“Hoof mapping – guide or rule?” – The accuracy of using external landmarks to localise internal structures in the equine hoof

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DECLARATION

I hereby declare that the work within this Fellowship dissertation is my own. Any sources have been duly referenced and any illustrations or diagrams that are not mine are used with the permission of the owner

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ABSTRACT

Background

Various hoof mapping protocols have been used to provide a practical guide for standardisation and teaching of trimming and shoe positioning in the horse, however its accuracy has not been evaluated in three dimensions.

Aim and hypothesis

The aim of this study was to determine the accuracy of using external landmarks on the solear surface of the hoof capsule as part of a specific hoof trimming protocol to localise anatomical structures within the equine hoof. It was hypothesised that external landmarks would be accurate enough to provide an estimation of the position of key anatomical parameters in every day practice.

Materials and Methods

100 cadaver hooves (52 front and 48 hind hooves), free of gross abnormalities, were used in this study. Computed tomographic (CT) scans were performed before and after trimming. The hooves were trimmed by a single farrier according to a standardised trimming protocol. External landmarks were marked with hypodermic needles so they could be identified on the CT images. The difference between the landmarks and the internal structures, namely the centre of rotation of the distal interphalangeal joint (COR), centre of the articular surface of P3 (COAS), extensor process (EP) and the apex of the distal phalanx (ADP) were measured. The differences were compared statistically between front and hind and before and after trimming.

Results

There was no significant difference in accuracy between trimmed and untrimmed hooves and between front hooves (P=0.105) and hind hooves (P=0.565).

The magnitude of the difference between the estimated location and the true location was similar for the COR, COAS and ADP with around 0.5cm on average. The estimation of the EP was the least accurate with about 1cm in difference on average. In most hooves all the predictions were placed too far dorsal with very few exceptions. The one measurement where about a third of the predictions was placed too far plantar was the ADP in hind hooves.

Discussion

In a practical context the estimation of the COR, COAS and ADP is accurate enough for the positioning of horse shoes in the dorsopalmar (plantar) direction. The results of this study suggest that in the majority of hooves the estimation from external landmarks leads the farrier to underestimate the length of the horn capsule in relation to the internal structures.

The estimation of the EP by external landmarks is not within acceptable limits for practical use, however this parameter is not widely used in daily shoeing practice.

Conclusion

Hoof mapping provides a good guide, but should not be used as a rule. If accuracy beyond 0.5cm is required than radiographs with appropriate external markers are recommended to optimise trimming and shoe positioning.

LIST OF ABBREVIATIONS

Apex of the distal border of the distal phalanx: ADP

Centre of rotation of the distal interphalangeal joint: COR

Centre of the articular surface of the distal phalanx: COAS

Computed tomography: CT

Distal interphalangeal joint: DIP

Distal phalanx: P3

Extensor process: EP

Standard deviation: SD

INTRODUCTION

The shape of the horny hoof is largely defined by the inner bony and soft tissue structures (Davies, Merritt and Thomason, 2007) and influenced by its use and quality of hoof care. The horn capsule has to fulfil a multitude of roles in response to the stresses it comes under during the different phases of the stride. To be able to fulfil these roles, the hooves need to optimise their function (Balch, Butler & Collier*,* 1997): Firstly it is there to protect the internal structures within the horn capsule in any situation (Redden, 2003; Reilly, 2010). During movement it needs to absorb and dissipate concussion on impact and during deceleration (Foor, 2007), to support the weight of the horse during the stance phase of the stride and to provide a stable foundation for the hoof to take off (Barrey, 2013).

The hoof capsule responds to the stresses that it experiences and changes its shape accordingly (Douglas *et al.*, 1996; Davies, 1997; Burn and Brockington, 2001). Due to growth and stresses on the hoof it can change over time and the relationship between external landmarks and internal structures will alter (Jones, 2002; Ovnicek, Page and Trotter, 2003; Caldwell *et al.*, 2016). Leg conformation influences weight-bearing and can cause hoof distortion, for example a horse showing a valgus conformation will often develop a lateral toe flare and medial sheared heel due to the changed stresses the horn capsule comes under (Redden, 2003; Oosterlinck *et al.*, 2015). Another significant factor influencing hoof shape and function is the care the hoof receives. The quality of farrier care can vary between farriers and is influenced by the way they are taught.

The aim of farriery is to optimise function and minimize stresses in order to maximise performance and reduce the occurrence of lameness.

