Introduction

The hoof capsule is comprised of the hoof wall, sole, frog and bulbs of the heels; which, through the unique continuous bond between its components, form a casing or shell on the ground surface of the limb that affords protection to the soft tissue and osseous structures enclosed within the capsule[1]. The hoof wall is a viscoelastic structure that has the ability to deform under load and then return to its original shape when the weight is removed. It is well accepted that abnormal weight distribution on the foot or disproportionate forces placed on a section of the hoof will, over time, cause it to assume an abnormal shape [1-4]. These abnormal stresses within the foot will also predispose the foot to injury or disease. Increased stress or weight bearing placed on a section of the hoof capsule may originate from a single source or it may be from multiple contributing factors such as abnormal limb conformation, the pattern in which the foot strikes the ground, amount of work, type of footing and inappropriate farrier practices. Excess stress (forces) placed on one section of the hoof capsule can manifest itself in a variety of ways such as; compressed growth rings at the coronet, flares or under running of the hoof wall, dorsal migration of the heels and either focal or diffuse displacement of the coronary band
[6,7]
. Distortion of the hoof capsule of the forelimbs appears to be related to limb alignment and load where as deformation in the hind feet seems to be different and related to propulsion. As the hoof capsule distortion of the forelimbs is commonly associated with lameness and various disease processes, only the forelimbs will be considered in this paper.
As the ‘normal’ foot has never been defined, each view will begin with what is perceived to be an ideal, good or healthy foot
[1, 8]
. The goal of evaluating the hoof capsule is to identify deformation and changes in growth pattern that indicate abnormal distribution of forces (stresses) on the foot. As hoof capsule distortion and abnormal loading usually accompany lameness, farriery will form part of or sometimes the entire treatment. Farriery is used to help redistribute the load and help improve or resolve the hoof capsule deformation.

The mechanism of distortion

Evaluation of the hoof capsule morphology will indicate where the hoof wall is unduly stressed; however, the evaluation has to be coupled with an understanding of the abnormal distribution of forces that lead to hoof capsule deformation. Understanding the biomechanical forces leading to hoof capsule distortions is also helpful for the clinician in applying the appropriate farriery to modify these stresses. There are many excellent reviews of basic biomechanics of the hoof in the veterinary literature [1-5]. Increased load or weight bearing by a portion of the wall has three consequences:(1) it may cause deviation of the wall outwards (flares) or inwards (under running) from its normal position;(2) it may cause the wall to move proximally; or(3) it may decrease hoof wall growth. A reduction in load or weight bearing generally has the opposite effect.

Limb conformation

When evaluating hoof capsule deformation, limb conformation should be considered. Abnormal limb conformation affects the landing pattern of the foot and stance phase of the stride where full weight is placed on the foot. Few horses have ideal limb conformation and any change in conformation is going to change the distribution of forces within the hoof capsule leading to deformation. In the frontal plane, the forelimbs should be of equal length and size and bear equal weight. A line dropped from the scapulohumeral joint to the ground should bisect the limb. Certain types of abnormal limb conformation have been described [9]. In the frontal plane, abnormal conformation is described as valgus (the limb's segment distal to the affected joint will deviate laterally) or varus (the distal segment of the limb will deviate medially). The joint most often affected is the carpus and to a lesser degree, the metacarpalphalangeal joint. Here there will be excess load placed on the hoof opposite the direction of the deviation. If a line dropped from the metacarpalphalangeal joint through the digit to the ground does not bisect the hoof capsule, the foot is considered offset to one side (usually laterally) and therefore increased load is placed on the opposite side of the foot (Figure 1). In the transverse plane, conformation abnormalities are characterized by axial rotations of the limb or its segments, either laterally or medially. For example, a horse with a narrow chest and a lateral axial rotation will land on the lateral side of the hoof and then load the medial side resulting in proximal displacement of the quarter /heel on the medial side and causing the hoof deformation termed sheared heels [10,11]

(Figure 2). A limb with a medial (inward) rotation of the digit relative to the third metacarpal bone (toed-in) will develop a hoof with a diagonal asymmetry, with a narrow lateral toe and medial heel and a wide medial toe and lateral heel.

