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Relationship between the Distal Phalanx Angle and Radiographic Changes in the Navicular Bone of Horses: A Radiological Study

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Abstract- The aim of this study was to determine the relationship between the distal phalanx angle and the radiological condition of the navicular bone and establish a database of reference values for hoof radiographic A retrospective study was measurements in Chilean horses. performed considering radiographic examinations on 146 feet from 92 horses. Linear and angle measurements of the hoof capsule and distal phalanx were obtained and compared statistically. Radiographic condition of the navicular bone was determined and statistically compared with the radiographic hoof values. Additionally, horses were categorized by breed to elucidate differences between breeds.There was a significant negative correlation between the palmar angle and the navicular score. Also, there was a significant negative correlation between the hoof angle and the navicular score. There were significant statistical differences between the distal phalanx angle, weight-bearing surface of the toe and second phalanx length when compared by breed.The information gathered in this study can help to prevent the presentation or the advance of the radiological changes in the navicular bone. A radiographic-guided shoeing should always be considered. Additionally, the present study provides a database of normal values of the hoof capsule in Chilean horses that can be used by veterinarians and farriers as a guideline for routine and orthopedic shoeing.

Keywords: horse, foot, palmar angle, navicular disease, radiographs.

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RELATIONSHIPBETWEENTHEDISTALPHALANX ANGLEANDRADIOGRAPHICCHANGESINTHENAVICULARBONEOFHORSESARADIOLOGICALSTUDY

Strictly as per the compliance and regulations of:

Relationship between the Distal Phalanx Angle and Radiographic Changes in the Navicular Bone of Horses: A Radiological Study

Cristobal Dörner [α], Pablo Fueyo [σ] & Rodrigo Olave [ρ]

Abstract- The aim of this study was to determine the relationship between the distal phalanx angle and the radiological condition of the navicular bone and establish a database of reference values for hoof radiographic measurements in Chilean horses. A retrospective study was performed considering radiographic examinations on 146 feet from 92 horses. Linear and angle measurements of the hoof capsule and distal phalanx were obtained and compared statistically. Radiographic condition of the navicular bone was determined and statistically compared with the radiographic hoof values. Additionally, horses were categorized by breed to elucidate differences between breeds.There was a significant negative correlation between the palmar angle and the navicular score. Also, there was a significant negative correlation between the hoof angle and the navicular score. There were significant statistical differences between the distal phalanx angle, weight-bearing surface of the toe and second phalanx length when compared by breed.The information gathered in this study can help to prevent the presentation or the advance of the radiological changes in the navicular bone. A radiographic-guided shoeing should always be considered. Additionally, the present study provides a database of normal values of the hoof capsule in Chilean horses that can be used by veterinarians and farriers as a guideline for routine and orthopedic shoeing.

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I. Introduction

Foot pain is described as the most common cause of forelimb lameness in sport horses(Dyson2011[a]) and has been associated with poor hoof balance and conformation (Turner 1986). Some authors have been suggested that changes in foot conformation increase the load on the palmar aspect of the foot and so the navicular bone is overstressed predisposing to foot pain and lameness. Unfortunately, there is limited information about the relation between the distal phalanx (P3) orientation within the hoof and the radiological changes in the navicular bone.

A condition that causes foot pain is the one called "Negative palmar angle syndrome (NPAS)". This is a term in which the solar or palmar and/or plantar margin of P3 has a negative angle in relation to the ground surface, and sole depth under the dorsal-distal margin of P3 is greater than that under the palmar processes when viewed on a lateral radiographs (Floyd 2010). The term "long toe, low heel" has been used to describe this condition and has been accepted as being abnormal among veterinarians and farriers. Conversely, a recent study in horses with foot pain indicated the variations in shape of the distal phalanx were not accurately predicted by external characteristics of the hoof capsule (Dyson *et al* 2011). On the other hand, a marked correlation between hoof conformation and forces applied to the equine foot has been also described (Eliashar *et al* 2004). According to the aforementioned, in many cases it is very difficult to predict an abnormal condition in the structures inside the hooves when only the external hoof capsule is seen.