The basis of hoof care is the trim. There has been an on-going struggle with the description of what a good trim is and the definition of what hoof balance is (Caldwell et al., 2016; Clayton, Gray, Kaiser, & Bowker, 2011; Jones, 2002a, Balch, Butler & Collier, 1997)). The industry does not seem to have a definition of what acceptable tolerances of trimming and shoe position are. Radiographs are often used to allow the visualisation of the internal anatomy and provide a guide for trimming and shoe positioning to improve biomechanics (Caldwell et al., 2016; Colles, 1983; Eggleston, 2012; Eggleston, 2012). However, radiographs are not always available due to financial and practical constraints and most commonly, assessment of hoof shape is performed by eye using external parameters. These, for example include hoof-pastern angle, distortions of the hoof wall, flatness of the solear surface, proportion of solear surface of the hoof in front or behind the centre of rotation (COR) of the distal interphalangeal joint (DIP). Farriers and veterinarians have tried to standardise hoof assessment by using devices such as the hoof angle gauge, T-square, callipers and transparent templates (Caldwell *et al.*, 2016). These devices allow measuring of the external dimensions of the hoof capsule and do not reference to internal structures. Knowledge of the topographical and functional anatomy of the internal hoof is essential to inform the farrier of the optimum way that the hoof should be trimmed to achieve balance in all planes.

Most farriery and some veterinary textbooks provide guidelines on trimming (Riemersma *et al.*, 1996; Buechner-Maxwell *et al.*, 2003; O'Grady, 2003; Foor, 2007; Clayton *et al.*, 2011; Caldwell *et al.*, 2016). To further help standardise the trim, trimming protocols based on hoof mapping have been proposed for more than 100 years (Russell, 1897). Over the years multiple protocols have been developed since. Some of these protocols were developed on the basis of feral horses with the aim of emulating their hoof shape in domestic horses

(Ovnicek, 1993; Jackson, 1992); others were developed to map external to internal structures (Duckett, 1990; 2008, Savoldi, 2007, Caldwell *et al.,* 2016).

Hoof mapping can help the farrier with the assessment and trimming process, deciding how much to trim off the toe or how much to take off the heels. This is important for all farriers to know and especially helpful for less experienced individuals. Mapping can be performed by taking the time to physically draw lines onto the bottom and the sides of the hoof or -with practice- the lines can be visualised. The scientific evidence behind many protocols is scarce, evidence is anecdotal and lacking scientific review. Recently Caldwell *et al* (2016) has tested a hoof mapping protocol with the help of radiographs, however this study was limited to two internal landmarks (extensor process of P3 and COR of the DIP) and the use of planar radiography limited the assessment to the sagittal plane.

The aim of the presented study was to determine whether external reference points on the solear surface could be used to identify internal anatomical landmarks in 3D.

The mapping protocol assessed in this study has been used by the author, in practice, for over 20 years (Moon, 1994). It aims to identify the COR of the DIPJ, the centre of the articular surface of P3 (COAS), the extensor process of P3 (EP) and the apex of P3 (ADP). These internal structures were chosen since the author considers these to be important to optimise dorsopalmar/plantar hoof balance and shoe placement. COR in relation to solar surface determines leverage (Barrey, 1990)and hence load distribution within the hoof. In many textbooks it is recommended that 50% of the base of the hoof is palmar/plantar of the COR and 50% dorsal (Parks, Ovnicek and Sigafoos, 2003; 2013, chap. 8). This is however rarely achievable in practice. Hence the author has used the COAS as a more achievable dividing landmark. The EP and ADP are not used by the authors in his daily practice however have been proposed by others to be of importance (Caldwell *et al.*, 2016).

The author proposes the following hypothesis:

> **The external solear landmarks proposed in this study, can be used to accurately determine the location of biomechanically important internal anatomical structures.**

MATERIALS AND METHODS

The study has been approved by the Ethics and Welfare Committee of the Royal Veterinary College.

Materials

100 hooves were sourced from a local abattoir; the horses and ponies were euthanised for reasons unrelated to the study. The limbs were selected randomly including various sizes of horses and ponies to reflect the variety of the UK horse population. All limbs had been transected at the carpus or tarsus level. Limbs were not included in the study if they showed any signs of gross pathologies such as laminitis, gross hoof capsule distortion, cracks or serious horn defects. The limbs were stored frozen at -18^{o}C and defrosted in warm water prior to the start of the study. To prepare the hooves for data collection the hooves were thoroughly cleaned and any sole that was ready to exfoliate was removed but no hoof wall trimming was performed. Five shoes were removed in the preparation process, the majority were unshod when collected.