Evaluation of the hoof capsule

A detailed morphological examination of the foot should begin with observing the horse in motion, both going away from and toward the examiner, on a firm flat surface to note the landing pattern. The foot is then viewed from all sides while it is on the ground. Finally the ground surface is examined with the foot off the ground. Additionally, small changes in the shape of the hoof capsule (such as the coronet and the digital cushion) may be better appreciated by careful palpation of the foot than by visual inspection.

Dorsal aspect

When the foot is viewed from the dorsal aspect, the ideal hoof should be approximately symmetrical. An imaginary line drawn between any two comparable points on the coronary band should be parallel to the ground. The medial wall should be the same height as the lateral wall, but because it is often slightly steeper, it may be slightly shorter. An imaginary line that bisects the third metacarpal should bisect a line drawn between any 2 comparable points on the coronary band or the ground surface of the hoof. Similarly, the hoof should be symmetrically related to the distal limb such that an imaginary line that bisects the third metacarpal bone (Canon bone, bisects the pastern and the hoof, allowing for the slight asymmetry due to the different angles of the medial and lateral wall (Figure 3)[1]. When the foot is viewed from the dorsal aspect the shape of the forefeet may be asymmetrical with one hoof being narrower than the other (“mis-matched feet”). Several abnormalities may be visible at the toe / quarters such as flares or under-running of the wall. The coronary band may be unevenly distributed, most commonly by an uneven slope from one side of the foot to the other. Examination of the growth rings below the coronet may show divergence of the rings from one side to the other indicating uneven or excessive load (Figure 4). The angulation of the dorsal horn tubules toward the medial or lateral side of the hoof capsule should be noted; normally they are parallel, so when they appear tilted medially or laterally, it suggests that the whole hoof capsule may be tilted in that direction (figure 5).

Lateral aspect

When viewed from the lateral aspect, the angle the dorsal hoof wall forms with the ground is variable and typically related to the conformation of the digit. The heel tubules of the hoof capsule should form an angle with the weight bearing surface similar to the angle of the horn tubules in the toe region. Tradition has it that the angle of the wall at the heel should match that of the dorsal hoof wall; however, it is usually a few degrees less. As the foot accepts weight, it expands and the ground surface at the heels moves against the shoe causing wear which decreases the heel angle. The amount of wear is dependent on the integrity of the structures in the heel. The length of the dorsal hoof wall is similarly variable, but is determined by the amount of sole depth present. There are two guidelines that relate the proportion of the foot to the rest of the distal limb. First, the foot-pastern axis describes the relationship between the angles made by the dorsal hoof wall and the dorsal aspect of the pastern with the ground. Ideally, the dorsal hoof wall and the pastern form the same angle with the ground so that the angle between them is 180º and the axis is considered straight. Second, an imaginary line that bisects the third metacarpal should intersect the ground at the most palmar aspect of the ground surface of the hoof. These two guidelines used in conjunction with the angle of the dorsal hoof wall and the ground surface of the foot combine to form a triangle of proportions that represents the relationship between the hoof and the distal limb regardless of the size of the horse (Figure 6)
[1]

.Evaluation of the hoof capsule from the side view should begin with the coronet as this structure can provide very useful information. The healthy coronary band should have a gentle even slope from the toe to the heels and the hair should lie flat against the hoof capsule; hair projecting horizontally may indicate excessive forces on the associated hoof wall
[1]

. The coronary band is dynamic, and its shape can be affected by chronic overloading
[14]

. A proximally directed diffuse arch at the quarters or a focal directed arch toward the heels is evidence of chronic overloading of that section of the foot (Figure 7)
[9]

. A coronary band with an acute angle at the heels relative to the ground that bends distally at the heel to form a “knob” appearance is an indication that the foot has poorly developed or under run heels and the hoof wall at the heels has migrated dorsally (Figure 8). A coronary band that is horizontal relative to the ground and often accompanied by a flare in the dorsal hoof wall would denote an upright or clubfoot conformation (Figure 9). Asymmetry of the height of the coronary band in the quarter / heel region on one side occurs when the horse develops a “sheared heel”; a hoof capsule distortion resulting in proximal displacement of one quarter/heel bulb relative to the contralateral side of the foot
[1,9]

