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The effect of hoof trimming on radiographic measurements of the front feet of normal Warmblood horses

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Abstract

The understanding of the normal position of the third phalanx (P3) and the distal sesamoid bone in relation to the size and shape of the hoof capsule in sound horses is helpful in the diagnosis of equine foot lameness. Some measurements on radiographs used to define the position of the pedal bone within the hoof capsule are significantly influenced by hoof trimming and the height of the withers. In this study, the front hooves of 40 Warmblood horses were radiographed twice, eight weeks apart, both before and after their hooves were trimmed by an experienced farrier. Using the software programme Metron PX, 22 parameters on the lateromedial view and 16 parameters on the dorsopalmar view were measured and the effect of hoof trimming and height of the withers were calculated, respectively.

Some of the hoof parameters showed mild positive correlation with the height of the withers. In 70% of the horses the left hoof capsule and P3 were significantly larger than the right. Hoof trimming had a remarkable influence on hoof conformation, especially for parameters in the toe region. Of all the measurements that describe the position of the third phalanx (P3) in relation to the hoof capsule, the distances between the distal tip of P3 to the solar surface of the foot, P3 to the tip of the toe and P3 to the point of breakover showed the greatest differences before and after trimming. The database of the present study can be used by farriers and veterinarians as a guideline for routine and corrective shoeing of Warmblood horses.

Keywords: Equine hoof; Trimming; Radiography; Measurements; Hoof parameters

1. Introduction

Hoof-related lameness is common in performance and pleasure horses. Radiographic examination of the equine hoof has been widely used to diagnose this condition and to plan corrective shoeing, because it is widely recognised that proper trimming and shoeing have an enormous influence on the soundness of a horse (O'Grady and Poupard, 2001). Many veterinarians and farriers assert that a large proportion of the lamenesses seen today, could be prevented or treated through good farriery (O'Grady and Poupard, 2003).

It is assumed that a straight alignment of the three phalangeal bones is optimal for mechanical function. Malalignment of the digital bones is seen in 72.8% of horses with forelimb lameness (Page and Hagen, 2002). The shape and size of the hoof take a central place in relation to the alignment of the hoof-pastern axis and the mediolateral hoof balance (O'Grady and Poupard, 2001).

Lateromedial (LM) and dorsopalmar (DP) views of the distal limb are very helpful in assessing the hoof with all the structures in it. The normal radiographic anatomy has been described in detail elsewhere (Quick and Rendano, 1977; Shively, 1977; Rendano and Grant, 1978; Colles, 1983; Butler et al., 1993; Becht et al., 2001), but only a few studies on measurements of hoof structures are available.

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Linford et al. (1993) evaluated the bone structures in relation to the associated soft tissue and hoof capsule in 41 Thoroughbred horses. Cripps and Eustace (1999) investigated the normal position of the pedal bone (P3) in sound horses with relevance to laminitis in different breeds. The vertical distance between the proximal limit of the dorsal hoof wall and the proximal limit of the extensor process of the distal phalanx, the so called "*Founder distance* " (FD), was defined as an important measurement in their investigation. Kane et al. (1998) described hoof size, shape and balance as possible risk factors for catastrophic musculoskeletal injuries in Thoroughbred racehorses. Other authors focused on the correct longitudinal and mediolateral hoof balance (Colles, 1983; Stashak, 1987; Butler et al., 1993).

In all the studies mentioned above, the effect of trimming of horses' hooves was never considered. A lot of parameters concerning hoof shape and size depend strongly on the trimming procedure. To the authors' knowledge, no studies have investigated the influence of hoof trimming on radiographic measurements of the hoof.

Trimming and shoeing remain important issues in equine orthopaedics. Recently, farriers and veterinarians started to evaluate the quality of the treatment with the help of radiographs or use them as a guide for corrective shoeing in daily practice. The goal of the present study was to establish a database of normal values of radiographic measurements for the front hooves in a population of Warmblood horses with a defined range of wither height. Within this population, the effect of the height of the withers and hoof trimming on the measured parameters was to be evaluated.

2. Materials and methods

2.1. Horses

Forty Warmblood horses (2 stallions, 14 mares and 24 geldings) ranging in age from 6 to 12 years (8.6 years ± 2.0 years) and with a height (measured at the highest point of the withers) between 162 and 172 cm (168 ± 3 cm) were included in this study. The horses were regularly shod by one of six different farriers at usual intervals of 8–10 weeks, therefore every farrier had six or seven horses. Over the 12 months prior to the study, all horses were trimmed by the same farrier. Due to poor horn quality, two horses were fed a biotin supplement for more than a year. The horses were used for either show jumping or dressage. None of the horses had a previous history of lameness. Before trimming, when trotted on a hard surface in straight line, all horses were clinically sound and the feet showed no abnormality or distortion.