The aim of the study was to use an equal number of front and hind limbs, but once the computed tomography (CT) scans had been performed two limbs had to be re-categorised resulting in 52 front limbs (27 left, 25 right) and 48 hind limbs (21 left, 27 right). One front limb was taken out of the study after the CT had identified a fracture of P3. One CT dataset was not transferred correctly and hence lost to the study. This resulted in complete datasets of 50 front limbs and 48 hind limbs.

Computed Tomography

Each leg was scanned twice, one scan was acquired before trimming and one scan after trimming using the same CT machine (GE Lightspeed Pro 16, GE Healthcare, 352 Buckingham Avenue, Slough, UK) and the same settings (80 kV, 150 mA, 1.25mm slice thickness). The scans were continuous from the hoof to include the fetlock. Images were stored in DICOM format. Osirix Lite was used for image processing and analysis. CT scans result in a stack of image slices, which the computer can virtually re-cut in any plane. This has the advantage of creating a 3D picture that allows accurate identification of landmarks in space. For the measurements the images were orientated as if the horse was standing and slices were chosen that cut straight through using the entry point of the pins which were placed on the solear surface to identify the external landmarks according to the proposed mapping protocol. Fig. 2 shows CT images illustrating the measurements performed. A horizontal line was drawn through each internal structure of interest (COR, COAS, ADP, EP). The distances between the internal structure and the vertical line drawn up from the external landmark were measured and it was recorded if the vertical line was dorsal or palmar/plantar to it.

Hoof Trimming protocol

A hoof map was used to standardise the trimming in a collaborative study with Jonathan Nunn FWCF. The trimming of the hooves was performed by the same farrier.

The soles and frogs of the hooves were trimmed in accordance with a trimming for the application of a shoe. Figure 1 illustrates the solear landmarks.

Position of solar landmarks

To be able to identify the solar landmarks on the CT images hypothermic needles were placed based on the above described mapping process, as seen in Figure 1.

The hooves were all trimmed using the following reference points:

- A line was drawn down the middle of the frog and across the sole to centre of toe (red line). Pin 1 was placed on the centre line at the widest part of the hoof using the white line. It is hypothesised that vertical to this is the COR. Pin 2 was located using digital callipers on the centre line 10mm dorsal to the widest point. It is hypothesised that vertical to this is the COAS. Pin 3 was placed at the point of the frog and it is hypothesised 3/8" or 9.525 mm palmar/ plantar and vertical to this point is the EP, this is commonly referred to as Duckett's Dot, or centre of mass of P3
- Two parallel lines each side of the centre line were drawn from the buttress of the heel at the level of the intersection of the highest and widest point of the frog, forward to the white line (brown line).
- A line was then drawn perpendicular to the centre line from the two brown lines where these lines met the white line (green line). Pin 4 was placed where the green line crossed the centre line. It is hypothesised that vertical to this point was the ADP.
- The buttresses of the heels were marked at the level where the highest and widest parts of the palmar/plantar part of the frog intersected to determine the level at which the heels would be trimmed to (blue line). As this the most caudal part of the bearing surface of the hoof wall.

- A line was drawn across at the widest point of the white line to mark the widest point of the hoof (pink line).

The widest part was found using the white line not the outer perimeter of the hoof wall, as this marker becomes distorted as the hoof grows or is more influenced by imbalances in the hoof wall. The true widest part of the hoof at the white line is where it changes direction at the quarters, this may become a flattened zone in some distorted hooves and the middle of the flattened zone was used (Figure 2). Once this widest point was found a line was drawn from white line to white line across the quarters.

Mediolateral balance was addressed to an industry standard using the short axis of the pastern and trimming as flat as possible but leaving areas untrimmed where the hoof wall had been broken.

