AN INVESTIGATIVE STUDY INTO THE APICAL ANGLE OF THE DISTAL PHALANX IN THE UNTRIMMED AND TRIMMED EQUINE HOOF

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CONTENTS

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ABBREVIATIONS

AA: Apical Angle - relating to the apex or tip of a pyramidal or pointed structure. Often used in medical terminology to describe apicular areas of anatomy. Derived from the word "*apicalis*" (new latin).

P3: Distal Phalanx.

AAP3midsag: Apical Angle – refers to the angle of the apex of the distal phalanx in the mid sagittal plane.

AAP3rad: Angle of the Apex of the distal phalanx at the distal border, as usually measured on radiographs.

PA: Palmar/Plantar Angle measured to the lower process of distal phalanx.

WBS: Weight Bearing Surface.

DSP3: Dorsal Surface of the Distal Phalanx to the Weight Bearing Surface angle.

DHW: Dorsal Hoof Wall angle of the dorsal hoof wall to the weight bearing surface.

DD: Dorso-Distal.

HWA: Hoof Wall Angle.

COR: Centre Of Rotation – in a rotation the point that does not move – the rest of the plane moves around one fixed point.

DDFT: Deep Digital Flexor Tendon.

MRI: Magnetic Resonance Imaging.

CT: Computed Tomography.

SUMMARY

Introduction:

Foot conformation and especially the position of the distal phalanx (P3) within the foot is related to soundness in the horse, however, little is known how this differs between front and hind limbs and how this is influenced by trimming.

Aim: to determine the position and the apical angle of the distal phalanx within the front and hind foot before and after trimming. It was hypothesised that there would be a significant difference between front and hind and pre- and post-trim.

Materials and Methods: The position of the distal phalanx was determined in 100 cadaver feet (52 front, 48 hind feet) using computed tomography before and after they were trimmed to a standardised protocol. Measurements were taken of the angle of the dorsal hoof wall to weight bearing surface (DHW), the angle of the dorsal surface of the distal phalanx (DSP3), the apical angle of the distal phalanx in the midsagittal plane (AAP3 midsagittal) and at the level of the rim of the distal phalanx (AAP3 radiograph) to mimic the view that is commonly assessed on radiographs. Parameters were compared between front and hind feet, pre- and post-trim and correlated with each other.

Results:

There was a significant difference in conformation measurements between front and hind feet and between trimmed and untrimmed feet. In the untrimmed feet there was a significant difference between the front and hind feet in the angle between dorsal hoof wall ($P=0.016$), apical angle of distal phalanx (radiograph) ($P=0.028$) apical angle of distal phalanx (mid sagittal) ($P<0.0001$), but not between the PA ($P=0.161$) or the Dorsal Surface of P3 (DSP3) to WBS ($P=0.065$). After trimming there was a significant difference between the front and hind feet for all measured parameters ($P<0.0001$). The dorsal hoof wall angle (DHW) and dorsal surface of distal phalanx (DSP3) were significantly steeper in the hind feet when compared to the front after trimming, but the palmar/plantar angle (PA) was significantly lower.

Trimming had a significant effect on DHW angle, DSP3, PA ($P<0.0001$) in the front feet and hind feet DHW ($P<0.0001$), and the hind feet DSP3 ($P=0.027$) and PA ($P=0.039$). DHW angle was significantly steeper after trimming in front and hind, DSP3 and PA were significantly less steep after trimming.

Conclusion:

The Apical angle of P3 is an unused reference for evaluating the relative angles within the hoof. Angles within the hoof vary greatly pre and post trim as do the variation of angles within the distal phalanx both apical and sole angle. Accurate radiographic assessment will be crucial to successful treatments and lameness diagnosis and prognosis. Recognising and measuring high or low angles relating to distal phalanx will have direct relevance to hoof health and soundness.

INTRODUCTION

It is widely recognised that many common causes of equine lameness occur within the foot and that foot conformation plays an important role: “70% of all sport horses will sustain at least one musculoskeletal disorder in any one season. Three quarters of those injuries are caused or contributed to by imbalances in the feet” (Williams and Deacon 1999). From as early as 400 BC weakness in the feet of equines was identified as a cause of lameness and unsuitability for athletic performance (Xenophon around 400 BC). When the horse was relied upon for transport and warfare, defects and abnormalities would have rendered these animals as unsuitable for purpose. While the purpose of the horse today has changed, the importance of foot health is still recognised and more deeply understood: “Appropriate hoof balance is defined as hoof preparation that enhances performance and interferes minimally with long term athletic ability” (Balch *et al.,*1997).

Farriery has always been central to foot health and with advancements in diagnostic imaging, the farriery profession is now able to access information about anatomy deep within the hoof capsule.

Detailed analysis and evaluation relating to soft tissue areas prone to damage and injury are now possible. With the help of standing MRI it has, for example, been shown that the angle and position of the distal phalanx (P3) can be related to lameness (Holroyd *et al.,* 2012). A low or negative angle of P3 can have significant influences on the probability of occurrence of associated lameness including DDFT and distal sesamoid lesions (Holroyd *et al*.,2011).

These clinical findings are supported by biomechanical evidence that “Hoof conformation has a marked correlation to the forces applied to the equine foot” (Eliashar *et al*., 2010).

In practice it is debated as to what the ideal angle of P3 within the hoof capsule should be. Some authors suggest that the palmar/plantar angle of P3 should ideally be between 3° to 5° positive (Baxter 2011), while others propose that it should be ground parallel (Cook 2012). Evidence from recent studies suggest that a high PA angle can contribute to lameness in coldblooded horses with steep hoof wall angle (HWA), supporting theories that a HWA of more than 5° can potentially be detrimental. Pathologies affecting ossification of the distal phalanges were observed to be more commonly affecting the ungular cartilages in the front feet of cold blooded horses with steeper hoof angles (Dzierz *et al*., 2016). There are many other variables including different bone morphologies to consider when measuring the angle of P3 from radiographs. The radiographic angle is measured at the level of the distal rim of P3, whereas the attachment of the deep digital flexor tendon (DDFT) is more sagittal. Hence an important factor for load distribution within the foot is the solar curvature and concavity of P3, which are subject to change under load and distortion (Craig et al., 2014).

Previous studies relating to low hoof angles suggest that the flexor moment arm of DDFT remains constant and tendon lesions of DDFT and distal sesamoid can be associated to low sole angles and DDFT tension (K.Holroyd *et al* 2013; Eliashar *et al* 2004).

Angles of hooves vary greatly depending on the length of the horny wall and the height and angle of the heels (Dyson *et al*., 2010). While the introduction of portable digital radiography systems has made radiographic assessment of foot conformation more common it is not standard procedure for every horse. Hoof care professionals are rarely given the measured angles and position of P3 to conclude if a satisfactory ideal HWA has been achieved with standard trimming and shoeing methods (Dyson et al., 2011) leaving farriers to rely on the assessment of foot conformation externally. A farriers aim is to trim and shoe to maintain alignment of the bony column of the digit in order to create optimum balance and equilibrium of dynamic and static forces throughout the limbs and thus enhance, maintain and protect, potentially increasing athletic performance of each individual equine. In many cases a horse shoe is applied to help maintain “ideal” balance for the hoof capsule.

