In-Shoe Force Measurements and Hoof Balance

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ABSTRACT

Keywords: Horse; Hoof; Force; Load; Balance

INTRODUCTION

The term “balance” has been used as a general term to describe an ideal for hoof trimming, positioning, loading, and gait. The exact definition of balance is rather unclear because there are numerous descriptions presented in the published data. Furthermore, beyond the basic term, subcategories exist for the description of balance as either static or dynamic.

Numerous methods have been advanced that are intended to result in a balanced foot. However, these protocols can produce different results, depending on the reference points used. For example, one publication describes a foot as balanced when “the ground surface of the hoof is perpendicular to the axis of the limb (when viewed from the front), the medial and lateral hoof walls are equal in length, and the coronet is parallel to the ground.” Although these reference points might seem to be reasonable while trimming a hoof, a closer examination shows a disturbing result: these three reference points would result in a different trim 71% of the time because the limbs and feet of most horses showed consistent asymmetry. Dynamic assessment of the horse further confounds the issue because factors such as impact pattern and limb interference provide more reference points to be considered and lessen the probability of obtaining a standard definition of a “balanced” foot.

There have been attempts to examine the horse in its “natural” state to elicit more information about the ideal hoof. Although the value of this information has been debated at length, an undeniable result is that the hoof shape varies based on the environment in which the horse lives, and on the individual horse. Ponies living in Pennsylvania have different hooves compared with those of mustangs living in arid climates, and both differ from feral horses living in areas with soft footing. Furthermore, these environmental conditions may vary considerably from the conditions experienced by many of the domestic horses in the care of farriers. Thus, the value of these feral-horse models is not fully understood.

The addition of a rider and the unique demands of each equine athletic discipline further change the forces on the hoof, and are likely to change the idea of “balance” considered for each animal. It is important to note that these influences on balance, although potentially dramatic, are external to the horse. As such, the concept of balance as “one size fits all” is doubtful.

Finally, the term “balance” has ramifications for the entire animal and not just the individual digit. Conformation is not consistent within a particular horse, because a pair of feet is often categorized as uneven or “mismatched.” There is no consensus in the published data regarding the merits of allowing dissimilar feet to remain so, or in using trimming and shoeing to minimize these differences. Furthermore, the influence of time within a shoeing cycle has been shown to have a significant effect on the structures of the foot, unavoidably influencing the concept of ideal balance.

MEASURING LOADING FORCES

One of the goals of our study group has been to examine the loads experienced by the ground surface of the hoof under various conditions. The equipment used for data collection includes the following:

1. F-scan mobile in-shoe force measuring system (Tekscan, Cambridge, MA, USA). Sensor mats are cut to the shape of the hoof and placed between hoof and shoe.
2. Sigafoos Series I horse shoe (Sound Horse Technologies, Unionville, PA, USA).

An instrumented foot is shown in Figure 1. The system is calibrated according to the manufacturer’s directions before each study. The sensor cuff is mounted over a polo wrap on the outside of the cannon. For trials without a rider, the data collector is carried alongside the horse by the horse handler. In trials involving a rider, the data logger is attached to the rider’s belt.

For our studies on hoof balance, force at the solar surface of the hoof was recorded at rest and during the walk and the trot. Data were collected in intervals of 8 seconds at a collection rate of 200 frames/s. The data were analyzed using the F-shoe mobile research software (version 6.33).
CASE 1: RADIOGRAPHIC AND VISUAL ASSESSMENT OF BALANCE

An 16-year-old Quarter Horse mare was trimmed and shod, with hoof balance assessed radiographically using both lateromedial and level dorsopalmar views. Specifically, on the dorsopalmar view, the coffin joint space was determined to be even in width across the joint, and the distal margin of P3 was parallel to the ground (i.e., the vertical distance from distal P3 to the ground was equal on medial and lateral sides). The desired position of the shoe and sensor was also confirmed radiographically. A low palmar (abaxial sesamoidean) nerve block was performed just before data collection. Measurements were then made at rest and with the horse walking and trotting on a hard surface.

