contact surface area (cm²) was defined as the surface area of all loaded sensing elements. Calibration of the pressure mat occurred prior to data collection at each time period. The calibration weight was obtained by placing the right forefoot of each squarely standing horse onto an inground scale. This weight was then entered into the software program during the calibration mode with the same foot placed on the sensor.

Statistical analysis—For each response, data were analyzed by use of a linear mixed model with repeated measurements. Treatment and time (nested within treatment) were considered as fixed effects, and horse and its interactions with the fixed effects were considered as random effects. Foot was the subject of repeated measurements. Three structures were considered for the covariance matrix of the repeated measurements from the same subject: variance components, compound symmetry, and unstructured. The Akaike information criterion was used as a goodness-of-fit statistic for model selection. The covariance structure with the smallest Akaike information criterion was chosen for the report. Analysis was performed by use of a commercial software package. F tests with Kenward and Roger adjustment to df were applied for significance of the fixed effects. If a fixed effect was found to be significant, post hoc Tukey t tests were applied for pairwise comparisons between group means. Significance was set at \( P < 0.05 \).

Results

The foam sole supports were well tolerated by all horses, and all supports remained in place during the study. For total contact surface area, contact pressure, and center of pressure location, the unstructured covariance matrix structure gave the best fit to data. For peak contact pressure, a variance component covariance structure gave the best fit. For total surface contact area, both treatment and time were significant. By use of the Tukey adjustment for multiple comparisons, all pairwise differences between time periods (control, 0, 6, 12, 24, and 48) were significant (Figure 2). Twelve hours after sole support placement, 10 of 50 (20%) feet had dimensions of varying size that were devoid of any weight bearing in the areas of the sole and frog. At 24 hours, 23 of 50 (46%) feet had similar characteristics, and by 48 hours, this number increased to 42 of 50 (84%) feet (Figure 3). For contact pressure, both treatment and time were significant. By use of the Tukey adjustment for multiple comparisons, differences between the control time and all other times were significant and differences between time 0 and all other times were significant (Figure 4). For peak contact pressure, both treatment and time were significant. By use of the Tukey adjustment for multiple comparisons, differences between the control time and all other times (6, 12, 24, and 48) were significant and differences between time 0 and all other times (6, 12, 24, and 48) were significant (Figure 5). For center of pressure location, time was significant. At times 0 and 6, the center of pressure was significantly shifted cranially from the control location. By 48 hours, a significant shift of center of pressure in the palmar direction from the control location was detected (Figure 6).
Discussion

Results of this study indicated that the use of a foam sole support increased the weight-bearing contact surface area, decreased total contact pressure, and decreased peak contact pressure for at least 48 hours. Additionally, a significant palmar shift in the center of pressure was achieved by 24 to 48 hours. The decrease in contact pressure supports the hypothesis that recruitment of a larger surface area by use of the sole and frog reduces the weight-bearing demand on the hoof wall. Hence, it can be inferred that the weight bearing demand of the laminae is also reduced. Although it would have been advantageous to have measured the strain at the laminar junction, methods by which to measure internal strain of the hoof in vivo are not presently developed. Although the importance of recruiting the sole and frog to distribute the load placed on the foot during episodes of acute laminitis is recognized by most practitioners and farriers, the means of doing so are not standardized. This is supported by the myriad of homemade and commercially available products with varying degrees of evidence that weight bearing is altered.5,8–13 Foam supports have been advocated by many practicing veterinarians and farriers, but scientific evidence for their use has previously been unavailable.3,4,14,15