Hoof mapping using external reference points is often used for trimming evaluation and also now in farrier education worldwide. Hoof mapping is used to reference relevant points within the foot (O'Grady 2009 and Caldwell *et al*., 2015). “Duckett's Dot” is a known theory developed by David Duckett FWCF (Landmarks for evaluating, trimming, and shoeing the equine foot: web article “the Horse” 2017) which employs recognised external reference points discussed by farrier educators and is a technique using external markers and remains unsupported scientifically. These protocols are used to estimate the position of various structures within the foot, to help farriers in standardising foot trimming. While it is recognised that “Hoof size reflects the physical dimensions of the enclosed distal phalanx” (Balch *et al*., 1997), very little is known how foot trimming affects the position of P3 and its relative alignment with other hoof structures.

Source (authors own 2016)

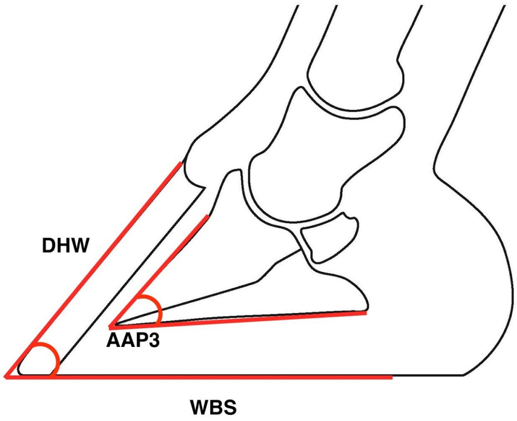


Figure 1A: Dorsal hoof wall to weight bearing surface *vs* P3 apical angle.

Source (authors own 2016)

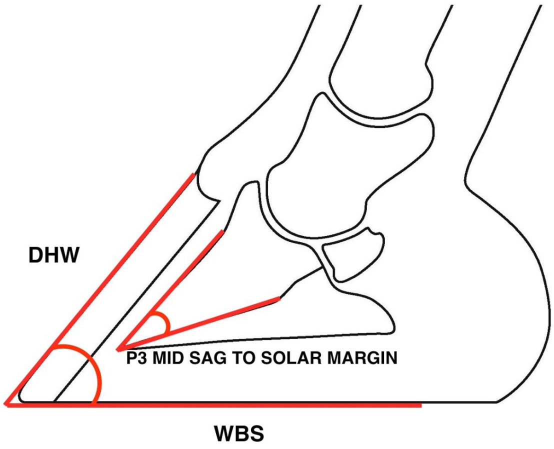


Figure 1B: Dorsal hoof wall to weight bearing surface *vs* P3 angle mid sagittal to solar margin.

Source (authors own 2016)

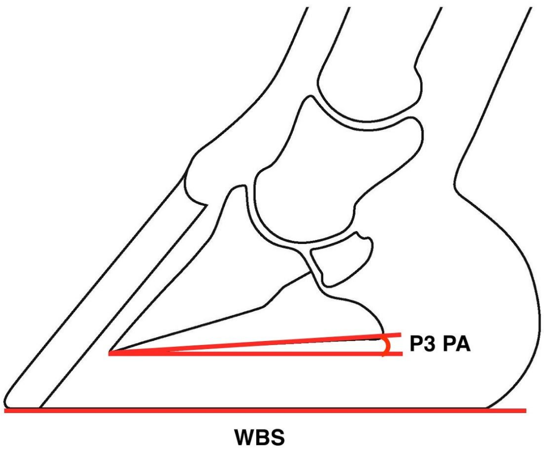


Figure 1C: P3 palmar/plantar angle accepted normal range is 3° to 5° positive PA

Source (authors own 2016)

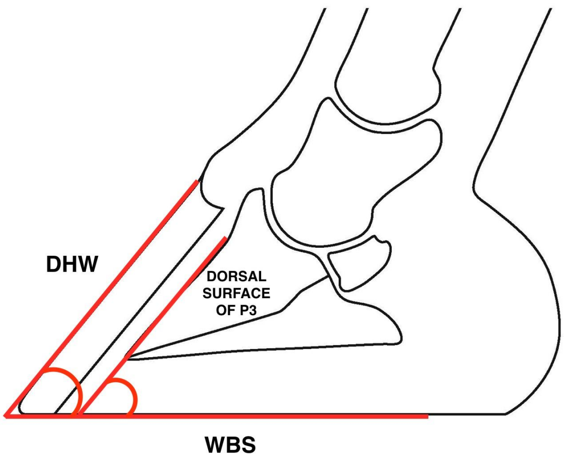


Figure 1D: dorsal hoof wall to weight bearing surface *vs* P3 dorsal surface of P3 to weight bearing surface.

Figures 1 A,B,C,D: Show schematic drawings of measured angles of the hoof and bone in the study. Source (authors own 2016)

AIMS AND OBJECTIVES

The aims were:

A: To collect measurements and use the data to test the relevance of variations of angles relating to the position of P3 within the digit.

B: To determine foot conformation parameters in front and hind feet both before and after trimming. It was hypothesised that :

1. There would be a positive correlation between apical angle of distal phalanx P3 and the dorso distal angle of the hoof wall to weight bearing surface.

2. This correlation will be stronger in the trimmed feet compared with the untrimmed feet.

3. The positional angle of P3 PA can be altered by foot trimming using visual reference points on the hoof from an applied foot mapping technique in front and hind feet.

MATERIALS AND METHODS

Cadaver material

100 cadaver hooves were randomly selected from freezer storage at Royal Veterinary College London (RVC). The legs were from horses euthanized for reasons unrelated to the presented study and the study was approved by the Ethics and Welfare Committee of the Royal Veterinary College. All of the limbs had been transected at the carpus or tarsus and were from various breed types of pony and horses. The aim was to use 50 front and 50 hind limbs, however based on the CT scans two feet had to be re-categorized from hind to front limbs, resulting in 52 front limbs (27 left, 25 right) and 48 hind limbs (21 left, 27 right)

Feet were not included if they showed signs of laminitis, severe hoof distortion, cracks or wounds. One foot was excluded after the CT scan showed a distal phalanx fracture.

2 hind feet had a severe hoof distortion and a P3 fracture and were replaced.

One foot had no post trimming CT scan hence no measurements due to technical issues.

The feet were defrosted in warm water 1 hour prior to the start of the study and the soles were cleaned and prepared. All Shoes (N=5) were removed. Mud and debris were removed with a wire brush but no trimming was undertaken at this stage.

Computed Tomography

Two CT scans were performed of each foot, one before and one after trimming with the same scan protocol (kV 80, mA150, slice thickness 1.25mm). All the feet were scanned from the fetlock joint distal to the solar surface using a 16 slice CT scanner (GE Lightspeed Pro 16, GE Healthcare, 352 Buckingham Avenue, Slough, UK) Figure 3 shows an example of a CT scan with frontal and sagittal multiplanar reconstructions that were used for measurements.

The images were stored in DICOM format. Osirix Lite was used for all measurements.

Figures 1A to 1D illustrate the measurements performed. DHW to WBS was measured twice: one measurement was performed in the mid sagittal plane and an additional measurement of the same angle was performed at the level to the distal rim of P3 lower palmar/plantar process to mimic the measurements commonly performed on radiographs. This study concentrates on lateromedial images which are familiar to farrier interpretation. CT provided a measuring system for the study with greater accuracy for measuring than radiographic images but still remain consistent with lateromedial images.

Foot Trimming

A standardised foot mapping protocol was used prior to foot trimming (configured by Grant Moon AWCF, collaborative study) (see Figure 2). All of the feet were trimmed by the author for consistency.