In normal conditions, the distal phalanx solar angle or palmar angle with the surface range between 2º – 10º (Parks 2003). As the border of the distal phalanx is the insertion point of the deep digital flexor tendon (DDFT), a change in its orientation, increases the DDFT tensile force and subsequently the force it exerts on the navicular bone during the different phases of a stride (Wilson *et al* 2001; Weaver *et al* 2009; de Zani *et al* 2016). Furthermore, biomechanical overloadexerted over the navicular bone has shown to be harmful and may result from aged related accumulation of workload (Dik *et al* 2001). Accordingly, in theory the more tensile forces exerted to the navicular bone (biomechanical overload) the moreradiographic changes should be found (Dik *et al* 2001; Wilson *et al* 2001; Weaver *et al* 2009). The changes seen in the navicular bone in horses presenting navicular disease are well documented (Verschooten *et al* 1989; Wright 1993; Buttler *et al* 2000; Dyson 2011[b]; Komosa *et al* 2013).

In this study, we hypothesized that the compressive force exerted by the DDFT over the navicular bone due to an abnormal distal phalanx angle,as described by different authors (Wilson *et al* 2001, Eliashar *et al* 2004; Weaver *et al* 2009; Holroyd *et al* 2013), has a correlation with the radiographic changes observed in the navicular bone. Additionally, we provided a database of normal values of the hoof capsule in Chilean horses that can be used by veterinarians and farriers as a guideline for routine and orthopedic shoeing.

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II. Materials and Methods

a) Horse Selection

One hundred and forty-six feet (146) from horses were used for the study (54.79% from Chilean Criollo horses and 45.21% from Warmbloods horses) (385 – 590 kg bwt) in routine work and shoeing status examined consecutively between July 2015 and December 2016. All horses were assessed for lameness. Sound horses were immediately enrolled for the study. Lame horses selected for this study had lameness abolished after a palmar digital nerve block was performed, using 1.5 mL mepivacaine 2% (Vetacaine™)[a] injected just proximal to the lateral cartilages of the distal phalanx. Horses presenting with laminitis or lameness located anywhere else were excluded from the study. Horses selected should have been trimmed within 5 weeks. Additionally, age, gender and breed were recorded.

To establish the normal reference values for the hoof radiographic measurements of the Chilean Criollo horses and to investigate the differences of hoof radiographic measurements between Chilean Horses and Warmblood horses, horses were categorized by breed.

b) Radiographic Image Adcquisition

Eighty forelimbs from Chilean horses (left front n=40; right front n=40) and sixty-six forelimbs from Warmblood horses (left front n=33; right front n=33) were radiographed obtaining a total sample of one hundred and forty-six feet (n=146). All radiographic examinations were performed after standard foot preparation as describe by Buttler *et al* (2000). Radiographic views selected to evaluate horses` feet were based on previous studies performed in different breeds (Dyson *et al* 2011; Dyson 2011[b]; Thieme *et al* 2015; Wright 1993). Lateromedial, 60º dorso proximal oblique navicular (upright pedal) and palmaro proximal – palmaro distal (Navicular Skyline) radiographic views were obtained. For lateromedial view, the foot to be examined was placed on a block 6 cm high and the x-ray beam was centered approximately 1 cm distal to the coronary band, midway between the dorsal and palmar aspects of the hoof. The x-ray generator was set at 76 Kvp and 1.2 mAs. For the 60º dorsoproximal navicular view, the hoof was placed over the x-ray tunnel in a square stance and the x-ray beam was centered in the coronary band and the x-ray generator was set at 78 Kvp and 1.6 mAs. The last radiographic view was obtained with the limb over the tunnel and placed backwards and the x-ray beam was centered between the heel bulbs following the pastern angle and the x-ray generator was set at 80 Kvp and 2.0 mAs.Radiographs were obtained using a digital x-ray machine (Envision G2 DR panel)[b] and a Poskom PXP-20HF x-ray generator.

c) Image Analysis

Radiographs were analyzed using an image analysis software (Metron-DVM 7.05 for windows)[c]. Following the instructions of the program, 10 parameters on the LM view were measured. The following measurements were obtained: Palmar angle, descent of the distal phalanx, distance of the distal phalanx to ground, hoof angle, proximal HL zone, distal HL zone, percentage of the weight-bearing surface of the toe, coffin joint angle, pastern joint angle, length of the middle phalanx (Figure 1 and Figure 2).To determine the radiographic condition of the navicular bone ("navicular score") a standardized classification was used as described by Dyson (2011[b]) (Table 1).

d) Data Analysis

Statistical analyses were run on a specialized statistical software (SPSS Inc, version 19 for windows)[d]. A Kolmogorov-smirnov test was performed to assess whether the data were normally distributed. A t-student test for independent variables was used to compare the data between breeds. All measurements were compared to determine whether they were significantly different between groups. A Spearman correlation test was run to determine the association between the radiographic hoof values and the radiographic score of the navicular bone. The significance level was set at $p<0.05$.