. The medial heel bulb/quarter is more commonly displaced proximally as it is more common for

the foot to be offset laterally. The width of the growth rings below the coronet should be equal from toe to heel. A disparity in the width of the growth rings between the toe and the heels is indicative of non-uniform circulation of the coronary corium or excessive forces below because wall growth is generally inversely related to load. An example of this disparity would be chronic laminitis typified by more horn growth at the heels than toe growth. However, regional irregularity in spacing of growth rings is not uncommon; the most frequently observed is a decrease in spacing at the quarter associated with proximal displacement of the coronary band as noted with sheared heels [10]. The angulation of the horn tubules from dorsal to palmar should be noted as horn tubules that are parallel with the ground in the heel area are associated with under run heels. Vertical cracks in the quarter are more likely to occur with a sheared heel. Horizontal cracks are usually the result of a disruption of production of horn caused by coronary band trauma or when a subsolar infection ruptures at the coronary band.

Palmar aspect

The heels are evaluated from the palmar aspect for their overall width and height. The heels frequently become narrowed when the foot itself is narrow. Additionally, the central sulcus of the frog may extend proximal to the hairline so that a cleft becomes apparent in the skin of the pastern between the heels. The overall height of the heels is readily assessed from the lateral aspect, but viewing from the palmar aspect is useful to compare the relative heights of the two heels. For example, in the case of the sheared heel, one heel is displaced proximally in relation to the other. Another example is mis-matched feet where there is a marked disparity in heel height. The contour of the junction of the heel bulbs with the skin can be evaluated relative to the width of the hoof wall at the heels and the thickness of the digital cushion (Figure 10).

Distal or solar aspect

When viewed from the distal surface, the ground surface of the foot should be approximately as

wide as it is long. The foot should be approximately symmetrical about the long axis of the frog; the lateral side of the sole frequently has a slightly greater surface area which corresponds with the difference in wall angles at the quarters described in the dorsal view. The width of the frog should be approximately 60-70% of its length. The ground surface of the heels should not project dorsal to the base of the frog. Imaginary lines drawn across the most palmar weight-bearing surface of the heels and across the heel bulbs at the coronary band should be parallel and both lines should be perpendicular to the axis of the frog (Figure 11)[1]. If a three dimensional object such as the foot changes in one plane, it will change in at least one other plane. Therefore, examination of the ground surface of the foot reveals much about the changes in the wall of the hoof capsule. The author begins the evaluation of the solar surface of the hoof capsule by drawing a line across the widest part of the foot. This line forms a consistent landmark and is located just dorsal to the center of rotation (of the distal interphalangeal joint). Using this line as a starting point, there should be approximate proportions from this line to the perimeter of the toe and to the base of the frog (Figure 12). This creates a relative proportion from the front of the foot to the palmar aspect that is related to the alignment of the center of rotation in the middle of the foot or, when shod, the middle of the shoe. The normal solar surface of the foot may be wider laterally than medially. The width of a healthy frog' should equal 60 - 70% of its length therefore the width and length of the frog should be critically evaluated using these guidelines

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. The untrimmed frog should be on the same plane with the hoof wall at the heels; it should not be receded between the hoof wall or protrude beyond the solar surface of the hoof wall. In general, the frog is usually constant in length and its axis is almost always aligned with the medial plane of the foot, but its width is variable. As the frog functions as an expansion joint, a decrease in width is generally associated with contracture of the hoof capsule at the heels. The frog of a healthy hoof has sufficient depth at its dorsal aspect to reach the bearing surface
1