As Table 1 shows, 65% of the force was located on the medial side of the hoof at rest. This disparity in load was reversed at the walk, with the horse showing a lateral loading pattern. On an average of six strides at the walk, 66% of the force at midstance was located in the lateral side of the hoof. However, at the trot, force was equally distributed between the medial and lateral sides of the hoof at midstance. Visually, this mare showed a lateral loading pattern when viewed from front at the walk.

Next, a urethane wedge was attached to the medial side of the shoe (as shown in Fig. 1). Wedge height was gradually adjusted until the hoof appeared to land evenly (i.e., both medial and lateral sides landed simultaneously) at the midstance. The in-shoe membrane (green sheet), positioned between hoof and shoe. A removable wedge (black material, attached here to the medial shoe branch) allows changes to be made in hoof balance in the mediolateral and dorsopalmar planes. Right: Cables and data recorders attached to the horse and tack. The Tekscan in shoe force measured membrane shown positioned between the hoof and the Sigafoos Series I Glue on horseshoe (Sound Horse Technologies). Removable wedges (left) allows the adjustment of hoof balance in the mediolateral and dorsal-palmar planes. Data collectors were, attached to the riders’ waist, the saddle, or carried next to the horse, depending on the testing conducted. (This is a two-part photo, showing an instrumented foot on the left and how the cables and data recorder are attached to the horse on the right).

### Table 1. Force distribution between medial and lateral sides of the hoof in case 1

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<th>Gait</th>
<th>Medial (% of force)</th>
<th>Lateral (% of force)</th>
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<tbody>
<tr>
<td>Rest</td>
<td>65%</td>
<td>35%</td>
</tr>
<tr>
<td>Walk</td>
<td>34%</td>
<td>66%</td>
</tr>
<tr>
<td>Trot</td>
<td>50%</td>
<td>50%</td>
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Before data collection, the hoof was balanced in the mediolateral plane using radiographic guidance (see text). Force distribution at mid-stance is shown for the foot at rest (i.e., standing still) and at the walk and trot.

With the hoof balanced in the mediolateral plane using the reference points of coffin joint spacing and a parallel solar margin of the distal phalanx in the mediolateral plane, distribution of force on the medians of the hoof at mid-stance differentiated by gait.
walk. Forces were again measured at rest and at the walk and trot. As shown in Table 2, altering the visual loading pattern to create an even landing lateromedially was effective at improving lateral-medial loading symmetry at the walk but it created greater load medially at the trot.

### CASE 2: MOVING WITH A RIDER

In a separate study, both the fore feet of a 4-year-old Dutch Warmblood gelding were instrumented as described previously and the forces in both the hooves were measured while riding the horse. The measurements were collected on a firm surface and then in a dressage arena, with the rider performing routine dressage movements appropriate to the horse’s level of training. Pertinent results included the following:

- On a firm surface, 100% of the force at the trot was transmitted to the perimeter of the hoof through direct contact with the shoe (Fig. 2).
- In the soft footing of the arena, 67% of the force at the trot was transmitted to the perimeter of the hoof through the shoe, and the remaining 33% was spread over the sole and frog.
- Force was equally distributed between the left and right feet (50% each).
- Hoof impact in both feet was slightly lateral.
- At the sitting trot, hoof impact was slightly heel-first.
- In the extended trot, hoof impact was slightly toe-first.
- On a 20-m circle at the sitting trot, force was equally distributed between both feet (averaged over 12 strides).
- Turns affected load distribution between the two feet, with more load placed on the inside limb (e.g. the left fore on a left turn) earlier in the stride and more load on the outside limb (e.g. the right fore on a left turn) in the second half of the stride.
- On a turn, the position of breakover (originally to the lateral side of the hoof) was moved in the direction in which the horse was turning.

Next, the open-heel shoes were removed and replaced over the original sensors with egg-bar shoes (Sigafoos Series print & web 4C.