III. Results

One hundred and forty-six feet (146) from horses were used for the study (47.83% geldings; 42.39% mares; 9.78% stallions). Eighty feet were from Chilean Criollo horses and sixty-six feet were from Warmblood horses (29.53% Holsteiner; 10.16% Selle Frances; 5.52% Warmblood cross). The mean ±standard deviations (s.d.)and t-student test of the data obtained for radiological hoof values for Chilean and Warmblood horses are summarized in table 2.

There was significant difference between groups for palmar angle, toe/support %, third phalanx distance to the ground, and length of the middle phalanx determined radiologically (table 2). Warmblood horses have a smaller palmar angle (3.39± 3.37) than Chilean Criollo horses (6.46± 3.88)(p= 0.000) as well as the toe/support % (65.12± 5.48 and 67.35± 5.78 respectively, p= 0.033). Additionally, there was a significant difference in the length of the middle phalanx in which the Chilean Criollo horses have a shorter middle phalanx bone (3.99± 0.53, p value 0.000). The other measurements determined radiologically showed no difference between breeds (table 2).

Table 3 summarizes means ±s.d. and t-student test results when horses were assessed by limb, showing no statistical differences when right and left legs were compared between each other. This situation was seen in both breeds.

Additionally, the mean ±s.d. for the navicular score for each breed was analyzed. Chilean Criollo horses (0.95 ± 0.80) showed a lesser value when compared with Warmblood horses (1.23 ± 0.83). These results were statistically different (p = 0.038).

Each measurement determined radiologically was correlated with its respective navicular score. The palmar angle and hoof angle (rho= -0.190, p= 0.024) showed a weak negative correlation with the navicular score (rho= -0.173, p= 0.041) (table 4). The other parameters measured did not show significant association with the navicular score.

IV. Discussion

This study was performed in order to establish the relationship between the distal phalanx angle within the hoof capsule and the radiological condition score of the navicular bone.Additionally,a database of reference values of the radiographic hoof values from the Chilean Criollo horses were obtained and compared with the values obtained from Warmblood horses. Hoof trimming has shown a remarkable influence on hoof conformation and in some measurements that describe the position of the third phalanx within the hoof capsule (Kummer*et al*2006) so in our study,horses were excluded when the feet had not been trimmed within 5 weeks.

The selection and use of Metron software for this study was based on the previous results obtained where it was determined that Metron software can be used to objectively measure most of the parameters predefined by the software (Vargas Rocha*et al* 2004).

Chilean Criollo horses showed a larger palmar angle when compared with Warmblood horses, finding somehow expecteddue to the described lower palmar angle of Warmbloods compared to other breeds (Kummer*et al* 2006). Toe/support % was larger in Chilean horses and thus they should have a better capacity to dissipate the ground reaction forces within the hoof capsule compared with Warmbloods. Nonetheless, one study showed no differences when the presentation of catastrophic pathologies and toe/support % were compared (Kane *et al* 1998). According to the *FédérationEquestreInernationale* (2017), a Pony is a small horsewhose height at the withersdoes not exceed 148 cms. Chilean horsesare considered as Ponies due to their height (<145 cms),so a shorter middle phalanx compared to Warmblood horses was expected. Chilean horses tend to have narrow, upright, and small feet relative to their body size (Reckmann 1999; Vergara 2012), hence the larger palmar angle in Chilean horses is mostly due to the hoof conformation and its relation with the inner structures of the hoof capsule (Dyson *et al* 2011). When the radiographic navicular score was obtained, Chilean horses showed a lower mean score than Warmblood horses used in this study. The above situation was suspected according to the hoof and palmar angle obtained, where larger palmar angle has been associated with a smaller probability to present navicular bone or DDFT lesions (Holroyd *et al* 2013). This situation is most likely related to the forces exerted by the DDFT to the navicular bone (Wilson *et al* 2001, Eliashar*et al* 2004, Weaver *et al* 2009).