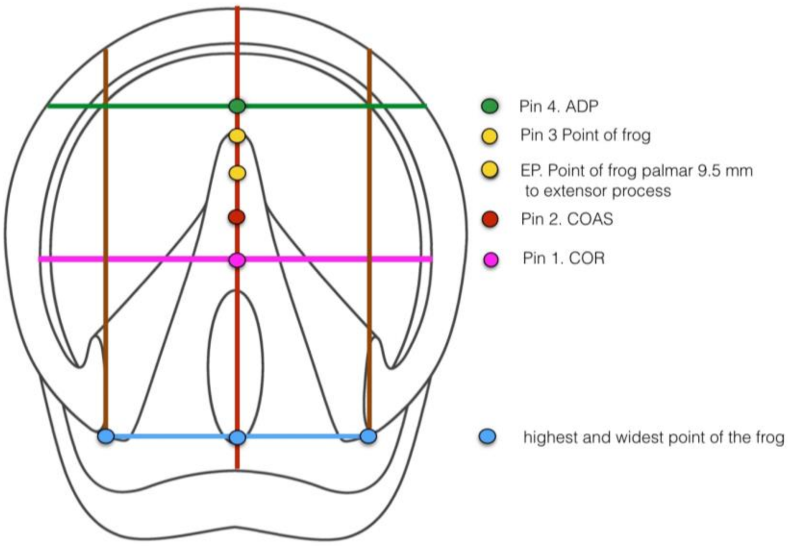


***Figure 1**. **Solear surface of a front hoof illustrating the external landmarks**. Pin1=external landmark pointing to the COR, pin2=external landmark for COAS, pin3= point of frog as external landmark for EP for measure point 10mm palmar on sagittal line, pin 4 =external landmark for ADP.*

Figure 2. Image of solear surface displaying the white line as a marker for the widest part of the hoof. *This picture of the solar surface of a half trimmed/half untrimmed hoof illustrates that the white line should be used to determine the widest point of the hoof rather than the perimeter which is reality influenced by growth (image courtesy of David Moseley).*

US).

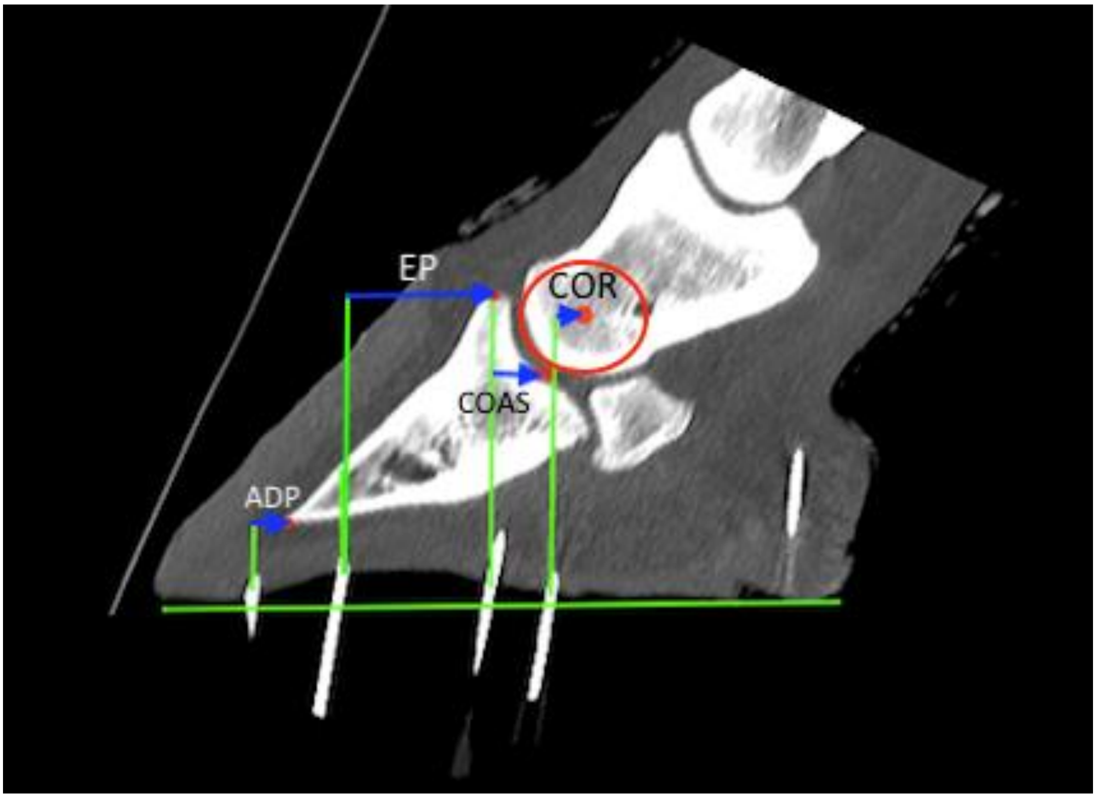


***Figure 3**. **Computed tomographic image in the midsagittal plane illustrating the relationship between internal and external landmarks.** The blue lines represent the distance between the actual anatomical structure and the predicted position (green lines) based on the respective solear landmark.*

Data analysis

Data distribution was assessed for normality using histograms and Kolmogorov Smirnov Tests and all data was normally distributed. Agreement between predicted position based on external landmarks and actual positional of anatomical structure was assessed by calculating the limits of agreement (Bland and Altman 1986). The P value was set at P=0.05. All data analysis was performed in Excel (Microsoft, Seattle, US) and SPSS (version 22, IBM, Armonk, US).