After sole exfoliation the excess wall was removed. The hoof wall at the toe was trimmed to the height of the sole and not beyond the sole depth at any point . To approximate heel height, a mark at the heel buttress at the highest and widest part of the frog was made after loose overgrowth was removed from the frog. Careful attention was observed to trim accurately, flat and level, to a standard interpretation of medio/lateral balance to the pastern axis of each individual limb.

A centre line was drawn through the middle of the frog, sole and central sulcus on every foot. (Figure 2A green line).

A line was drawn across the widest point of the foot at the widest point of the white line. This point related to the true widest point of the foot. It was considered that the external widest point of the hoof wall could be influenced by hoof wall distortions.

A line drawn across the highest and widest point of the frog would determine approximate heel height (Figure 2A blue line). Two parallel lines were drawn either side of the hoof centre line, (Figure 2A yellow lines) to bisect the highest and widest point of the frog (blue line), thus determining the ideal calculated heel height. A line drawn across the toe (Figure 2A Purple) bisected the two parallel toe quarter lines at the junction of the hoof wall and white line (Figure 2A yellow) and was parallel to the centre line. (Figure 2A Red). A marker was placed at the point where the green centre line and the purple toe line bisect. This point was hypothesised to reflect internally the dorsal distal border of P3. (Figure 2A and 2B pin 1). A hypodermic needle was inserted in the point of the frog in the sole/frog junction. (Figure 2A and 2B pin 2) A hypodermic needle was inserted at the point where the widest part of the white line and the hoof centre line bisected. This point was intended to relate to the Centre of Rotation (COR) of distal interphalangeal articulation (DIP). (Figure 2A and 2B pin 4). Vernier calipers were set at 10mm distance and these were used to measure 10mm in front of centre of rotation centre and a hypodermic needle was placed in this point on the centre line of the hoof. This point was intended to relate to the centre of articulation of the DIP joint. (Figure. 2A and 2B pin 3).

Wooden tongue depressors were pinned across the heels of the WBS of the hoof wall to make points visible on CT on every foot. This marked the ground bearing surface for consequent measurements.

After the pre trim CT scan, all pin markers were removed and the hooves were prepared for the trimming stage of the study.

All of the feet were trimmed taking into account the line markers in place, especially relating to heel height. Excess hoof wall was removed with hoof cutters and a rasp and the hoof wall was prepared relative to the applied foot map, hoof wall flares were removed achieving foot symmetry where possible and every foot was balanced to the pastern axis.

The selected feet were then re marked with hypodermic needle markers in the points used previously and the WBS of the hoof wall was marked with a wooden tongue depressor at the heels. The feet were then re scanned and measurements were taken from the images.

All the feet were measured in mm width, length, dorsal hoof wall length and width between the heel buttresses and weighed to give an indication to approximate size of the animal. Figure 4 illustrates the study process. The feet were mapped and marked with permanent marker pens and hypodermic needles (pin marker) (Figure 2A). Figure 2B shows the hypothesised position of the markers.

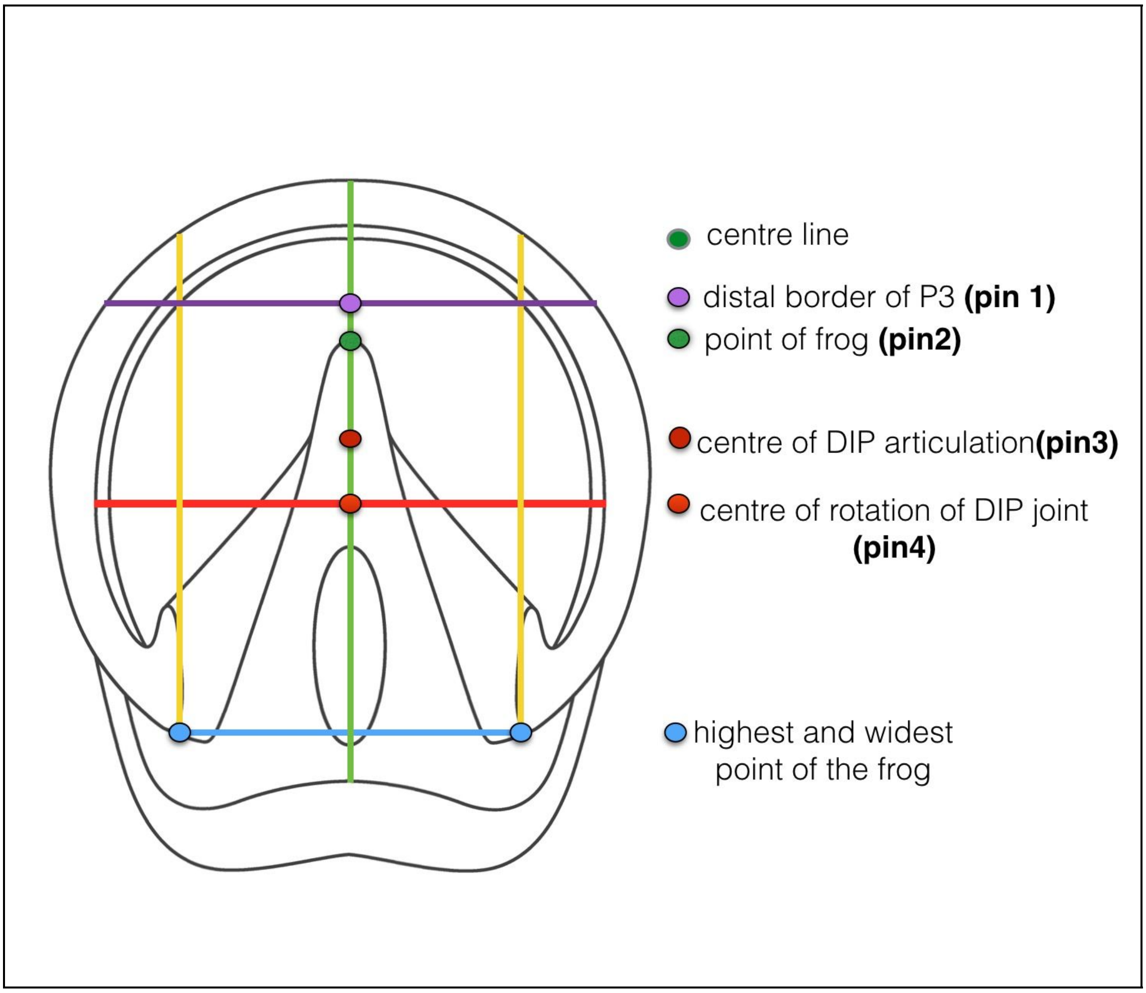


Figure 2A
Schematic drawing of the points of reference used for foot mapping before trimming. (Pin 1) mapped estimated tip of P3. (Pin 2) point of frog at frog/sole junction. (Pin 3) hypothesised centre of articulation (10mm forward from pin 4) (Pin 4) estimated centre of rotation of distal interphalangeal articulation. Source (authors own 2016)