According to the results of our study, there was a significant negative correlation between the navicular score and the palmar angle. There was also a significant negative correlation between the navicular score and the hoof angle. The aforementioned results, were in accordance to our expectations and these may be the reflection of the increased force exerted by the DDFT due to a highest moment arm force (Wilson*et al* 2001) to the navicular bone when the hoof presents a low palmar angle (neutral to negative) (Floyd 2010).This situation has also being documented by Weaver *et al* (2009)were they topographically map pressure distribution across the palmar surface of the navicular bone in response to forces applied by the deep digital flexor tendon (DDFT). This study showed and evaluated the effect of raising the heels in vitro showing the relationship between the DDFT and navicular disease.Moreover, Eliashar*et al* (2004) concluded that an increase in the palmar angle by 1° would decrease the force of the DDFT on the navicular bone by 4%, supporting the biomechanical overload suffered by the navicular bone when an abnormally low palmar angle is present. Additionally, no significant correlation has been found between heel collapse and the palmar angle (Floyd 2010) thus the radiographic evaluation to determine the hoof inner structures measurements is mandatory.Considering biomechanical and risk factors for development of navicular disease, the palmar angle of the distal phalanx should play an important role in the presentation of the disease. According to Dik and van den Broek (1995) and Dik*et al* (2001), horses presenting with different palmar angles should present different shapes of the navicular bone based on a shape-dependent distribution of the forces exerted on the navicular bone. For example, navicular bone shape 1 and 2 are associated with overloading of the distal interphalangeal joint, and navicular bone shape 3 is related with strain of the collateral ligament of the navicular bone (Dik and van den Broek1995).

As this study did not evaluated the correlation between the palmar anglewith the presentation of clinical navicular disease,further investigation is required in this matter. Nonetheless, recent studies has shown very interesting data regarding correlations between radiographic measurements of the foot and abnormalities of specific structures found with magnetic resonance imaging (MRI) (de Zani*et al* 2016). Moreover, it has been documented that the larger the palmar angle, the smaller the likelihood of a DDFT or navicular bone lesion (Holroyd *et al* 2013).

In conclusion, this study contributes to the informationalready available in the literature helping to have a better understanding of changes suffered by inner structures of the hoof capsule. We have documented the reference hoof values from the Chilean Criollo horses and at the same time we have shown a few difference between this breed and Warmblood horses. Additionally, we have demonstrated that there is a significant statistical correlation between the radiographic navicular score and the palmar angle. Given these results, a radiological evaluation of horse's feet before and after shoeing is always recommended. To fully understand the implication of the changes suffered on the palmar angle in horses presenting navicular disease, further investigation is needed.

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Table 1: Radiographic findings and classification of the navicular bone (Dyson 2011)

Grade	Condition	Radiographic Findings
0	Excellent	Good corticomedullary demarcation; fine trabecular pattern. Flexor cortex of uniform thickness and opacity. No lucent zones along the distal border of the bone, or <6 narrow conical lucent zones along the horizontal distal border.
1	Good	As above, but lucent zones on the distal border of the navicular bone more variable in shape.
2	Fair	Slightly poor definition between the palmar cortex and the medulla due to subcortical increased opacity. Several (<8) lucent zones of variable shape along the distal horizontal border. Mild entheseophyte formation on the proximal border of the navicular bone. Proximal or distal extension of the flexor border of the navicular bone.
3	Poor	Poor corticomedullary definition due to increased opacity of the medulla. Thickening of the dorsal and flexor cortices. Poorly defined lucent areas in the flexor cortex of the bone. Many (>7) radiolucent zones along the distal horizontal or sloping border. Lucent zones along the proximal border of the bone. Large entheseophyte formation on the proximal border of the bone. Radiopaque fragment on the distal border of the navicular bone.
4	Bad	Large cyst-like lesion within the medulla. Lucent region in the flexor cortex. New bone on the flexor cortex of the navicular bone.