The present study revealed that total contact surface area was significantly increased up to 48 hours after placement of foam sole supports. However, it is important to note that although there was a significant increase in surface area at 48 hours, compared with the control condition, after time 0, there was a significant decrease in surface area at each time point, compared with the previous time point. The steady decrease in contact pressure after time 0 was probably the result of 2 mechanisms. The first relates to the material properties of closed-cell foam, which is a point-compliant material that deforms at the point of force. In this study, compression of the foam support occurred because of the weight of the horse. The second factor was likely associated with the housing condition of the horses. The horses were housed on wood shavings on top of rubber mats. The cushion provided by the shavings was likely contributory to the compression of the foam support against the sole of the foot. This observation is supported by a study that evaluated the effect of a polyurethane-filled standard steel shoe on pressure distribution in clinically normal feet. No difference in pressure distribution pattern or mean pressure between horses with standard shoes and those with polyurethane-filled shoes was detected when horses were on a nondeformable concrete surface. Significance was found in both of these variables, however, when horses stood on a de-
formable surface. The decrease in the contact surface area after time 0 in the present study, then, may have been caused by plastic deformation of the foam support by the weight of the horse, with contribution by the deformable surface of wood shavings. When removed from the deformable surface and placed onto the non-deformable pressure mat surface, the measured contact surface area was less. If the study were to be repeated with a deformable surface between the pressure mat and the foam support or with a pressure measurement film between the sole and the foam support, the results may be different. The contact pressure steadily and significantly decreased until 6 hours after application. Because pressure is a measurement of force over area, this result was expected. However, after 6 hours, there was no further significant decrease in contact pressure. This was likely caused by the foam support reaching its limit of compression, resulting in the plateau seen graphically. Likewise, the peak contact pressure decreased significantly following application of the supports and remained significantly decreased from the control condition throughout the study, but when compared with the peak pressure immediately following foam placement (time 0), the peak pressures at the remaining time periods were significantly increased. This also was likely the result of maximal compression of the foam support at 6 hours after application. Subsequent studies aimed at application of a second layer of foam support at this time may reveal further therapeutic effect.

By the end of the study, 16 of the 50 (32%) foam sole supports were worn through, exposing the toe of the foot. The authors recognize that this study was performed in clinically normal ambulatory horses, some of which spent considerable time walking about their stalls, and this may have been a contributory factor in foam support wear. Yet, if a horse with acute laminitis is reluctant to lie down, treads in the stall in an effort to decrease the load on its feet, and spends most of its time standing, the results of this study would be expected to apply. The wear pattern may be different in affected horses, and the foam supports should be monitored closely.

In the forefeet, the center of pressure at midstance is usually located in the craniomedial quarter of the foot. However, center of pressure is dependent on limb and foot conformation, the manner in which the horse is standing with regard to its body mass, position of the foot in the stance phase, and shoeing and trimming. For these reasons, special care was taken to ensure horses were standing squarely and quietly before recording any data. A palmar shift in the center of pressure decreases the moment arm acting at the distal interphalangeal joint, thereby decreasing the stress on the third phalanx from the deep digital flexor tendon. This is an important concept in the acute phase of laminitis in which minimizing the pull of the deep digital flexor tendon may be desirable. In the present study, the palmar shift in the center of pressure may have partly been caused by the horses wearing the foam support into a wedge shape. Elevation of the heel would have caused a decrease in the palmar angle of the distal interphalangeal joint, thereby resulting in the palmar shift of the center of pressure. Although foot angle was not directly measured in this study, this theory is supported by the observation of wear-through at the toes of the pads but not the heels. The significant cranial movement of the center of pressure at the time of foam support placement was not expected. The center of pressure did not return to the control location until 12 to 24 hours after placement and was not significantly shifted palmarly until 48 hours after placement. It is not likely that the foam support was physically weaker at the toe because it is uniformly constructed and the cranial movement was not restricted to just a few horses. It could be explained as a reaction by the horses to an unfamiliar weight-bearing surface and exposure to a new situation that caused a change in their stance. The clinical importance of this finding, however, would indicate that it would be desirable to maintain a foam support for at least 48 hours to benefit from a palmar shift in the center of pressure.

Treatment of acute laminitis is a controversial topic. Even consensus on the appropriate use of foam supports is not established. Some practitioners advocate the use of 2 layers of foam support rather than 1. Some replace the support at 24 hours. Agreement on the appropriate thickness of the foam support is not recognized. According to data from the present study, 1.5-in-thick foam supports provide a significant increase in weight-bearing surface area and a significant decrease in contact pressure for 48 hours and a significant palmar movement of the center of pressure between 24 and 48 hours. Although the use of clinically normal horses is recognized as a limitation of this study, the evidence suggests that the use of foam sole supports as described holds promise in the treatment of early laminitis. Further studies of this treatment in a population of horses with acute laminitis are indicated.

References