### Table 2. Data for the same horse as shown in Table 1

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<th>Gait</th>
<th>Medial (% of force)</th>
<th>Lateral (% of force)</th>
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<tbody>
<tr>
<td>Rest</td>
<td>71%</td>
<td>29%</td>
</tr>
<tr>
<td>Walk</td>
<td>47%</td>
<td>53%</td>
</tr>
<tr>
<td>Trot</td>
<td>63%</td>
<td>37%</td>
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This time the hoof was artificially balanced in the medial-lateral plane using a medially placed wedge, so that visually the hoof appeared to land level at the walk (i.e., both sides of the hoof appeared to be loaded simultaneously).

With the hoof balanced in the medial lateral plane using the reference point of a flat impact at the walk (in the medial lateral plane), distribution of force on the medians of the hoof at mid-stance differentiated by gait. These data represent the same horse and hoof as in Table 1.

![Figure 2](image-url). Left: A hoof force map, showing the variations in peak force in the region of ground contact. The areas of highest force are shown in red, and the lowest in indigo and violet. In this case, the lateral side of the hoof is on the left (red box) and medial is on the right (green box). Right: Graph of force measurements over multiple strides. In this case, forces in the lateral side of the hoof are shown in red and medial in green. Data collection over multiple strides was compared, averaging multiple strides and comparing regions of the hoof contact area (lateral hoof force in red and medial in green, represented in the hoof force map on [left], and in the graph [right]). The colors of the force map (left) indicate different intensities of peak force for the four strides considered in this trial (This is a two-part graphic of the data; the image on the left shows the color spectrum of loading forces in a horseshoe shape and the image on the right is a line graph of loading forces over several strides).
II shoes, Sound Horse Technologies, Unionville, PA). The trotting trials were repeated to compare the two shoes. As compared with the open-heel shoes, the egg-bar shoes increased the force in the caudal half of the hoof by 6% and increased the force in the medial half of the foot by 3%, although the overall force in the hoof was unchanged.

**DISCUSSION**

The concept of hoof balance as an absolute value seems to be an illogical premise. Although certain aspects of balance are intrinsic to the limb and to the animal, there also exist external factors which have the potential to affect the landing of foot and loading of the limb. In case 1, the gait clearly affected the distribution of force across the hoof, regardless of the reference point used (static radiographic symmetry or dynamic visual landing symmetry).

In case 2, the application of egg-bar shoes affected the distribution of force across the hoof, moving it slightly to the caudal and medial aspects of the foot. Denoix et al. showed the ability of the egg-bar shoe to increase the loaded position of the hoof in soft footing, a change that would be expected to increase the compressive force on the heels in a manner similar to a wedge pad. The increase in force on the medial side of the hoof in our study is also supported by Denoix’s results, in which the egg-bar shoe increased support on the medial side of the hoof. The results of Wilson et al. suggest that the application of a heel wedge changes the loading of the distal limb joints, thus affecting most definitions of hoof balance. This effect would be similar to the positional change associated with an egg-bar shoe in soft footing.

The second case is further enlightening because it illustrates the effect of the sport or activity on the concept of hoof balance. The effect of the rider and his commands to the horse (e.g. sitting trot, extended trot, circles, turns, etc.) measurably changed the distribution of force in the hoof.

**FINAL THOUGHTS**

Hoof balance is affected by numerous variables, which might explain the reason we have been unable to reach a consensus in centuries of farrier teachings about the best method of achieving “balance.” Relatively new reference points (most notably radiography) have attempted to define hoof balance on the basis of internal anatomical features; however, these static determinations still fail to consider the dynamic factors which change the forces acting on the horse’s hoof during motion.

An interesting parallel to the goals and challenges of equine biomechanics may be reported in the field of human podiatry and biomechanics, particularly those pertaining to athletic footwear. Although performance, injury prevention, and comfort are the primary considerations, achieving each of these goals involves a measure of compromise, especially when the footwear is designed for multiple athletic endeavors. Consequently, the role of research is to reduce the amount of compromise required. Perhaps we could do well to consider the achievement of “hoof balance” as a compromise of several factors rather than an absolute ideal, and look to research tools such as those presented in this study to help us design better footwear for the horse.

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