RESULTS

Identification of the COR

Table 1a summarises the COR findings in front hooves.

In the front hooves the majority of observations for the COR were dorsal of the predicted location (44/50 in the trimmed and 42/50 in the untrimmed hooves). The mean±SD difference between predicted and actual position was 0.45±0.47cm with a maximum difference of 1.87cm in the untrimmed and in the trimmed hooves 0.70±0.46cm with a maximum of 1.62cm.

A small number of hooves (8/50 in the untrimmed and 6/50 in the trimmed hooves) showed the predicted position to be palmar to the actual position with a mean±SD difference 0.43±0.45 with a minimum of 0.1 and a maximum difference of 1.5 in the untrimmed hooves. In the trimmed hooves the mean±SD difference 0.44±0.20 with a minimum of 0.28 and a maximum of 0.83.

Table 1b summarises the COR findings in hind hooves.

In the hind hooves the magnitude of differences was similar to the front hooves. While the majority of observations were dorsal of the predicted location there was almost double the number of observations plantar compared to the front limbs where only a few observed locations were palmar of the predictions.

There was no significant difference in accuracy between trimmed and untrimmed front hooves (P=0.105) and hind hooves (P=0.565).

Table 1a: Difference in predicted versus actual position of the COR in the untrimmed and trimmed front hooves

Difference in cm	untrimmed		trimmed	
	dorsal	palmar	dorsal	palmar
n	42	8	44	6
mean	0.54	0.43	0.70	0.44
SD	0.47	0.45	0.46	0.20
Minimum	0	0.10	0	0.28
Maximum	0.87	1.5	0.62	0.83

Table 1b: Difference in predicted versus actual position of the COR in the untrimmed and trimmed hind hooves.

Difference in cm	untrimmed		trimmed	
	dorsal	palmar	dorsal	palmar
n	34	14	33	15
mean	0.55	0.54	0.62	0.49
SD	0.43	0.26	0.47	0.27
Minimum	0	0.21	0	0.4
Maximum	1.64	1.15	1.8	0.97

Identification of the COAS

Table 2a summarises the COAS findings in front hooves.

Similar to the COR by far the majority of the observations placed the COAS more dorsal of the predicted location, with only a few observed positions of the COAS to be more palmar than its actual location in the front hooves. There was no significant difference in the difference in observed between trimmed and untrimmed front hooves (P=0.79) or hind hooves (P=0.659). The mean±SD difference dorsally was 0.61±0.41 with a maximum of 0.92.

Table 2b summarises the COAs findings in hind hooves.

Similar to the COR the magnitude of differences between the predicted and observed locations were similar in hind hooves and the majority of observations were localised more dorsal to the predicted, however like for the COR there was a much larger proportion of hooves where the prediction was too plantar located compared to front hooves.

Table 2a: Difference in predicted versus actual position of the COAS in the untrimmed and trimmed front hooves

Difference in cm	untrimmed		trimmed	
	dorsal	palmar	dorsal	palmar
n	41	9	42	8
mean	0.61	0.39	0.63	0.36
SD	0.41	0.48	0.39	0.23
Minimum	0	0.11	0	0.11
Maximum	0.92	1.61	1.56	0.84

Table 2b: Difference in predicted versus actual position of the COAS in the untrimmed and trimmed hind hooves

Difference in cm	untrimmed		trimmed	
	dorsal	palmar	dorsal	palmar
n	30	18	32	16
mean	0.42	0.63	0.38	0.66
SD	0.34	0.40	0.31	0.34
Minimum	0	0.17	0	0.15
Maximum	1.21	1.23	1.36	1.14

Identification of the apex of P3

Table 3a and b summarise the apex of P3 findings in front and hind hooves respectively.

All predicted locations placed the ADP more dorsal than its actual position in all front hooves this was not the case in hind hooves where a considerable proportion of the predictions were placed too far plantar. There was no significant difference between trimmed and untrimmed hooves in front (P=0.672) and hind hooves (P=0.724).

