STRUCTURE AND FUNCTION

OF THE HORSE'S FOOT

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The structure and function of the horse's foot have been the subject of continuing debate and study by veterinarians, horsemen and farriers since the first writings on the horse.

Since the anatomy, the structure, of the foot is reasonably well described in readily available texts, it will not be redescribed here. We shall be concerned with function: how the hoof works.

First, the foot will be defined as the horny hoof and all structures contained therein up to the level, approximately, of the coronary band.

The foot is basically an impulse receptor designed to absorb, store, and dissipate the force and energy generated by the weight of the horse impacting with the ground. What sort of forces are we talking about? First, let's consider the total force exerted on the leg of the horse in the standing position (the static case). Assuming that 55% of the weight is on the forelegs and 45% on the rearlegs, the two forelegs of a 1000 lb. horse will be supporting 550 lbs. while the two rearlegs will be supporting 450 lbs. The precentage figures will vary from horse to horse depending upon how the horse is built (the conformation). To find the percentages for a given animal: stand the horse on a platform scale and record the total weight. Next, stand the horse's forelegs on the scale and record the weight; next, stand the rearlegs on the scale and record the weight. Then:

Weight Carried by Forelegs ÷ Total Weight x 100 = % support of forelegs

Weight Carried by Rearlegs ÷ Total Weight x 100 = % support of rearlegs

Assuming 55% for a 1000 lb. horse, each foreleg will be supporting 275 lbs. and each rearleg, 225 lbs.

Before moving on to the moving horse (the dynamic case), we must ask just what is "weight"? Every physical body has mass and that mass is acted upon by the acceleration of gravity directed toward the center of the earth. When we weigh a horse, we are actually determining the force that the mass of horse, accelerated by gravity, is exerting on the scale. Therefore:

$\mathbf{F} = \mathbf{m} \times \mathbf{a}$

where **F** is force; **m** is mass; and **a** is acceleration. The acceleration of gravity is usually symbolized by "g", and g = 23 ft/sec^2. Thus, a horse of 1000 lbs. is actually exerting 1000 ft. lbs./sec^2 of force on the scale:

$\mathbf{F} = \mathbf{m} \times \mathbf{a}$

$\mathbf{g} = \mathbf{a}$

$\mathbf{F} = \mathbf{m} \times \mathbf{g}$

$\mathbf{F} = \mathbf{W}$

$\mathbf{W} = \mathbf{m} \times \mathbf{g}$

Thus, a 1000 lb. horse = m x 32 ft/sec^2, and the mass = 31.25.

We can now move on to the horse at the walk. An approximation in mechanics is that the dynamic force (the impulse or impact) will be twice as great as the static force. A one pound block resting on a table is exerting one pound of force (1 ft lb/sec^2). If the block is held just in contact with the table, but not resting on the table, and then is suddenly released it will exert 2 ft lb/sec^2, twice the resting or static force. (Try this with the bathroom scale).

Therefore, the one foreleg, standing still, is subjected to 275 ft lb/sec^2. As soon as the horse begins to walk, that force will be doubled on the moving, impacting leg; the leg will be subjected to 550 ft lb/sec^2 of force with the other three legs in support. At the gallop, the lead foreleg, when it is supporting all the body weight (force) will be subjected to twice the body weight: 2000 ft lb/sec^2

Let's follow a horse through the galloping stride. Say the left hind (LH) foot impacts first after the flight phase (that phase when all four feet are off the ground). The force on LH, then, is 2000 ft lb/sec^2. When RH impacts, the force will be shared: 1000 ft lb/sec^2 per LH and RH. LH leaves the ground and RH supports 2000 ft lb/sec^2 until LF impacts, forming the diagonal. RH now supports 45% of 2000 ft lb or 900 ft lb/sec^2. LF, of course, supports 55% of 200 ft lbs or 1100 ft lb/se₂2. RH comes off the ground, and LF supports 2000 ft lb/sec^2 until joined by RF: 1000 ft lb/sec^2 each. LF leaves the ground, and RF supports 2000 ft lb/sec^2 until it, too, leaves the ground for the next flight phase.

