Horses stand on the tips of their middle fingers and toes. In each forelimb, they bear their weight on an adapted fingernail which forms the hoof wall. This hoof wall is strongly attached to the last bone (third phalanx) which, in turn, is tied into the column of support in such a way that the complex locomotory forces received through the hoof capsule are directed up into the limb in alignment with the long axis of the limb. Analysis of the hoof during exercise in vivo is limited, due to the complexity of the interaction between the numerous anatomical structures involved in this support of the hoof wall. In this issue (p 719), Thomason et al. (2002) pursue the subject of analysis of strains in the hoof capsule, employing a finite element model. Why is such a model of potential interest to clinicians and farriers?

The treatment of debilitating hoof conditions, such as cracks, infections, bruises, abscesses, navicular syndrome and laminitis, as well as their prevention in the first place, still depends on the skill and experience of the farrier in visualising the best shape of each hoof within a particular horse. The farrier has to guess where and how to trim the hoof and, perhaps, how to form and place the shoe, so that the hoof might be loaded in such a way that it is comfortable, effective and stimulated to grow into the best possible shape. This is an art. Attempts to assist this skill with particular measurements and rules to follow have led to the temporary adoption of many different methods. The horse industry is notorious for its reliance on tradition as well as the many methods of trimming and shoeing that follow a cycle of increasing and decreasing popularity. Why is this so? Perhaps an explanation can be found in our insufficient understanding of how the locomotory system of the horse actually works.

This deficient understanding is not from any lack of effort in that direction. Scientists have been trying to elucidate the mechanics of the gait of horses since antiquity (van Weeren 2001). Instead, the lack of a coherent description of the mechanics of the distal forelimb is due to the complexity of the problem of predicting the effects of tiny changes in a system that is under a high degree of local feedback control. Despite being tied together by strong ligaments and joint shapes that prevent most movements outside the sagittal plane, the distal forelimb is still a jointed pendulum. This means that a very small change anywhere in the system may create large effects on the exact placement of the hoof within a stride. If you set a simple model of a pendulum with a single joint swinging, then it is clear within a couple of cycles that anything can happen at the distal end. From the carpometacarpal joint distally, there are still 3 more joints to contend with in the column of support. Despite this, catastrophic breakdown of the system is remarkably rare and then, generally, only occurs when human interference has changed the mechanics of the system beyond its capacity to adapt, such as in shoeing with toe grabs (Kane et al. 1996), or when there are other interfering factors, e.g. kicks from other horses, pre-existing damage, or sudden holes in an otherwise even working surface.

The distortion of the hoof capsule during use directs the way in which the hoof capsule grows, so that any changes show within a few weeks in a change in the shape of the hoof capsule. An example of this is the ‘overload’/’underload’ situation in the front hooves when the load on one forelimb is reduced in comparison with the other. Trimming and shoeing are used to direct hoof growth in a required way to ‘improve’ the appearance or function of the limb. Often this is done because of various assumptions about the way the horse is moving, and how that movement might be changed to improve the aesthetics or possibly the function of other structures (and hence performance). Kinematic and force plate investigations into such adaptations (Back 2001) generally include assumptions about the anatomy and function of these structures with minimal, if any, material evidence for that function. It is probable that the inconsistent findings of many of these studies may be explained by a misinterpretation of the importance of differences in conformation between individual horses.

To understand how to trim the hoof capsule to the ‘best’ possible shape, we need to understand how it loads, the potential effects of particular shapes and any changes that can be made to the shape. Hoof loading can be determined experimentally through measurements of its distortions with strain gauges, photoelastic coating, and indirectly through kinematics. Strain gauges are the most widely accepted and reliable way of directly measuring the surface distortions of a material, but they only measure distortion in the region immediately under the gauge. Photoelastic coating can show the pattern of distortion across the surface, but its application is technically difficult and has been done only a few times with live horses (Davies 1997). When it is performed with cadaver hooves, any results must be highly questionable because of the volatile nature of the hoof capsule to dermis interface, as well as the difficulty of recreating in vivo loading conditions with cadaver limbs. If the method of using the coating in live horses can be improved, then this line of research may prove more fruitful.

Therefore, the present experimental methods of measuring the loading of the hoof are not yet able to provide sufficient information to predict or easily measure the effect of changes in shape on the whole hoof in the
living horse. The theoretical modelling of the hoof capsule such as that described by Thomason et al. (2002) provides a potentially useful way to bypass this problem and develop hypotheses that may be tested experimentally using, for example, just a few strategically-placed strain gauges. To develop a model, it is first necessary to investigate the anatomy of the hoof capsule and its contents, as well as the material properties of these structures, because the assumptions that are made about these structures determine the accuracy of predictions made by the model.

The anatomy of this region is difficult to investigate, and is shown mostly through cut sections or radiographs which necessarily lack a 3-dimensional insight into the functions of the structures. The increased availability of newer imaging modalities presents the opportunity to improve our understanding of the anatomy of this region (Denoix 2000). However, there is still work to be done in the area of basic anatomical description. For example, if the frog and the underlying digital cushion are removed in such a way that all the deep digital flexor tendon attachments are followed, then some of this tendon material may be shown to be continuous with the dermis of the bars, and the digital cushion itself. It is not clear what, if any, significance this has on the mechanics of the region, although it may be hypothesised that these connections encourage the ‘sucking up’ of material under this region of the hoof during fetlock hyperextension, and may assist in hoof stability, reinforcing a ‘suction cup’ effect on some surfaces, in some horses at least.

In examining function, it is necessary to know the material properties of each tissue, as well as the anatomical form, but perhaps equally important is what feedback is being provided to the central nervous system from the hoof. A structure will not perform predictably for the horse if this feedback is inadequate, and on the distal end of a jointed pendulum this feedback is essential to prevent catastrophic breakdown of the system due to inappropriate loading. A high concentration of nociceptors have been described in the region of the navicular bone (Bowker et al. 1995), but it is difficult to investigate the function of these structures without invasive methods that necessarily interfere with their function.

In constructing their finite element analysis (FEA) model, Thomason et al. (2002) have chosen to assume isotropy in the material of the hoof wall, despite the fact that the hoof wall is a good example of a composite material that is anisotropic (has different mechanical properties depending on the direction of loading) and work has been done to describe these differences (Kasapi and Gosline 1997). Ignoring the potential effect of the frog may also restrict the usefulness of the model, as there is some work that shows that there can be an effect of frog pressure on the amount of expansion of the heels (Roepstorff et al. 2001).

The classic method of validating a theoretical model is to test it against experimental evidence. The attempt by Thomason et al. (2002) to do this with their FEA model of the hoof shows that they are approaching a theoretical construction that may sometimes be close enough to the actual hoof of some horses in some conditions for some predictions to be made and tested. As their model is tested and adapted and tested again, then a better understanding of the effects of different measurable variations in hoof shape, size, and material construction between horses may gradually be made. This may be equated with the farrier learning their trade by experience but, in this case, the experience is being accumulated within a mathematical construct that can be used as a tool to investigate what criteria determine function in the structures of the hoof.

Another method that may act to improve the specificity of predictions made using the FEA model is an artificial neural network that may be used, for example, to equate hoof strain data with another measurement so that the network can learn by trial and error how to determine one measurement from another (Savelberg et al. 1997). Both of these methods are likely to improve our understanding of the functions of the hoof capsule and its contents, and may make it possible to identify what to measure clinically to predict the effect of hoof shape and hoof treatments on the horse’s soundness and performance.

H. M. S. Davies
Faculty of Veterinary Science
University of Melbourne
Victoria 3010
Australia

References