. The position of the heels of the hoof wall relative to the base of the frog should be evaluated. Ideally, the most palmar extent of the bearing surface of the heel tubules would be at the base of the frog and very near a vertical line drawn thru the middle of the third metacarpal bone. When the ground surface of the heels is dorsal to the base of the frog, the heels are low, under run and/or increased in length. The structures of the heel (hoof wall, buttress, angle of sole, bars) should be present and well defined. If the heels have migrated dorsally relative to the frog and the structures are present, the heels are considered low; if the structures of the heel are absent or damaged, then the heels are considered under run. The bars of the heel should be straight as curvature indicates contracted heels. The proportionality of the foot dorsal to the widest part of the foot should be evaluated. As the heels move forward there will generally be a substantial increase in the proportion of the toe relative to the heels. A long toe will also be accompanied by an increased distance between the toe and the apex of the frog. The sole wall-junction should be solid and compact. Widening or fissures in the sole-wall junction and hoof wall separations dorsal to the sole wall junction occur with lengthening of the toe. The healthy sole tends to be concave and callused adjacent to the sole wall junction (white line). It should have a gradual slope from the apex of the frog to the sole wall junction and not a significant "trough". The sole should be between 10 to 15 mm thick beneath the margin of the distal phalanx and should not deform when hoof testers are applied. Horses with poor heel structures typically have a poorly developed digital cushion and thin collateral cartilages. It is

these soft tissue structures that determine the overall conformation of the palmar portion of the foot. Clinicians should gain an appreciation for variation in the consistency and overall size of the digital cushion and collateral cartilages. The digital cushion can be palpated between a thumb placed between collateral cartilages and the fingertips placed on base of the frog. A sense of normal can be acquired by palpating the digital cushions of sound horses with “good feet” and comparing those findings with those of horses with poorly conformed feet.
The depth of the combined tissues of normal digital cushion and frog should be approximately 2 inches but this can vary among different breeds. Horses with underdeveloped digital cushions typically have low or under-run heels that lack stability and can be easily distracted independently or they may have contracted heels and narrow, non-weight bearing frogs.

Conclusion

The clinical examination of the equine foot has been well described and is generally performed in lameness cases. Evaluation of the hoof capsule during the lameness examination will provide additional information as to the etiology and treatment of the lameness but will also serve as a guideline to apply therapeutic farriery and other preventive measures to maintain a healthy hoof. The morphology of the hoof capsule reveals deformation and changes in growth that occurs following increased or reduced force. The relationship between the limb and the foot indicate conformations that predisposes the foot to abnormal weight bearing. Inversely, using the abnormal distribution of forces and the subsequent hoof capsule distortion as a template, appropriate farriery or therapeutic farriery will form at least part of the treatment plan. Here it is essential to be familiar with the biomechanics of the foot and how these forces can be altered to change the distribution of forces or the focal stresses on a given section of the foot.

Figures 1, 2

Figures 3, 4

Figures 5, 6

Figures 7, 8, 9

Figures 10, 11

Figure 12

References

1. Parks AH. Form and function of the equine digit. *Vet Clin N Am Equine* 2003;19:285-307

2. Parks, AH. Aspects of Functional Anatomy of the Distal Limb. in Proceedings. Am Assoc Equine Pract 2012;58:132-137.

3. Johnston C, Back W. Hoof ground interaction: when biomechanical stimuli challenge the tissues of the distal limb. Equine vet J 2006;38:634-641.

4. Eliashar E. An evidence based assessment of the biomechanical effects of the common shoeing and farriery techniques. Vet Clin N Am Equine 2007;23:425-442.

5. Parks, AH. Therapeutic Trimming and Shoeing. In: Baxter GM, ed. Adams & Stashak's Lameness in Horses 6th ed. West Sussex: Wiley-Blackwell, 2011;986-992.

6. Turner TA. The use of hoof measurements for the objective assessment of hoof balance in *Proceedings, Am Assoc Equine Pract*
1992 38;389-395.

7. Redden RF. Hoof capsule distortion: understanding the mechanisms as a basis for rational management. *Vet Clin N Am Equine* 2003;19:443-462.

8. O'Grady SE, Poupard DA. Physiologic horseshoeing: an overview. *Eq Vet Edu*
2001;13:330-334

9. O'Grady SE, Castelijns, HH. Sheared heels and the correlation to spontaneous quarter cracks *Equine vet edu* 2011;23:262-269.