Table 3a: Difference in predicted versus actual position of the apex of P3 in the untrimmed and trimmed front hooves

Difference in cm	untrimmed		trimmed	
	dorsal	palmar	dorsal	palmar
n	50	0	50	0
mean	0.85	-	0.88	-
SD	0.33	-	0.41	-
Minimum	0.22	-	0	-
Maximum	1.57	-	1.65	-

Table 3b: Difference in predicted versus actual position of the apex of P3 in the untrimmed and trimmed hind hooves

Difference in cm	untrimmed		trimmed	
	dorsal	palmar	dorsal	palmar
n	36	12	34	14
mean	0.46	0.70	0.43	0.59
SD	0.39	0.49	0.32	0.49
Minimum	0	0.28	0	0.17
Maximum	1.39	1.64	1.12	1.62

Identification of the extensor process of P3

Table 4a and b summarise the extensor process of P3 findings in front and hind hooves respectively.

This landmark showed the biggest difference between predicted and actual position with a minimum of 1cm, a maximum of 3cm in both front and hind hooves. The majority of predictions placed the landmark more dorsally than its actual position with no significant difference between trimmed and untrimmed hooves (P=0.105 front hooves, P=0.768 hind hooves).

Table 4a: Difference in predicted versus actual position of the extensor process in the untrimmed and trimmed front hooves

Difference in cm	untrimmed		trimmed	
	dorsal	palmar	dorsal	palmar
n	45	5	48	2
mean	0.86	0.22	1.01	0.21
SD	0.50	0.11	0.54	0.27
Minimum	0.03	0.01	0.08	0.09
Maximum	2.08	0.39	2.55	0.39

Table 4b: Difference in predicted versus actual position of the extensor process in the untrimmed and trimmed hind hooves

Difference in cm	untrimmed		trimmed	
	dorsal	palmar	dorsal	palmar
n	45	3	44	4
mean	1.04	1.3	1.04	1.01
SD	0.43	1.5	0.47	0.19
Minimum	0.11	1.2	0.21	0.75
Maximum	1.82	1.5	1.80	1.21

DISCUSSION

In this study the accuracy of matching external landmarks was investigated; commonly used as part of a standard hoof mapping protocol to internal anatomical structures. Trimming is a vital part and some may argue the most important part of hoof care. However within farriery practice and the available literature for examination or competition there does not seem to be a united theory of trimming tolerance or a definition of hoof balance (Caldwell *et al.*, 2016).

It was hypothesised that the external solear landmarks proposed in this study can be used to accurately determine the location of biomechanically important internal anatomical structures. The results of this study show that while it was within acceptable tolerances for some landmarks there were other that were outside acceptable tolerances. My personal thoughts on what may be an acceptable level of tolerance may be as high as 3mm. In engineering tolerances are easily assignable due to known properties of materials used, with biological systems there are a range of normal parameters, where with the hoof this is still work in progress.

Centre of rotation

The COR of the DIP plays an important role in the biomechanics of the hoof and indeed the whole limb. Most publications propose that 50% of the base of the hoof is positioned in front of the COR and 50% behind and the widest point of the hoof is used as an external reference point to identify this spot. In this study, the majority of front hooves showed the actual COR was positioned on average 5mm dorsal to the predicted COR in front and hind hooves. The discrepancy of 5mm in this study corresponds well with another study investigating the accuracy of predicting the COR using the widest point of the white line which was done using planar radiographs (Milner and Hughes, 2012; Back and Clayton, 2013). There was no significant difference between trimmed and untrimmed hooves. This indicates that the external landmark used are relatively independent of the condition of the hoof capsule and the map can be used to the same accuracy in the trimmed and untrimmed state. While there was lack of accuracy the degree of accuracy does make the method useful in the set up of the trimming and shoe placement process. Whether the magnitude of the difference between predicted and actual COR is acceptable depends on the individual situation. Trimming creates the basis of the biomechanics of the limb. But in the shod hoof it is the position of the shoe relative to the COAS and the distal border of the hoof that gives the functional mechanics. To address imbalances and proportionality of the trimmed hoof in the DP and LM planes, the shoe can be used to improve the interaction between the hoof and the ground. Shoes features such as rolled, rocker toes, set back toes or support /extensions can be used to further improve the mechanical function of the trimmed hoof.