Those are all approximate values but do give an overall, general picture of the total forces experienced by each leg of the galloping horse. What about the weight (the force) of rider and tack? If the rider

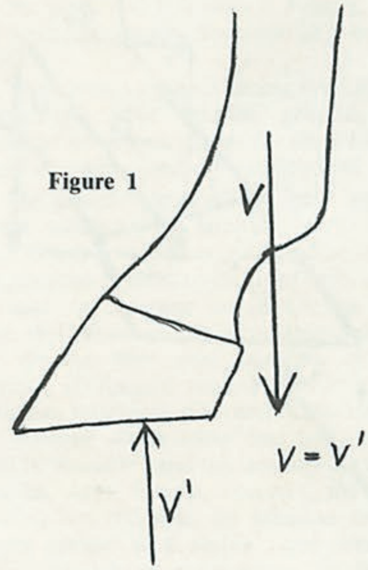
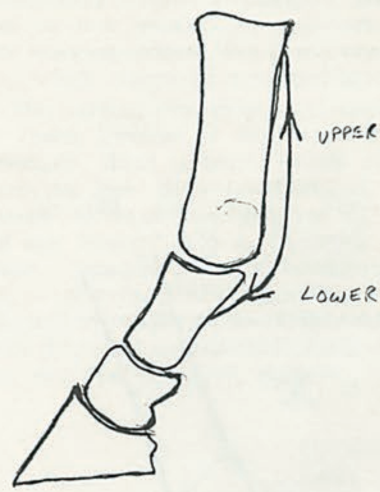


Figure 1



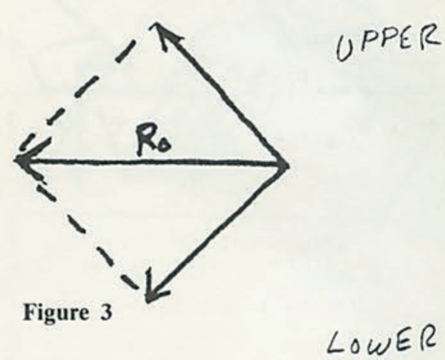


Figure 3

Figure 4

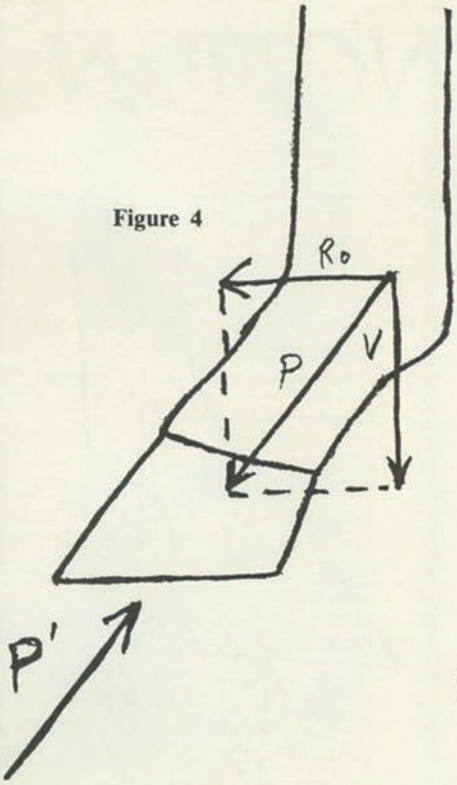


Figure 5

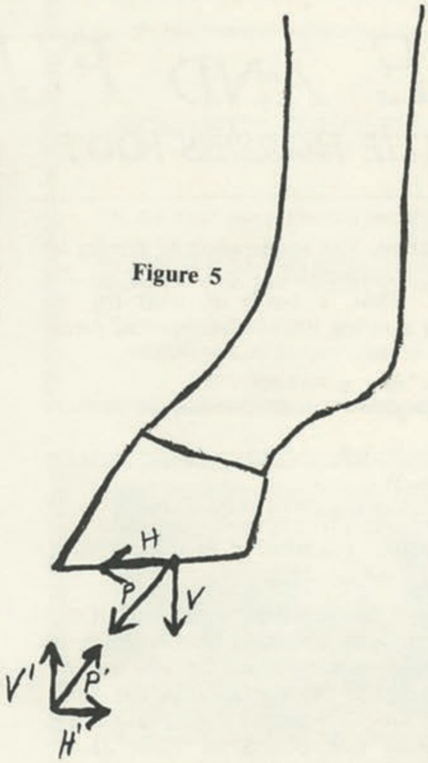
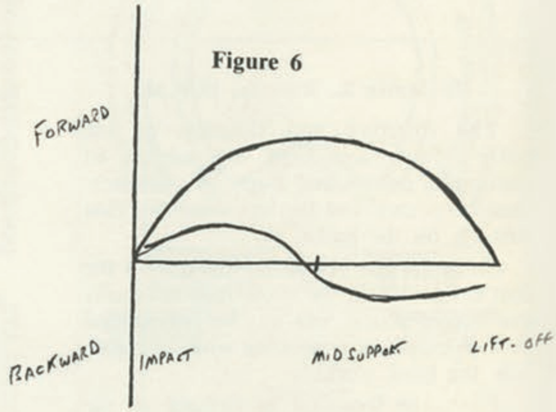