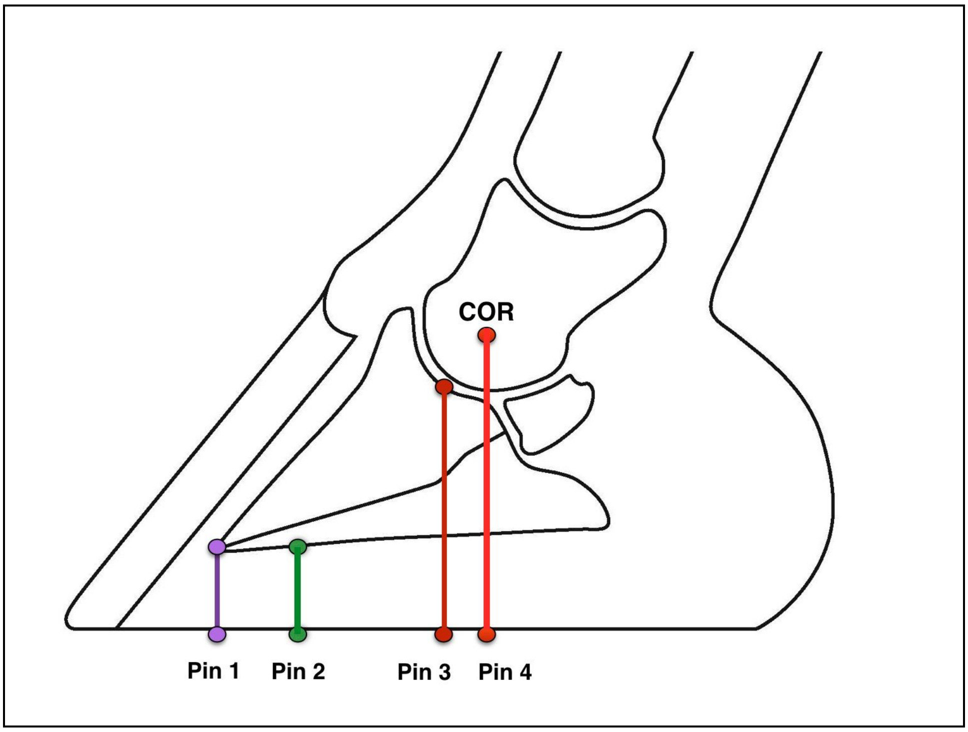


Figure 2B Schematic drawing of the external reference points of hoof mapping relating to internal hoof anatomy (Pin 1) mapped estimated tip of P3. (Pin 2) point of frog at frog/sole junction. (Pin 3) hypothesised centre of articulation (10mm forward from pin 4) (Pin 4) estimated centre of rotation of distal interphalangeal articulation. Source (authors own 2016)

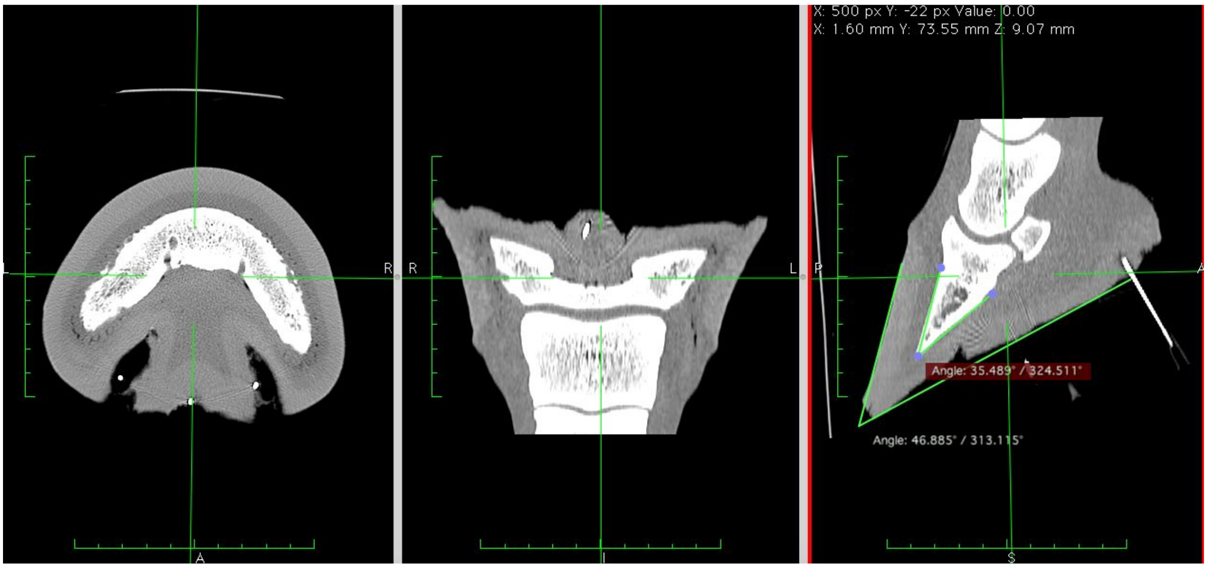


Figure 3: images of CT scan measuring method; transverse scan at the level of the distal phalanx (left image), frontal scan (middle image), midsagittal (right image)
The green lines on the right image show the apical angle of P3 and the angle between the dorsal hoof wall and the solar surface. Source (authors own 2016)

Figure 4A: image of foot N11 pre trim

Source (authors own 2016)

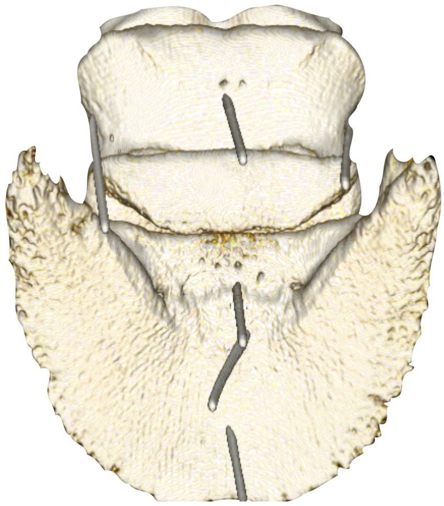


Figure 4B: 3D bone image of foot N11 showing pin markers

Figure 4C: foot N11 mapped pre trim showing foot mapping pen marked lines at reference points

Source (authors own 2016)

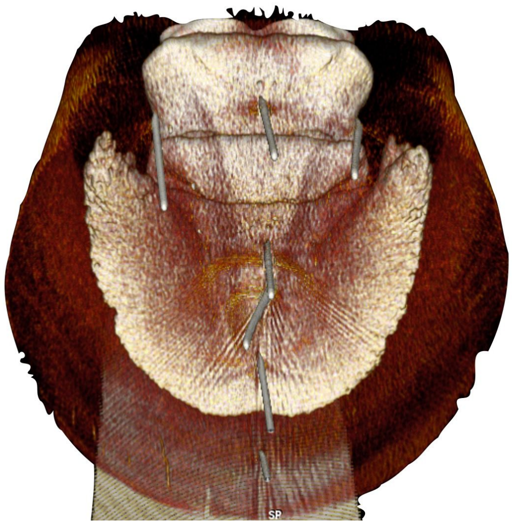


Figure 4D: foot N11 CT 3D image part rendered showing the solar orientation of P3 and the positional relationship of pin markers

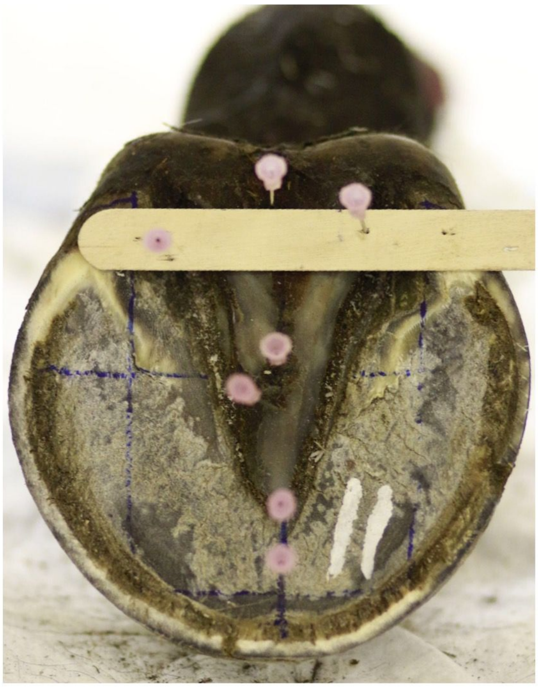


Figure 4E: hoof N11 with markers showing foot map markers and wooden tongue depressor to mark WBS on CT scan