In the author's opinion these features/modifications may well be within a tolerable degree for the practical purpose of trimming and shoe fitting, when shoe position and surface area are greater than the degree of variance observed. The observed difference may lie in the fact that this map requires the identification of the widest point of the white line which, while being a very defined point in some horses, is actually more gradual in others and hence more difficult to identify. In many horses it resembles more of a zone than an actual point in change in direction. This may be because the centre of rotation is a defined 1mm point on the CT images, while the centre of rotation relative to the ground surface is the broader articulation of the coffin joint and the movement of P3 inside the hoof capsule. This could explain the small proportion of horses in which the prediction of the COR was too palmar in comparison to its actual position.

The five front hooves where the predicted COR was more than 1.5 cm dorsal to the actual COR all showed a similar very pronounced flat hoof conformation with collapsed heels that migrated forward (Figure 4.) As this form of mapping only takes into consideration the solear surface, hoof-pastern angles or hoof conformation could not be assessed in the study. In reality these would be a normal part of the farrier assessment.

Figure 4. Solear View of a Collapsed Heel. *This solear view shows a very round collapsed heel front hoof giving the illusion of the widest point of the white line being too far dorsal. In this hoof the predicted COR was 1.54cm dorsal to the actual position. This indicates that the exclusive use of the mapping system used in this study is less accurate in these types of hooves and this is when professional experience comes into play.*

While the average difference between predicted and actual position of the COR in hind hooves was similar to the front, there were fewer which showed a difference of more than 1.5 cm between predicted and actual value. There was however, almost twice the number of hind hooves, compared to front hooves, in which the predicted position was plantar to the actual position. This may be due to the difference in position of P3 within the hind hoof capsule compared to the front (Nunn, FWCF Thesis 2017). Variability in the relationship of internal anatomy to external landmarks may be increased in hind hooves as this mapping system was originally developed for fore hooves. As all of the limbs involved in the study were transected cadaver limbs, none were bearing weight. The effects of load on the position of COR had not been evaluated and no comparative data could be found in the literature.

Identification of COAS

In the farriery industry the terms COAS and COR are often used interchangeably. In this study the COAS was defined as the centre of the articular surface of P3. In the author's opinion using the COAS which is positioned dorsal to the COR this is often a more practically applicable parameter. In many horses it is impossible to achieve the 50:50 ratio postulated by most textbooks and the COAS is a more realistic parameter to use as a guide for trimming and shoe position in the dorsopalmar orientation. The accuracy of identification of the COAS is similar to that of the COR following a similar pattern and similar differences between front- and hind and trimmed and untrimmed hooves. This is not surprising since the same marker (and hence landmarks) were used to identify both internal structures and there is a close anatomical relationship between the two structures. The external landmark for the COAS was identified 10mm dorsal to the external landmark of the COR. The 10mm distance is an absolute measurement which does not take the size of the hooves into consideration. In this study we used a range of hooves sizes to evaluate the applicability of the mapping to horses of different sizes. The fact that similar differences between COAS and COR measurements were found is probably due to the fact that the differences averaged out. In future studies we will investigate the relationship between the size of the joint surface of P3 and overall hoof size, e.g. dorsal wall thickness and thus improving the external mapping of this internal structure.

Identification of the ADP

The identification of the ADP is important for the application of shoes and some people postulate that it is important to break-over (Caldwell *et al.*, 2016). In all front hooves the external landmark was positioned too far dorsal in relation to the internal structure with an average difference of almost 1cm, whereas in the hindlimb in about 25% of hooves the external landmark placed the apex too far plantar. The external landmark for this anatomical structure is heavily influenced by the width of the heels, width of the quarters and by hoof distortion. In the experience of the author other anatomical landmarks such as the COR and COAS are much more useful for optimising biomechanics through farriery. There are some instances where it is useful to know the position of the apex of P3, namely in horses who have sustained a puncture wound (as it indicates the likelihood of it reaching the bone), and also in horses with laminitis and club hooves. However, in these cases radiographic assessment of the affected hooves is essential. Note that the results of this study cannot be applied to horses with laminitis or club hooves since any hooves showing signs of these problems were excluded from this study.