Figure 6



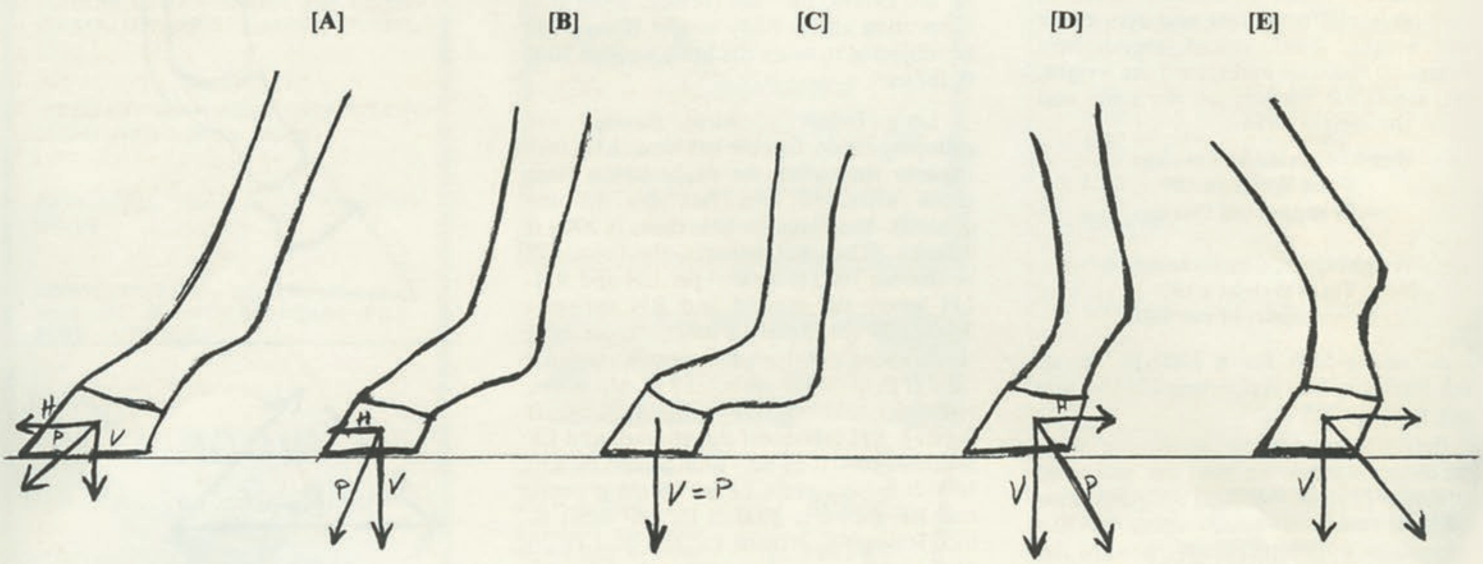


Figure 7

sits in the proper place, over the center of gravity of the horse, that weight simply adds to the horse's weight. Two hundred pounds of tack and rider on a 1000 lb. horse means a 1200 lb. horserider "system"

Let's move on now to a more specific consideration of the forces applied to the foot and the lower part of the leg, starting with the standing horse (the static case).

Without, at this time, explaining just how it gets there, we'll deal with that portion of the force applied to one front leg, coming down the lower part of the leg. It is a basic law of mechanics that for every force in a real physical system there is an equal and opposite reaction (opposing force). In Fig. 1, then, the force coming down the leg (V) must have an equal and opposite force (V') exerted on the foot by the ground. In other words, the horse pushes down on the ground, and the ground pushes back on the horse. Clearly, the two forces, V and V', must meet somehow, so that they cancel each other: V = V'

By inspection of the figure the reader can see that, given a fetlock and coffin joint, V will cause the pastern to move down with rotation of both the coffin and fetlock joints. Clearly, for the horse to remain standing, this rotation of the joints must be resisted. While several structural elements provide the resistance, the most important is the suspensory ligament (SL).

We must now have recourse to a mathematical device in order to demonstrate precisely how the SL resists V In Fig. 2 the SL is shown as the two upper and lower arrows which are "vectors" representing the tensile force exerted by the SL and its attachments to the bones: the upper end of the cannon bone and the upper end of the long pastern bone. (While the proximal sesamoid bones are important, we can consider them, for present purposes, simply as a part of the SL.) It is both legitimate, and necessary, to move these two vectors, so that they can be manipulated more readily. In Fig. 3 then, we have the two vectors moved away from the leg and connected, tail to tail. We now wish to discover the effect of these two vectors on the fetlock joint. (In fact the forces acting on the fetlock joint. The vectors represent the forces.) In order to find the **resultant** (the effect or result of the action of the two forces), we draw two more lines (the dotted lines) parallel to and attached to the heads of the two vectors (Fig. 3). Finally, we draw a diagonal as shown. This diagonal vector is the resultant, the actual force exerted on the fetlock by the SL. We have added one vector to another and come up with the sum the resultant, and we have added not only numbers but also direction.

