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Variation in foot conformation in lame horses with different foot lesions

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ABSTRACT

Foot conformation in the horse is commonly thought to be associated with lameness but scientific evidence is scarce although it has been shown in biomechanical studies that foot conformation does influence the forces acting on the deep digital flexor tendon (DDFT) and the navicular bone (NB). The aim of this study was to determine the relationships between foot conformation and different types of lesion within the foot in lame horses. It was hypothesised that certain conformation parameters differ significantly between different types of foot lesions. Conformation parameters were measured on magnetic resonance images in the mid-sagittal plane of 179 lame horses with lesions of their deep digital flexor tendon (DDFT), navicular bone (NB), collateral ligaments of the distal interphalangeal joints and other structures.

Conformation parameters differed significantly between lesion groups. A larger sole angle was associated with combined DDFT and NB lesions, but not with NB lesions alone. A more acute angle of the DDFT round the NB was associated with DDFT and NB lesions, and a lower heel height index with DDFT injury. The larger the sole angle the smaller the likelihood of a DDFT or NB lesion with odds ratios of 0.86 and 0.90, respectively. This study shows an association between foot conformation and lesions but it does not allow the identification of conformation as causative factor since foot conformation may change as a consequence of lameness. Future studies will investigate foot-surface interaction in lame vs. sound horses, which may open a preventative and/or therapeutic window in foot lame horses.

Introduction

Deep digital flexor tendon (DDFT) and navicular bone (NB) pathology are common causes of lameness in the horse (Dyson et al., 2005). The NB (or distal sesamoid bone) maintains a constant angle of insertion of the DDFT and increases the moment arm of the DDFT around the distal interphalangeal (DIP) joint thus reducing the force in the DDFT (Wilson et al., 2001). A moment is the product of the force and its moment (lever) arm. On the extensor side the moment is the product of the ground reaction force (GRF) and its moment arm; on the flexor side it is the force through the flexor tendons and their moment arms. To prevent a joint from collapsing the flexor moment (rotational force acting on the flexor side of a joint) has to equal the extensor moment (rotational force acting on the extensor side of a joint). The moment arm around the DIP joint influence the forces acting on the DDFT and navicular bone (Moleman et al., 2006). At the level of the DIP joint, the flexor moment = $Force_{DDFT} \times MA_{DDFT}$, where MA is the distance from the centre of rotation of the DIP joint to the DDFT. Thus, an increase in MA_{DDFT} will decrease the force through the tendon with a given extensor moment.

The DDFT exerts compressive forces on the NB, which may be implicated in the development of NB disease (Wilson et al., 2001). Foot conformation influences the forces acting in the DDFT and NB by influencing the moment arm of the DDFT and the ground reaction force around the DIP joint (Willemen et al., 1999; Eliashar et al., 2004; Moleman et al., 2006). It has been demonstrated that a steeper sole angle will decrease the force in the DDFT and NB, and it was proposed that, as a result, horses with a flatter sole angle would be predisposed to lesions of the DDFT and NB (Eliashar et al., 2004). However it was recently shown that there was no significant association between a variety of conformation parameters measured on radiographs (including sole angle) and injury category (Dyson et al., 2011). The same study also indicated that there was a large variation in the degree of concavity of the distal phalanx (Dyson et al., 2011).

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It has been suggested that the sole angle of the border of the distal phalanx should be between 2–10° (Parks, 2003); however, the DDFT does not attach to the border of the distal phalanx but centrally and it may be a more appropriate to measure the angle of the distal phalanx at the actual attachment side (concave sole angle) than the sole angle, which depicts the sides of the distal phalanx. In a preliminary study, non-lame horses showed a tendency to have a steeper concave sole angle compared to horses with DDFT injuries, although the difference was not significant (Smith et al., 2004).

Heel conformation has also been associated with forces in the foot and hence with injury (Colles, 1982; O'Grady and Poupard, 2003; Eliashar et al., 2004; van Heel et al., 2005; Moleman et al., 2006). However, a collapsed heel conformation has also been found in 52% of sound horses (Turner and Stork, 1988). To date, there are limited data available on how biomechanical effects of foot conformation translate to the relationship between foot conformation and injury.

The use of magnetic resonance imaging (MRI) has led to a more accurate diagnosis of foot lesions and is currently the preferred diagnostic technique to assess horses with pain localised to the foot (Busoni et al., 2005; Dyson and Murray, 2007). MRI allows the visualisation of the foot in 3D and hence can be used to perform more accurate conformation measurements in the mid-sagittal plane compared to radiographs, which sums up 3D data in a 2D image.

The aim of the present study was to determine the relationships between foot conformation and different lesions within the foot in lame horses. It was hypothesised that certain conformation parameters differ significantly between different foot lesions; more specifically, we hypothesised that (1) there would be a significant difference in foot conformation parameters between horses diagnosed with DDFT and NB lesions and those diagnosed with other lesions in the foot; (2) a decrease in concave sole angle, angle of deviation of the DDFT around the NB and/or lower heels would be associated with a DDFT/NB lesion, and (3) the flexor moment arms would be significantly smaller in horses with DDFT/NB lesions.

Materials and methods

For this retrospective study, the files of 205 horses that had undergone MRI of the front feet at one referral hospital between 2007 and 2009 were reviewed. Studies where the quality of the images prevented the precise measurement of the conformation parameters were excluded, as were horses with laminitic changes on MRI, and any studies performed purely for research purposes. This resulted in 179 horses being included in this study. Age, breed, discipline and lameness score were recorded.