Source (authors own 2016)

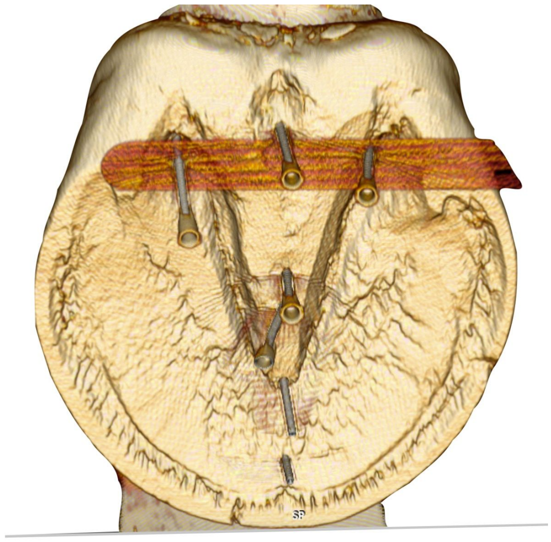


Figure 4F: 3D CT hoof N11 image showing pin markers visible on CT imaging

Data Analysis

All data analysis was performed in Excel (microsoft, Seattle, US) and SPSS (vers, 22, IBM, Armonk, US). Data distribution was assessed for normality using histograms and Kolmogorov Smirnov normality tests. The relationship between parameters was assessed by calculating the Pearson correlation coefficients. A paired T-test or a Wilcoxon Signed Rank test was used to determine the difference in conformation parameters before and after trimming and an independent T-test or Mann-Whitney test between left and right limbs. P value was set at P=0.05.

RESULTS

Conformational parameter in front and hind before and after trimming.

Table 1 summarises the conformational parameters in front and hind before and after trimming.

In the untrimmed feet there was a significant difference between front and hind feet in DHW Mean 49.78° SD 4.23 front. Hind 51.75 SD 3.75 ($P=0.016$), AAP3rad Mean 47.32 SD 3.05 front. Hind 49.68 SD 2.94 ($P=0.028$), AAP3(midsagittal) 33.49 SD 3.05 front. Hind Mean 32.74 SD 2.94 ($P<0.0001$), but not between PA ($P=0.161$) or DSP3 ($P=0.065$). In the untrimmed feet the DHW and the AAP3rad were less steep in the front feet when compared to the hinds, but the AAP3(midsagittal) was steeper in the front feet. In all parameters the range of values was wider in the hind feet when compared to the front .

After trimming there was a significant difference between front and hind for all measured parameters ($P<0.0001$). The DHW and the DSP3 were significantly steeper in the hind feet compared to the front after trimming but the PA was significantly lower.

Trimming had a significant effect on DHW, DSP3, PA ($P<0.0001$) in the front feet and also after trimming the hind feet DHW ($P<0.0001$), DSP3 ($P=0.027$) and PA ($P=0.039$).

The DHW was significantly steeper after trimming in the front and hind, DSP3 and the PA were significantly less steep after trimming.

Table 1 mean ±SD(Standard Deviation) maximum and minimum of the measured conformational parameters for front and hind feet. (°)angle. Source: (authors own 2016)

Parameter		Front		Hind	
(°)angle		Pre-trim(°)	Post-trim(°)	Pre-trim(°)	Post-trim(°)
Dorsal hoof wall to WBS	Mean	49.78	52.56	51.75	55.11
	SD	4.23	3.31	3.75	3.27
	Min	41.48	44.27	40.14	47.94
	Max	60.22	59.82	60.94	63.08
Apical angle Of P3 (radiograph)	Mean	47.32	Same as pre-trim	49.68	Same as pre-trim
	SD	3.05		2.94	
	Min	41.80		45.11	
	Max	55.61		58.33	
Angle of P3 (mid sag)	Mean	33.49	Same as pre-trim	32.74	Same as pre-trim
	SD	3.05		4.08	
	Min	27.82		25.16	
	Max	42.47		45.47	
Palmar Plantar positive angles		N=44	N=40	N=42	N=33
	Mean	5.07	3.12	4.23	3.86
	SD	2.46	1.83	2.73	2.06
	Min	0.12	0.02	0.06	0.77
	Max	11.6	7.84	11.20	8.7
Palmar/ Plantar negative angles		N=6	N=10	N=7	N=15
	Mean	-2.07	-2.27	-2.68	-1.84
	SD	1.28	2.51	1.37	1.99
	Min	-0.91	-0.15	-1.09	-0.10
	Max	-4.38	-0.91	-5.27	-6.02

Of N=50 trimmed and untrimmed fronts PA N= 28,29,44 remained negative PA post trim but had no significant similarities.

Of N=49 trimmed and untrimmed hinds PA N= 72,74,77,96 remained negative PA post trim these feet showed similarities and could be from two horses RH/LH.

Correlation between conformational parameters in front and hind before and after trimming.

Table 2 shows correlation between the different parameters in front and hind before and after trimming.

The strongest significant correlations were observed between DHW angle and DSP3 in both front and hind before and after trimming.

A moderate negative correlation was observed between the AAP3rad and PA and a moderate positive correlation between AAP3rad and DHW angle, but no significant correlation between AAP3midsag and any of the other parameters in the front limb. This was not the case in the hindlimb where a moderate negative correlation was found between AAP3midsag and PA.

All significant correlations were stronger after trimming with the exception of DHW versus AAP3rad in the front feet.

Table 2 A: Correlation between the different conformational parameters for front feet in the trimmed and untrimmed feet. r = Correlation Coefficient. P = Significance

Parameters	Untrimmed	Trimmed
Dorsal hoof wall to WBS versus Apical Angle of P3 (radiograph)	r = 0.370 P = 0.08	r = 0.345 P = 0.014
Dorsal hoof wall to WBS angle versus angle of P3 (mid-sagittal)	r = 0.048 P =0.740	r = 0.177 P = 0.218
Dorsal hoof wall to WBS to dorsal surface of P3	r = 0.672 P = 0.0001	r = 0.750 P = 0.0001
Dorsal hoof wall to WBS vs solar angle	r = 0.309 P = 0.029	r = 0.384 P = 0.006

Table 2 B: Correlation between the different conformational parameters for hind feet in the trimmed and untrimmed feet. r = Correlation Coefficient. P = Significance

Parameters	Untrimmed	Trimmed
Dorsal hoof wall to WBS versus Apical Angle of P3 (radiograph)	r = 0.396 P = 0.005	r = 0.501 P = 0.001
Dorsal hoof wall to WBS angle versus angle of P3 (mid-sagittal)	r = -0.083 P = 0.571	r = 0.136 P = 0.357
Dorsal hoof wall to WBS to dorsal surface of P3	r = 0.659 P =0.0001	r = 0.726 P = 0.0001
Dorsal hoof wall to WBS vs solar angle	r = 0.359 P = 0.011	r = 0.243 P = 0.096