Table 2: Radiological values of the hoof of both groups expressed as the mean ± s.d. and the results of t-Student test

	Chilean Horses	Warmblood Horses	
Parameters	Mean ± s.d.	Mean ± s.d.	*P* value
Palmar angle	6.46± 3.88 [a]	3.39± 3.37 [a]	0.000
P3 descent	0.38 ± 0.49	0.53 ± 0.60	0.096
P3 dist. to ground	1.86 ± 0.54 [a]	2.02 ± 0.56 [a]	0.048
Hoof angle	51.38 ± 5.96	51.21 ± 4.34	0.885
Prox. HL zone	1.51 ± 0.33	1.58 ± 0.26	0.204
Dist. HL zone	1.47 ± 0.42	1.43 ± 0.24	0.405
Toe/Support %	67.35± 5.78 [a]	65.12± 5.48 [a]	0.033
Coffin joint angle	9.89 ± 6.71	9.24 ± 7.13	0.791
Pastern joint angle	2.47 ± 4.66	3.36 ± 5.21	0.354
Length of P2	3.99± 0.53 [a]	4.66 ± 0.33 [a]	0.000

P3, distal phalanx; HL, hoof-lamella; P2, middle phalanx.
[a]Significant difference $P < 0.05$

Table 3: The mean ± s.d. values for radiological hoof parameters for Chilean and Warmblood horses when assessed by limb and results of t-Student test

	Chilean Horses			Warmblood Horses		
	LF	RF		LF	RF	
Parameters	Mean ± s.d.	Mean ± s.d.	*P* value	Mean ± s.d.	Mean ± s.d.	*P* value
Palmar angle	6.69 ± 4.02	6.19 ± 3.94	0.474	3.59 ± 3.28	3.05 ± 3.48	0.768
P3 descent	0.45 ± 0.48	0.32 ± 0.51	0.321	0.53 ± 0.65	0.56 ± 0.56	0.588
P3 dist. to ground	1.83 ± 0.56	1.87 ± 0.52	0.754	2.08 ± 0.56	1.97 ± 0.58	0.500
Hoof angle	51.99 ± 2.37	50.64 ± 8.41	0.360	51.17 ± 4.08	51.24 ± 4.75	0.713
Prox. HL zone	1.52 ± 0.33	1.53 ± 0.34	0.991	1.57 ± 0.23	1.61 ± 0.27	0.823
Dist. HL zone	1.47 ± 0.32	1.50 ± 0.51	0.865	1.42 ± 0.25	1.45 ± 0.23	0.710
Toe/Support %	67.00 ± 6.34	67.49 ± 5.53	0.736	65.41 ± 5.27	64.84 ± 5.85	0.949
Coffin joint angle	9.20 ± 6.44	9.91 ± 6.92	0.846	8.98 ± 7.19	9.51 ± 7.28	0.751
Pastern joint angle	3.28 ± 4.46	1.96 ± 4.39	0.320	3.66 ± 4.81	1.98 ± 5.41	0.147
Length of P2	4.00 ± 0.53	3.98 ± 0.55	0.988	4.63 ± 0.33	4.71 ± 0.33	0.892

P3, distal phalanx; HL, hoof-lamella; P2, middle phalanx; LF, left front limb; RF, right front limb.

Table 4: Results from the Spearman correlation test assessing correlations between the hoof values obtained from all horses and the radiological score of the navicular bone

Parameters	Rho Spearman	*P* value
Palmar angle & Navicular score	-0.173	0.041 [a]
P3 descent & Navicular score	-0.136	0.108
P3 dist. to ground & Navicular score	0.096	0.259
Hoof angle & Navicular score	-0.190	0.024 [a]
Prox. HL zone & Navicular score	-0.045	0.595
Dist. HL zone & Navicular score	-0.058	0.498
Toe/Support % & Navicular score	0.118	0.165
Coffin joint angle & Navicular score	0.074	0.386
Pastern joint angle & Navicular score	0.021	0.801
Length of P2 & Navicular score	0.113	0.182

P3, distal phalanx; HL, hoof-lamella; P2, middle phalanx.
[a] Significant difference $P < 0.05$