Horses were categorised according to the injured structure, namely, (1) horses with a lesion of the DDFT alone; (2) NB alone; (3) NB/DDFT combined; (4) collateral ligament of the distal interphalangeal joint (CL) alone; (5) DDFT/CL combined; (6) NB/CL, combined; (7) DDFT/NB/CL combined; or (8) OTHER. The group 'OTHER' comprised horses with lesions of the distal sesamoidean impar ligament, the middle phalanx, the distal phalanx, the lateral cartilages of distal phalanx, the DIP joint, the proximal interphalangeal joint, the annular ligament, the collateral sesamoidean ligaments, the straight sesamoidean ligament, the oblique sesamoidean ligament and the metacarpophalangeal joint.

All MR images were acquired in the standing horse using a 0.27 T U-shaped open low-field MRI scanner (Hallmarq Veterinary Imaging) and data were interpreted by the same experienced, veterinary surgeon (RCVS specialist, DECVMI, AssocECVDI). For the conformation measurements, the multiplanar reconstruction facility of dedicated DICOM reviewing software (Image Viewer, Visbion) was used to identify and display the mid-sagittal T1 weighted image of the affected foot. If both feet were diagnosed with abnormalities, the foot with the higher lameness score prior to blocking was used. All measurements were performed only by one operator, who had no knowledge of any other data related to this study.

The following measurements were performed and are illustrated in Fig. 1.

Angles

The concave sole surface of the distal phalanx to horizontal angle (sole angle); the dorsal hoof wall to horizontal angle (toe angle); the palmar heel wall to horizontal angle (heel angle), and the angle of the DDFT around the NB (DDFT angle).

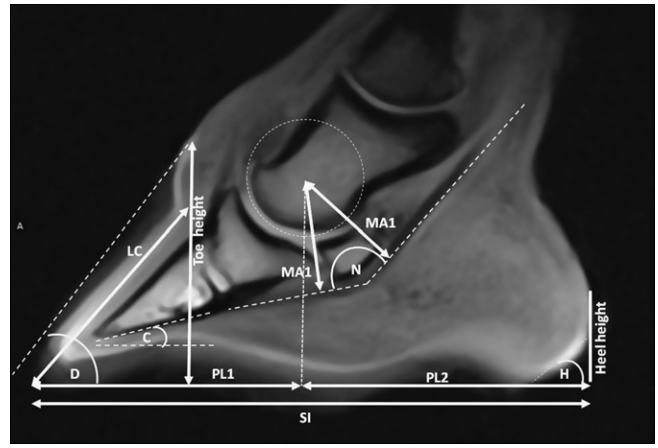

Fig. 1. Measurements taken to assess the association between type of lameness and hoof conformation: C, sole angle; D, toe angle; H, heel angle; N, deep digital flexor tendon angle; PL1, plumb line 1; PL2, plumb line 2; MA1, proximal moment arm; MA2, distal moment arm; SI, distal phalanx length; LC, toe length.

Distances

The centre of rotation of the DIP joint to the centre of the DDFT tendon proximal to (proximal MA_{DDFT}) and distal to (distal MA_{DDFT}) the NB at 90° to the DDFT; toe to a plumb line originating from the centre of rotation of the DIP joint and bisecting the sole (PL1); heel to a plumb line originating from the centre of rotation of the DIP joint and bisecting the sole (PL2); internal surface of the sole (distal phalanx length); coronet to sole (toe height); proximal border of the heel bulb to sole (heel height), and coronet to the border between the laminar and solar corium (toe length).

Ratios

Ratios between the vertical measurements and the moment arms and the distal phalanx lengths were calculated to allow comparison amongst individuals irrespective of size. The proximal and distal MA_{DDFT} were normalised for size by expressing them as a percentage of toe length. Heel collapse index (HCI) and heel height index (HI) (Eliashar et al., 2004) were calculated to determine whether collapsed hoof conformation was associated with different lesions. HCI was defined as the ratio between heel angle and toe angle. HI was defined as the ratio between the dorsal coronary band height and heel height.

Repeatability of the measurements

Repeatability was determined for all measurements in a preliminary study by performing two repeat measurements on the same image in 44 horses. To assess the effect of repeat positioning on the measurements the scans were repeated twice in 12 horses with the foot being repositioned between acquisitions. The repeatability coefficients (Bland and Altman, 1986) lay between 0.54 and 1.61 mm for distances and 0.71° and 1.54° for angles, which was deemed acceptable by the authors.

Data analysis

Data were assessed with a one-sample Kolmogorov–Smirnov test to confirm that there were no significant departures from normal distribution. Differences in conformation parameters between injury groups were assessed with a one-way analysis of variance with a Bonferroni test used post hoc when there were significant differences. Differences between DDFT and NB categories and non-DDFT and non-NB groups were assessed with independent sample t test. Direct logistic regressions were performed to assess the association between conformation parameters and the likelihood that horses would have a DDFT lesion or a NB lesion. All analyses were performed using SPSS 19 (IBM); significance was set at $P < 0.05$.

Results

Study population

The mean age ± SD of horses included in the study was 10.54 ± 3.73 years, and the mean ± SD lameness score was 3.0 ± 1.2 on a 1–10 lameness grade. Breeds included Warmbloods (37), Thoroughbreds and Thoroughbred crosses (51), Irish sports