Table 3; results of tested parameters relating to P3 correlations and significance values

Parameters	Correlations	P value	Comments
DHWA versus P3 apical angle (radiographic view) front feet untrimmed.	r = .370 N=50	P< .08	moderate positive correlation
Dorsal hoof wall angle versus P3 apical angle (radiographic view) front feet trimmed.	r =.345 N =50	P< .014	moderate positive correlation
Dorsal hoof wall angle versus P3 apical angle (radiographic view) hind feet untrimmed.	r = .396 N =49	P<.005	moderate positive correlation
Dorsal hoof wall angle versus P3 apical angle (radiographic view) hind feet trimmed.	r = .501 N =48	P<.001	moderate positive correlation
Dorsal hoof wall angle versus P3 apical angle (mid sagittal) front feet untrimmed.	r = .0495 N =50	P>. 05	no apparent correlation
Dorsal hoof wall angle versus P3 apical angle (mid sagittal) front feet trimmed.	r = .177 N =50	P>. 05	weak positive correlation
Dorsal hoof wall angle versus P3 apical angle (mid sagittal) hind feet untrimmed.	r = - .083 N =49	P>. 05	No correlation
Dorsal hoof wall angle versus P3 apical angle (mid sagittal) hind feet trimmed.	r = .136 N =48	P>. 05	very weak positive correlation
Solar (palmar) angle of P3 to WBS front feet before and after trimming	Wilcoxon signedRank test N =50	P<0.0001	highly significant difference in reduced solar angle after trimming
Solar (plantar) angle of P3 to WBS hind feet before and after trimming	Paired t-test N=48	P>. 05	no significant difference in solar angle after trimming
Dorsal hoof wall to weight bearing surface vs Dorsal surface of P3 to hoof wall weight bearing surface (untrimmed foot)	r = .672, N=50	P< .01	significant, strong positive correlation
Dorsal hoof wall to weight bearing surface versus dorsal surface of P3 to hoof weight bearing surface (trimmed front foot)	r = .750, N=50	P< .005	highly significant, strong positive correlation
Dorsal hoof wall to weight bearing surface versus dorsal surface of P3 to hoof weight bearing surface (untrimmed hinds)	r = .659, N=49	P< .005	highly significant, strong correlation
Dorsal hoof wall to weight bearing surface versus dorsal surface of P3 to hoof weight bearing surface (trimmed hinds)	r = .726, N=48	P< .005	highly significant, strong correlation

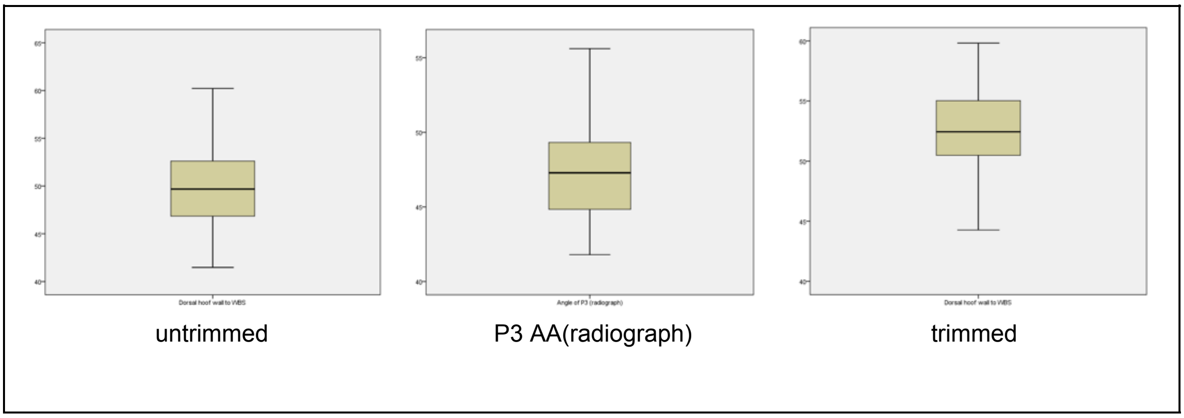


Figure 5 A: Box and whisker plots showing Dorsal Hoof Wall to WBS *vs* Apical Angle (radiograph) in the untrimmed and trimmed front feet N=50

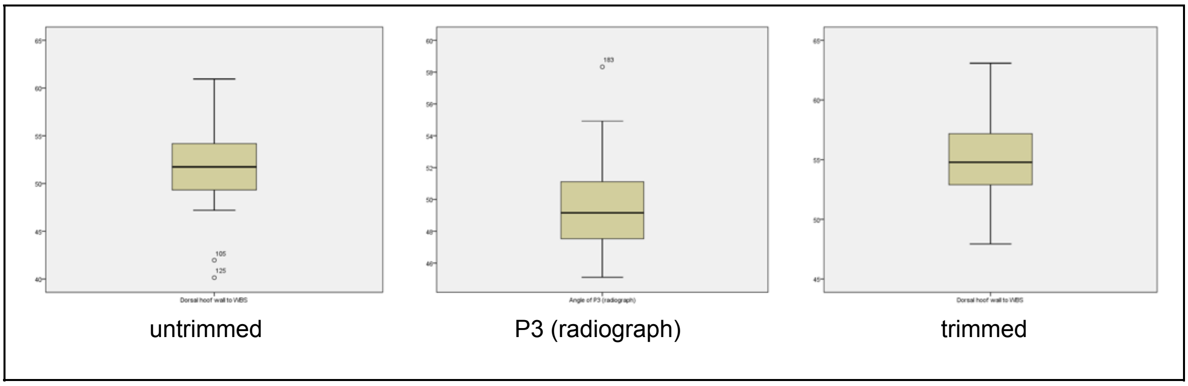


Figure 5 B: Box and whisker plots showing the Dorsal Hoof Wall to WBS *vs* Apical Angle (radiograph) in the untrimmed and trimmed hind feet N=49 pre trim N=48 post trim. Source (authors own 2016)

