Effects of Ground Surface on Solar Load Distribution

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This study indicates that the solar surface of the normal foot is a structure directly involved in weight bearing when the foot is on a natural surface. The wear of the weight-bearing hoof wall is unevenly affected by natural ground surface, resulting in a four-point contact pattern when the horse is on a flat solid surface. When maintained on flat concrete, the four-point loading pattern disappears. The four points of contact result from the relative lack of wear and thus represent those portions of the wall that are not in high load contact. Until it is known how, or if, unequal loading on the bearing wall affects load distribution and dissipation through the foot, speculation that it is harmful, beneficial, or inconsequential to the horse is open to clinical interpretation. Authors’ address: Hoof Project, Dept. of Veterinary Physiology and Pharmacology, College of Veterinary Medicine, Texas A&M University, College Station, TX 77845. © 1997 AAEP.

1. Introduction

Mechanical failure of the equine foot can result in lameness that is either due to traumatic pathologies within the foot itself or to the muscles, ligaments, tendons, or skeletal components of the limb.1 Understanding the pathophysiology of these injuries requires an understanding of how the foot is loaded during weight bearing, how the foot responds to that load, and how modifications made to the foot through trimming and shoeing affect its biomechanics.

Numerous references support the concept that the primary supporting structure of the horse’s foot is the wall.2,3 This concept extends from such general statements that the bearing surface of the wall is the primary contact region and that the distal phalanx is suspended from the inner surface of the wall. Data supporting these statements appear to be based largely on the appreciation of the relationship between the foot’s form, its anatomy and conformation, and its function. Recently, an appreciation of digital biomechanics has been expanded to include concepts gained from studies of the wild horse’s foot.4

Data from these studies demonstrated that the contact between the foot and the ground was not uniform but instead demonstrated a consistent pattern wherein the heels and medial and lateral regions of the toe were longer than the intervening wall in the quarters or across the dorsal toe. This pattern has been designated the four-point load pattern. These data have been interpreted to signify that these regions are the primary contact points during normal weight bearing. This loading pattern has been clinically extended to include suggestions that trimming and shoeing a foot to allow this solar conformation would be beneficial to the horse.
Prior studies in this laboratory have utilized a force mat system\(^9\) to document the load distribution across the solar surface of the hoof.\(^5\) These studies provided data that document that domestic horses maintained unshod on pasture demonstrate a loading pattern similar to that recorded in wild horses. The study reported here was designed to evaluate the origin of this loading pattern. The hypothesis being tested is that the four-point loading pattern is the result of ground contact on natural surface and represents those areas of the solar surface that are not in contact with, or as worn by, ground contact as the surrounding solar surface of the foot.

2. Materials and Methods

Five adult horses were used in this study, each of which had been maintained unshod and untrimmed for a minimum period of 6 weeks on pasture. Pasture conditions varied during the 6-week conditioning period, from being relatively dry during the first 4 weeks to being extremely muddy during the last 2 weeks. Individuals used consisted of a Dutch Warm Blood gelding, an Arabian mare, and three Quarter Horse geldings.

The experimental design for this effort consisted of two separate experiments. The first sought to evaluate if the four-point solar loading pattern present in horses on a solid flat surface was significantly different from that present in the horse standing on a deformable, more natural surface. In this experiment the regional ground reaction forces between unshod horses on a flat solid surface and those placed on a loose sand surface were compared. For this experiment the ground reaction pattern was collected immediately following removal of the horses from pasture. All data sampling was completed under quasi-static conditions, which consisted of having the horse restrained in a stock while loosely cross-tied. Pretreatment for this study consisted only of picking out the horse’s feet and brushing the solar surface of the foot to remove accumulated dirt.

The ground loading pattern was collected by using a carbon-fiber force mat system. This system detects and records regional ground reaction forces at a \(1/4\)-in. (~0.6 cm) discrimination. Data collection was completed by using a 50-Hz sampling rate over a 5-s duration data-collection period. Data consisted of a two-dimensional map of the pressure (pounds/in.\(^2\)), documentation of the location of the center of load, and the total contact surface area of the solar surface of the foot against the ground.

Following data collection on the solid flat surface (hard rubber over wood), the foot was lifted and placed on 1 in. of loose dry sand and a second data set was collected by using the same data-collection procedures. Data were visually examined to denote the general loading patterns subjectively. The total surface contact areas were compared by using a paired t test.