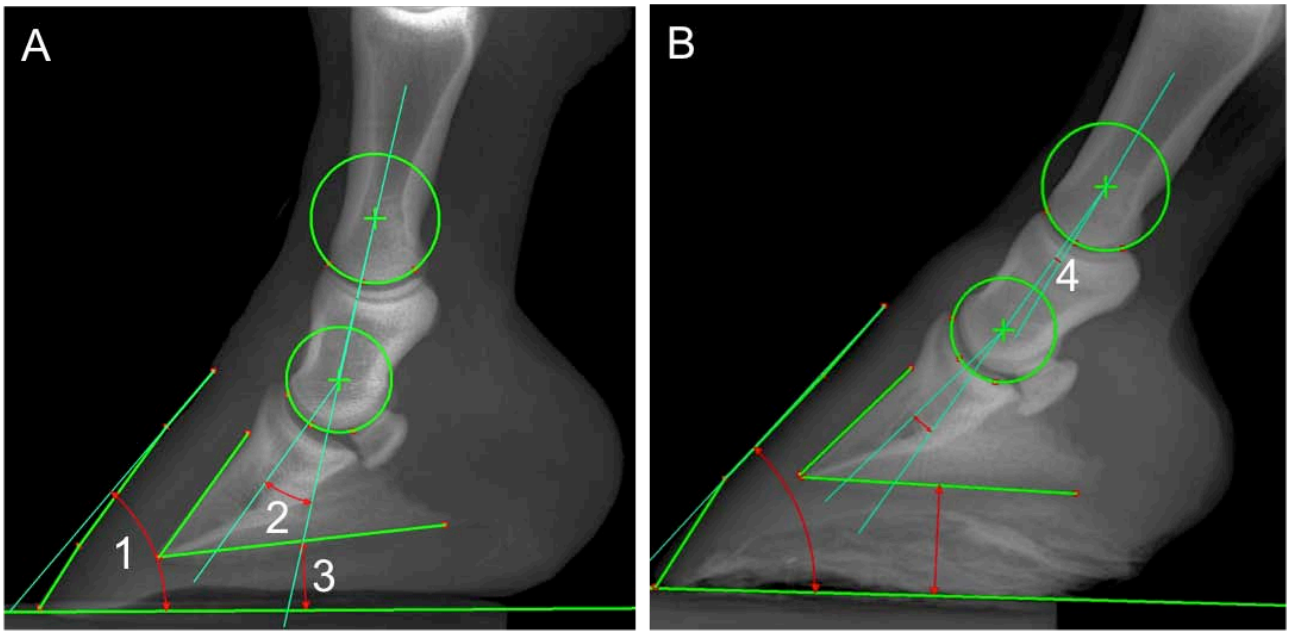

Figure 1: Angle measurements using Metron software. A. Normal palmar angle. Podophalangeal axis is broken backwards. B. Notice the negative palmar angle. There is an overgrown hoof capsule, classical upright conformation seen in Chilean Criollo horses. 1, hoof angle.2, coffin joint angle.3, palmar angle. 4, pastern joint angle.

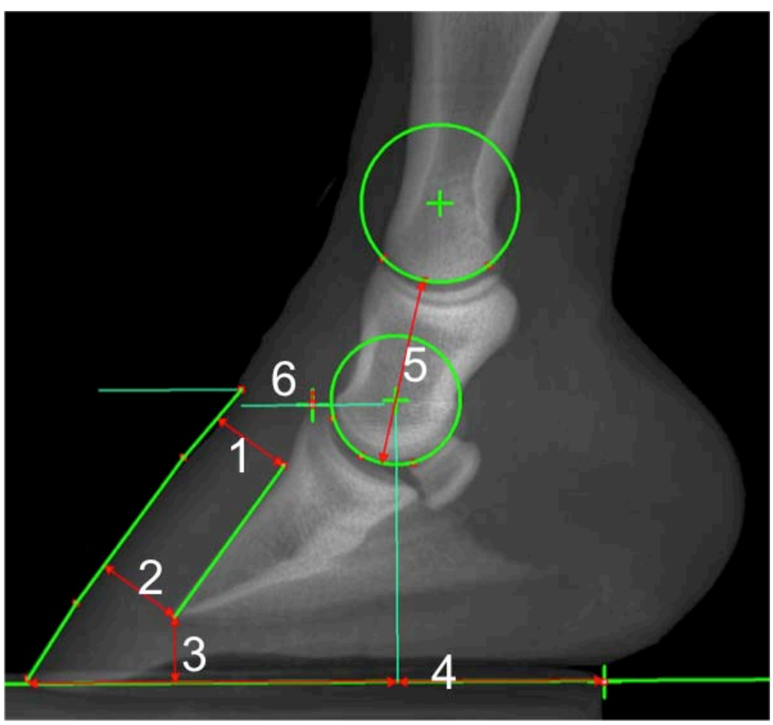

Figure 2: Linear measurements using Metron software.1, proximal HL zone.2, distal HL zone.3, distance of the distal phalanx to ground.4, percentage of the weight-bearing surface of the toe.5, length of the middle phalanx. 6. descent of the distal phalanx.