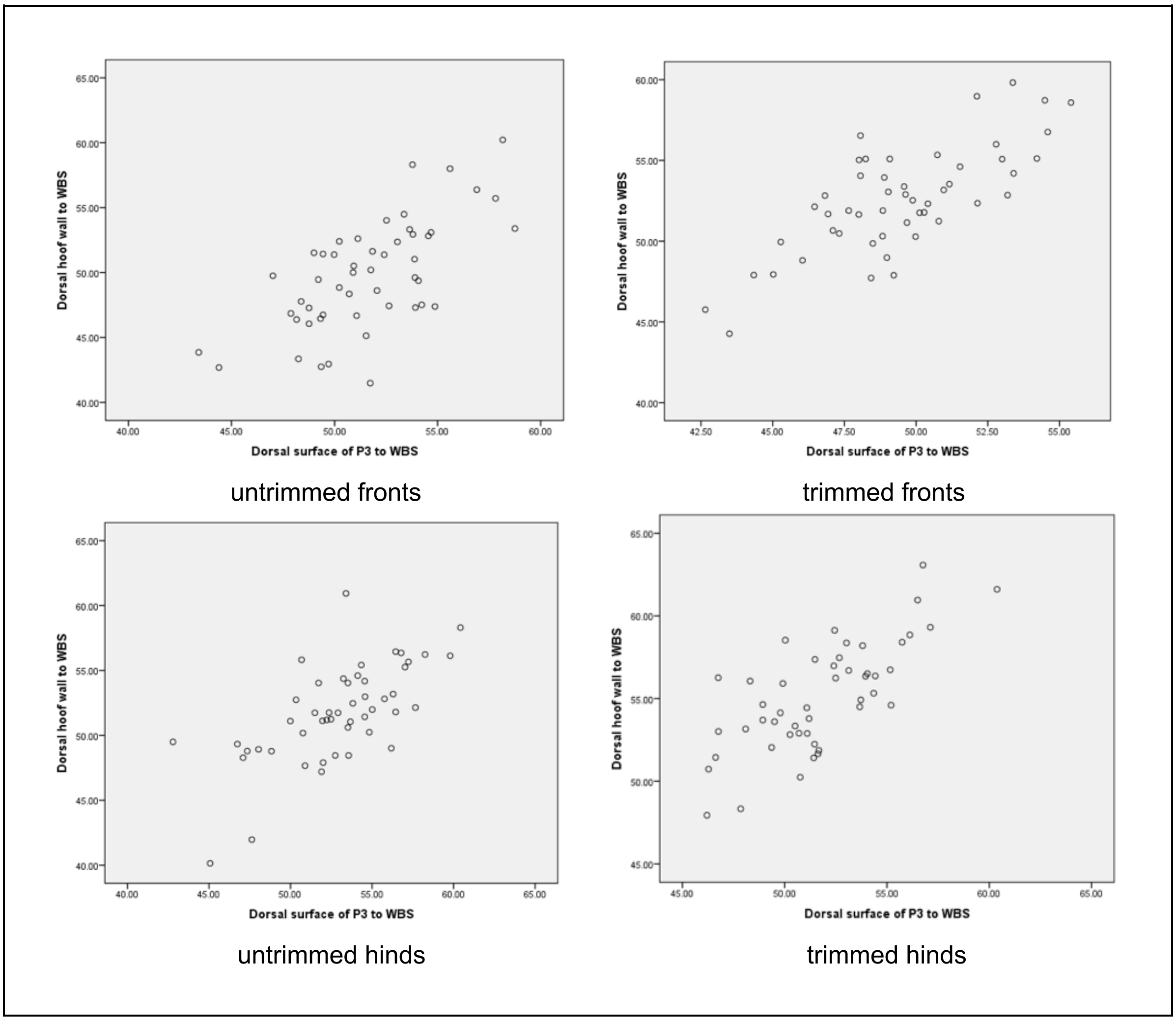
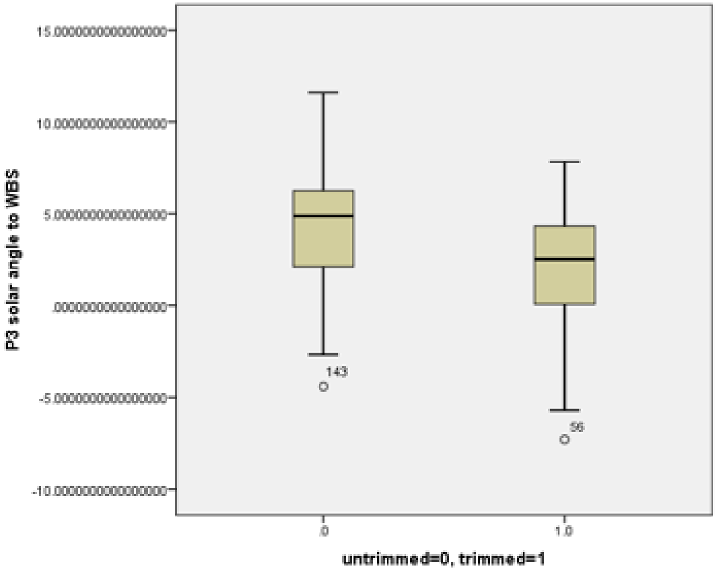
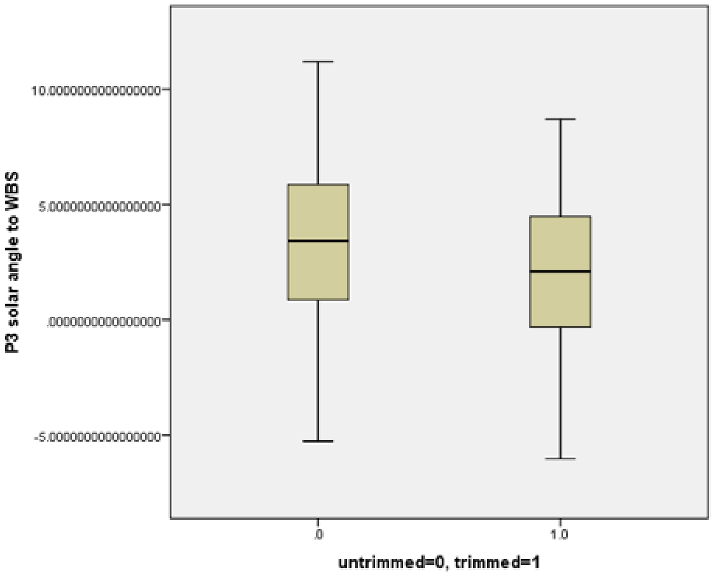


Figure 5 C: Scatter plot graph showing Dorsal Hoof Wall to WBS vs DDP dorsal surface to WBS in untrimmed and trimmed front and hind feet. Source (authors own 2016)

Wilcoxon signed Rank test: P<0.0001: significant difference in solar margin between untrimmed and trimmed feet





Paired t-test: P=0.101 no significant difference in solar margin before and after trimming

Figure 5 D: PA of P3 to WBS in the untrimmed front feet N=50 Source (authors own 2016)

DISCUSSION

The authors interest in the apical angle of the distal phalanx resulted in his attention being drawn to how overlooked and unused the P3 apical angle is when assessing lateromedial radiographs. Referring to table 1 and 3 (Appendices) results looking at the AA(radiographic view) of distal phalanx, it is apparent there was a moderate correlation in the front and hind feet AA(radiographic view) *vs* DHW to WBS trimmed and untrimmed.

The mean apical angle (radiograph) of front feet in this study was 47° with a standard deviation of 3.05°. The mean apical angle (radiograph) of the hind feet in this study was 49.68° with a SD of 2.94°. These angle measurements show a difference in mean apical angle of 2.36° steeper in the hind feet, which would conform to expectations of a steeper hind foot angulation.

In comparison the mean angle of P3(mid Sag) front feet 33.49° with a variance range of 9.32° shows similar variance to the front angulation P3 radiograph 8.63°.

The mean angle of P3(mid sag) in the hind feet was 32.74° with a variance range of 16.65°.

It should be noted that the significance of these comparisons of the apical angle show that the DSP3 is generally slightly steeper in the hind and the angle mid sagittal corresponds to these findings that P3 has a steeper angle of insertion of DDFT in the hind feet thus supporting previous studies (K.Holroyd *et al* 2013) and the findings that DDFT lesions are more common in feet with lower HWA (Eliashar *et al* 2004). Sagittal sole angle measurements front feet compared to hind feet however show a similar Mean angle in the hind feet and a much greater variance range in the hind feet also. These results could be affected by a greater range of maximum/minimum outliers but as the data sample was large and randomly selected the results reliably show that the sole angle varies greatly in hind feet in this study.

The hoof mapping technique used can help assess alignment but it would seem that this cannot account for low or negative angles of P3 and could contribute to decreasing or increasing these angles more, which may have a detrimental effect on hoof balance.