The second experiment evaluated if the four-point pattern was affected by maintaining horses on a solid, flat, nondeformable surface. This was accomplished by comparing the regional ground reaction patterns of unshod horses maintained on pasture with the patterns in the same horses following maintenance on a flat concrete surface for 7 days. Horses were examined twice daily for foot condition and evidence of lameness. Data sets were collected after 5 and 7 days of concrete maintenance. The data analysis used in this experiment was the same as that used in the first experiment.

3. Results

All five horses demonstrated a four-point loading pattern after being maintained on pasture for a period of 6 weeks. The highest pressure contact was at both heels and just medial and lateral to the wall at the dorsal toe. The center of load was characteristically in the medial anterior quadrant of the foot. The average surface contact area was 2.78 ± 0.43 in.\(^2\)

The loading pattern present in horses standing on loose sand was characteristically a solar loading pattern, with the highest contact being made in the central regions of the sole and little on the walls. The pattern was elongated, running from the medial to lateral quarters of the foot. This sand loading pattern was typically the opposite of that observed when the horse was on a solid flat surface. Average contact area in sand was 11.49 ± 1.78 in.\(^2\) and was significantly \((p = 0.0003)\) greater than that recorded with the horse on a solid surface.

None of the horses maintained on concrete demonstrated obvious discomfort or lameness. The feet of the horses were visually affected by contact with the concrete. The wall was significantly worn and the anterior regions of the sole were in contact with the ground. The rate of wear appeared to be related to the weight of the horse relative to the size of the foot. The heaviest horses with normal hoof conformation demonstrated the fastest wear, the lightest horse with a normal conformed foot wore more slowly, and the horse with the least body mass and largest foot demonstrated the slowest change.

Data collected following maintenance on concrete demonstrated a characteristic loss of the four-point loading pattern and a significant increase in the solar contact area. At 7 days, all five subjects demonstrated that wall and solar loading was present extending from one heel around the dorsal surface to the opposite heel. The average area after 7 days on concrete was 6.198 ± 0.52 in.\(^2\). This value was significantly different from the control. Several horses demonstrated contact between the frog and bars. The midregions of the sole were not in contact. A physical examination of the feet of these horses demonstrated that the wall at the dorsal toe was not in contact with the ground.

An evaluation of the sand loading patterns following maintenance on concrete demonstrated an apparent change in load distribution. Rather than the elongated pattern present in the horses maintained
on pasture, the after-concrete sand pattern was more circular and located in the center of the sole and frog of the foot.

4. Discussion

These data support the concept that the four-point solar loading pattern, present on the feet of horses on pasture and wild horses on natural terrain, is the result or effect of wear of the hoof secondary to ground contact. The reduction of the four-point contact pattern by maintenance on concrete implies that the foot obviously responds to ground surface. That is, a deformable surface is required for uneven wear of the hoof wall.

These results also suggest that when the horse is on a natural ground surface, the regions of the foot that are in primary contact with the ground are across the solar surface rather than the four points on the wall. This conclusion is based on the loading patterns obtained when the horse was placed on sand, which uniformly resulted in contact on those regions between the four-point pattern observable when the horse was on a flat solid surface.

In this study, the use of sand is acknowledged to represent an extreme in ground softness. Its dryness and looseness allowed it to be easily displaced and fill the solar surface of the foot. It thus represents the opposite extreme for the evaluation of regional solar loading relative to a flat solid surface. It thus follows that when the horse is placed on surfaces between these two extremes of relative hardness, such as is expected of a natural ground surface, load distribution will be placed at least partially on the sole. When the ground is hard, more of the load will be distributed to the bearing portions the wall. These data, coupled with anatomical evidence, suggest that statements that imply that the distal phalanx is totally suspended from the inner surface of the hoof wall cannot be considered accurate. The solar surface of the distal phalanx must bear partial and variable responsibility for the support of the horse during digital loading.

These data also validate the hypothesis that the concavity of the solar surface may play an important role in foot biomechanics. Not only should this domed shape be viewed as a weight-bearing structure, but it may also be responsible for shaping the ground surface to allow maximum load distribution across the solar surface of the foot. This is supported by the change in the sand loading pattern following change in the structure of the foot imposed by contact with a solid ground surface.

These data neither support or refute that a four-point loading pattern is a desirable conformation for the normal horse. This hypothesis can only be tested after a much more thorough knowledge of digital biomechanics is obtained. These data suggest that a four-point pattern develops secondary to the uneven wear on the solar surface and bearing wall. Until it is known how, or if, unequal loading on the bearing wall affects load distribution and dissipation through the foot, speculation that it is harmful, beneficial, or inconsequential to the horse is open to clinical interpretation.

References and Footnotes


Tekscan Matscan system, Tekscan Inc., South Boston, MA 02127-1342.