Let's now move that resultant, which we'll call Ro, back to the leg. There are now two vectors operating on the fetlock: V, the vertical or downward force, and Ro, the horizontal, SL force. Now we add vectorially, just as was done above, in order to discover the resultant of those two forces (Fig. 4). This new resultant, which we'll call, P, runs down the pastern, toward the ground. Clearly, then, one effect of SL is to redirect the force, V, along the column of bones.

Since the pastern joint moves very little, the pastern (the long and short pastern bones) can be considered, for present purposes, a single bone. P, then, travels down to the ground, through the pastern and, as already noted, must be opposed by an equal and opposite ground reaction force (Fig. 4), P'

You may be anticipating what comes next. Just what is the effect of the force P on the hoof and the relationship to P'? Previously we added vectors in order to obtain a resultant. Now we are going to reverse the process and decompose the resultants in order to find the component vectors. From Fig. 5 it is apparent that the force, P, tends to press the hoof into the ground (V) and to slide it forward (H). The ground resists by pressing up on the hoof (V') and pressing parallel to the hoof (H'). This latter force, H', is friction. If the hoof were resting on a slippery, virtually frictionless, surface such as ice, a banana peel, it would tend to slide forward.

Up to this point we have been considering only the static case, the standing horse. Next, let's delve just a bit into dynamics, the more difficult case of the moving horse. Experimental studies have given us a quantitative idea of the relationships of the two component forces, V and H. In Fig. 6 these forces are shown during the support phase, from the moment of impact of the hoof with the ground until lift-off, when the hoof leaves the ground. The vertical axis is the amount or quantity of force, and the horizontal axis is the successive stages of the support phase. During the first half of support, the horizontal force, H, is directed forward, the hoof tending to slide forward. During the second half of support, the hoof is pushing backward against the ground and, thus, the curve goes below the line. Also, you can see that the vertical force, V, increases to midsupport and then decreases until lift-off.

In Fig. 7, V and H are represented, once again, as vectors. Although it hasn't been mentioned before, the length of the force vector is a measure of the amount or quantity of the force. Thus, the vector tells us both the direction of the force and its amount. At A in Fig. 7, then, H is rather large and V rather small; the resultant, P, is is shown. P is essentially parallel to the pastern and to the hoof wall at the toe. As support progresses, H decreases and V increases (Fig. 6). B, then, the resultant has changed direction. At C, midsupport, vertical cannon bone, there is no H. This is the point in Fig. 6 where H goes through zero, changing from sliding forward to pushing back. The total force at midsupport, therefore, is V, as shown (P = V). As H reappears, pushing back, we have the leg in D, and P is shown. Finally, at E we have the vector situation just before lift-off.

To summarize, then: during the support phase, the hoof on the ground, the resultant force exerted on the foot by the horse changes direction continuously.

The actual "meeting" of the P and P' forces occurs in the laminae of the hoof wall. These laminae, as indicated in Fig. 8 are oriented parallel to the hoof wall at the toe and, for reasons we cannot get into here, this orientation is the "best possible" for dealing with this "meeting of the forces" At impact, then, P and P' are in optimum relationship to each other and to the laminae which must deal with them. That is, P and P', and the laminae are all in parallel. As P rotates, however, the hoof itself is not rotating, the laminae are no longer parallel to P and P', and shearing forces develop in the laminae. It would seem clear that the hoof should normally rotate in order to maintain this normal, mechanically efficient parallelism. That it does not is a function of horseshoes and hard working surfaces. But that is another story which cannot be developed here.

This has been a rather quick overview of the forces involved in the horse's foot. Obviously, there is much, much more. Have you ever given consideration, for example, to the different shape of the fore and rear hooves? Why is the inside wall steeper, more nearly vertical on the inside than on the outside? These questions can be answered by consideration of the mechanics of the forces applied to the foot. We'll look into that next time.

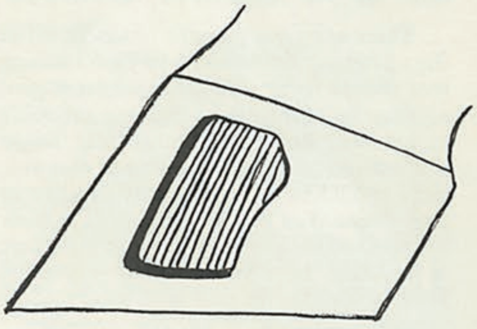


Figure 8