Extensor process

In this study the extensor process was predicted to be 1cm behind the point of the frog. Predicting the EP has been important as in literature it is often stated as the insertion of the DDFT, this has important relevance to the lever action of DDFT. This has proven to be almost one cm too far dorsal to its actual position in the majority of hooves. This was more pronounced in the hind hooves compared to the fronts but there was no significant difference. Neither was there a significant difference between trimmed and untrimmed hooves. Of all the measurements this showed the biggest difference between prediction and actual position of the structure. It appears that the only hooves that this is anywhere near accurate are very compact, short hooves. The author was unable to find literature regarding pedal volume size to horse/hoof size. Having considerable experience assessing hooves with x-ray before trimming and in his opinion these are not that common due to the horses being x rayed under performance or lameness.

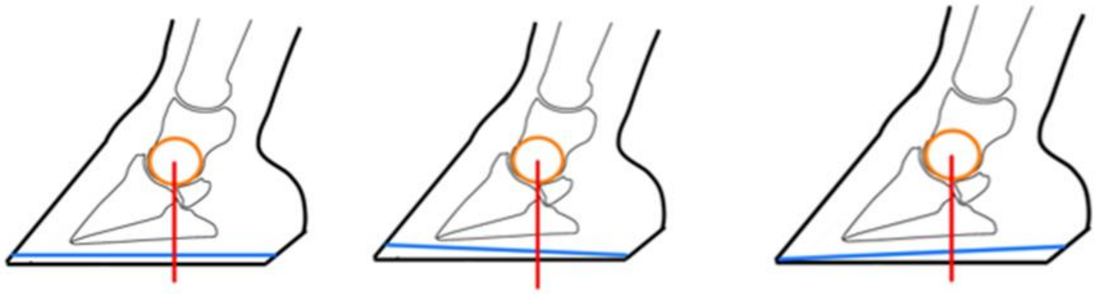
General discussion

In the author's opinion the COAS and COR were more predictable than the other structures due to them being closer to the centre of weight bearing. The toe and the heels were more prone to the effects of leverage and collapse, so hoof distortion was more pronounced in the dorsal palmar /planter areas of the hoof capsule. As the hoof capsule is a time sensitive structure hoof distortion becomes more obvious due to the length of excess hoof making the distal border of P3 and the extensor process being less predictable.

The author believes that the exterior markers are affected by the ratios of excess hoof wall that needs to be trimmed from the toe and the heel. The DP plane of the trim will be affected by the toe to heel trim that is dictated by the excess hoof for examples (Fig5).

A. Trim ratio 1 toe to 1 at heel (even trim)
B. Trim ratio 1 toe to 0 at heel (trim will elevate hoof angle)
C. Trim ratio 0 toe to 1 at heel (trim will give less elevation of hoof angle)

Depending on the change of hoof angles after the trim there will be a change in relationship between the vertical axis drawn from the external landmarks to the internal structures. The use of x-rays and measurement programs and markers on the weight-bearing surface of the hoof would be the ideal. Then the vet and farrier would be able to measure down from the internal points and relate these positions to the markers to allow an individualised trimming. Distortions and change in the shape of the hoof capsule also affects the position



of P3 and the alignment of P2 and the distal sesamoid bone inside the hoof, so this also will affect the predictability of internal landmarks.

Figure 5. The effect of trim ratios on the COR.

CONCLUSION

The results of this study indicate that the accuracy of external landmarks to identify the position of anatomical structures within the hoof is different for each structure and varies between horses. The big question here is what error margin is acceptable in a practical setting. Acceptable levels of tolerance in trimming and shoe positioning are not established and people are reluctant to discuss these. There is no doubt that tolerance levels vary between horses and situations and it is up to the individual farrier to decide what is within acceptable limits. Good shoeing has tolerances in every area for the farrier craft from shoeing to shoe making /shoe fitting. Trimming in the dorsopalmar orientation is what has been investigated in this study. Toe length, toe thickness, heel height all could vary by mm and would change external reference to internal landmarks. Another factor that needs taking into account is the shoeing interval. As hooves grow they become imbalanced and it is up to the farrier to try to re-balance consistently. The farrier industry is poor in keeping records for a variety of reasons, for example it would be helpful to have records of hoof length, previous distortions of the hoof capsule or seasonal changes to assess the success of previous shoeing strategies. There can be no substitute for the use of x-rays for the farrier or the horse and there is no doubt that trimming and shoeing is made easier if the position of P3 in the hoof capsule is known. However, in the majority of cases x-rays are not available, due to financial and practical constraints. Farriers will be asked to shoe without the benefit of x-rays for the foreseeable future, so some type of referencing and standardisation system is needed to help farriers to trim, position the shoe and make appropriate shoe adaptations. The farriers' main measuring device and quality control remains to be their sight and experience.

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