This study shows many varying relationships between the horny hoof capsule and the distal phalanx and these results raise some questions relating to many aspects of hoof anatomy and foot trimming. In order to measure the parameters set down for this study, many other related angles have to be subsequently included in the data set to support the required data.

All testing in this experiment had a method of standardising the preparation of trimming and applied foot mapping techniques were required to create a trimming standard to maintain consistency within the experiment.

There was a moderate positive correlation between the DHW to WBS and the dorsal surface of distal phalanx to WBS. This suggests that the alignment can be changed and improved with trimming to an applied foot trimming technique. Whilst strong, significant findings can be concluded from this part of the study with hind feet DHW to WBS angle increasing, the plantar angle has been reduced in more feet than were expected by the author. (see table 1)

The PA should be discussed. As hypothesized, the PA of P3 can be altered by foot trimming. (see Table 1 in results). Of the N=98 feet, PA angles were generally reduced in both fronts and hinds after trimming but it should be considered that many PA were reduced to within a more normal expected range of 3° to 5° positive (Baxter

2011). Table 1 and figure 5D show the mean of the measured PA of fronts after trimming (3.12°) and hinds after trim (3.86°) these conform to the expected average PA as previously published and reported by Baxter (2011) and other popular anatomy textbooks.

The hinds displayed a slightly higher angle of steepness which again conforms to the farrier educational expected standard normal of 3° to 5° positive. The trimming protocol did not seem to improve the PA in a number of feet in this study. Initial negative PA in front feet increased, post trim from N=6 to N=10 and hind feet N=7 to N=15 had a similar result. These results raise questions relating to the negative angles and upon further investigation, 4 of the negative PA hind feet in the data set remained negative PA. It was observed that two of the hinds (N=4) were likely to have been from the same horse so the results could be suggesting a false negative due to the abnormal parameters of non uniform conditions. Nevertheless it cannot be overlooked that the number of negative hind feet has doubled (N=15). These results could be attributed to the hoof map trimming technique having an effect on the results. Perhaps the mapped ideal did not apply as successfully to hind feet.

The author noted that *ex vivo* frozen cadaver feet are sometimes more difficult to trim as moisture is lost from the horny sole, wall and frog post mortem, and the resulting lack of moisture content makes the horny sole hard and compact, thus leading to limitations in removing horn easily.

The apical angle and position of P3 relating to the palmar/plantar angle must be an important consideration in hoof trimming and farriery, especially when carrying out remedial farriery with reference to lateral/medial radiographs of front and hind feet.

This data suggests a percentage of seemingly healthy hooves have low and sometimes negative palmar/plantar angles. It is widely accepted amongst farriers and veterinary surgeons, that the position and orientation of the distal phalanx PA, is always a consideration when viewing and assessing radiographs. (Holroyd *et al.,* 2012). In this study the author cannot be certain that the limbs used were from equines that were totally sound. Some of the CT images displayed bone morphologies which could be related to lamenesses, so it would be appropriate to assume that a proportion of the studied limbs were from lame animals. The exact number cannot be ascertained in this study.

The limbs in this study were transected carpus/tarsus and their flexor tendons had no part in maintaining alignment of the limbs. The author hypothesized that the DDFT may have some role in maintaining alignment of P3 when the limb is bearing weight statically, so this should be a considered factor in the results despite the fact that these limbs were measured unloaded for this study. However, farriers would normally trim and assess non-load bearing limbs in everyday practice. It is important to additionally assess the static and dynamic load after trimming and adjust if necessary according to foot fall.

Live horse studies could contribute further information regarding the DDFT role in supporting and maintaining the position and alignment of P3 within the loaded hoof capsule and test the hypothesis as to whether DDFT laxity is a contributing factor to low or negative P3 palmar/plantar angles.

CONCLUSION

It is evident from this study that foot trimming to a mapped "ideal" trim protocol can with some success, align the dorsal surface of the hoof wall to the dorsal surface of P3 to the WBS.

Trimming cannot always restore or create an ideal PA of P3 for individuals and sometimes a trimmed "ideal" can impose a lower PA when it is not appropriate for the foot or respectively the horse.

Radiographic evaluation therefore before and after trimming is a reliable method for optimum alignment of P3 to the bone column and the hoof capsule and can assist in alignment of the phalanges within the digit.

The term "apical angle" is generally not measured in radiographic evaluation by veterinary surgeons, farriers or clinicians but is a term used in medical reference, dentistry and horticulture. The author applied the terminology to this study as it describes the measured angle that is rarely used. It was hypothesized that there is a relationship between the apical angle plus PA and the shape of the dorsal hoof wall to WBS. If this hypothesis could be supported with collected data from test measurements, an additional hypothesis for further study could be formulated to calculate the ideal angle of DHW° to WBS° add the sum of the AA° of P3± the mean PA=±4° (see appendices A, B, C page 33,34 and table 4 results of Hypothesis). This hypothesis is recommended for further study. A preliminary test was carried out from the results data within this study of front and hind hooves showing a moderate and strong correlation to this further hypothesis. (See Appendix B table of results of hypothesis) from the results of this whole study (see Table 1) the Mean angles of front and hind feet dorsal hoof wall to WBS post trim can be added to the mean PA post trim. These angles show significantly, that the calculated measurements fall within normal published ideal angles of front and hind feet 50° to 55° (Baxter 2011).

Example front feet:

Mean Apical angle of P3 front feet post trim 47.32° added to Mean PA 3.12° = 50.44°

Example hind feet:

Mean Apical angle of P3 hind feet post trim 49.68 added to Mean PA 3.86° = 53.54°

There is an ever present demand on farriers to accurately interpret radiographic images and implement successful changes of remedial trimming and shoeing methods with greater precision.

It is important for veterinary surgeons and farriers to identify the limbs and hooves that display characteristics suggesting low hoof wall angles, high or low apical angles, high or low sole angles and high, low or negative palmar/plantar angles and act accordingly to employ remedial measures to the affected hooves using accurate measurements to assist in correcting alignment. Low apical angles of the distal phalanx could be an indicator of predispositions to potential injuries and or pathologies and by calculating specific ideal angles from the apical angles, veterinary surgeons and farriers can thus quickly ascertain the requirements for prescribing remedial farriery or advanced orthotics as required.

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Appendix A:

Table 4 of results for hypothesis PA ± 4° Source (authors own 2016)

Hypothesis	Correlations	Significance	Comments
DHW angle to GBS + 4° front feet untrimmed.	r = .370 N = 50	P< .008	moderate positive correlation
DHW angle to GBS + 4° front feet trimmed.	r = .345 N = 50	P< .014	moderate positive correlation
DHW angle to GBS + 4° hind feet untrimmed.	r = .396 N=49	P< .005	moderate positive correlation
DHW angle to GBS + 4° hind feet trimmed.	r = .501 N=50	P< .005	strong positive correlation

Appendix B: Hypothesis measuring method PA ± 4°

Figure 8 A radiographic image of HWA vs AA using Horos imaging. Source (authors own)
P3AA 43.8° + 4° = 48°

Appendix C: Hypothesis measuring method PA ± 4°

Figure 9 A radiographic image using Horos imaging showing measured angles. Source (authors own 2016)

P3AA 43.8° + 4° = 48° ∴ DHW° angle to WBS must be equal to or greater than 48°positive.

Hypothesis for further study:

To calculate the ideal angle of DHW° angle to WBS by the sum of the AA° of P3± the mean PA=±4°

It would be recommended to use a ground weight bearing dorsal hoof wall gauge for this experiment on live study of which there are few manufactured. (*Moleman et al.,2010)*