2.2. Radiographic method

The horse was positioned with both forelimbs simultaneously on a wooden block, both limbs perpendicular to the ground and with equal weight bearing (Kummer et al., 2004; Redden, 2003b). The foot to be radiographed was placed in such a manner as to ensure that the vertically positioned cassette touched the hoof capsule on the medial side. On either side of the central wooden block a board of 130 cm length carried the portable X-ray unit (Vet-Ray; Eikemeyer). The standing block and X-ray unit board were connected by a hinge, allowing 90° range of motion in order to take views in both LM and DP projections, without the need for alteration of the horse's position. The exposure factors for the LM and the DP view were 58 kV, 8 mAs and 62 kV, 8 mAs, respectively.

For the LM view, the horizontal X-ray beam was centred 2 cm below the coronary band, at the midpoint between the bulbs of the heel and the proximodorsal aspect of the hoof wall, according to the radiographic technique described by Kummer et al. (2004).

After moving the board with the X-ray unit by 90° for the DP images, the horizontal X-ray beam was centred on the median of the dorsal hoof wall, without changing the level of the X-ray beam.

For the LM view the dorsal hoof wall was marked with a flexible 5 cm long band of lead. The upper end of the lead-band was placed at the coronet, bordering the hair line. The distal part of the dorsal hoof wall and the line between the true apex of the frog and the most dorsal part of the toe were marked with barium paste. To mark the medial and lateral hoof wall in the DP view, equal pieces of lead were used. They were both placed parallel to the horn tubules with the proximal end at the coronary band at the broadest part of the hoof. All markers were placed by the first author.

2.3. Experimental method

The hooves of both forelimbs were radiographed for the first time after an average shoeing period of 9.2 weeks (range 8–10 weeks). A set of radiographs, consisting of a LM and DP view of both unshod front feet were taken before and after trimming. Before the first set of radiographs (Session A) were taken, the shoes were removed and the sole and frog were cleaned with a hoof pick. After trimming the hoof, a second set of radiographs (Session B) were made immediately before adjusting the shoe. Exactly eight weeks later, the same procedure was repeated correspondingly (Sessions C and D).

2.4. Measurements

All radiographs were digitalised with a portable scanner (Combo 2000, Vetray) and imported into the software program Metron PX (Epona Tech). Following the instructions of the program, 22 parameters on the LM view (Figs. 1 and 2) and 16 on the DP view (Fig. 3) were measured by the first author.

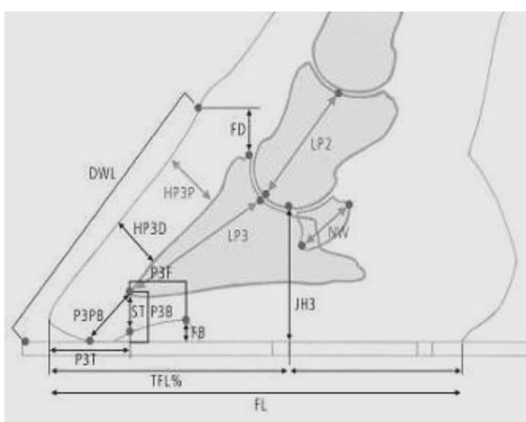
For statistical analysis, the software Statview (SAS) statistical software, was used. Descriptive statistics included calculation of the mean and standard deviation (SD). ANOVA for repeated measures (Bonferroni/Dunn) was used to determine the differences between the four sessions. Statistical significance was set at $P < 0.05$ (5%) and was based on a 2-sided null hypothesis of no difference. Differences in mean lengths between left and right were assessed using the paired *t* test, with the same probability level. Correlations quoted are those of Pearson.

3. Results

A basic statistical description of the data obtained before (Session A, C) and after trimming (B, D) from both front feet for the LM and DP views is given in Tables 1 and 2, respectively.

Parameters measuring anatomical structures that are not influenced by the trimming procedure are assigned as invariable (*) and are listed at the beginning of each table. In the LM view, two invariable parameters, LP3 and HP3P show significant differences within sessions ($P < 0.05$) (Table 1). However, the differences within the individual measurements for these parameters are maximally 0.1 cm. The same goes for the invariable parameters in the DP view, BW2, JW2 and JW3 (Table 2).

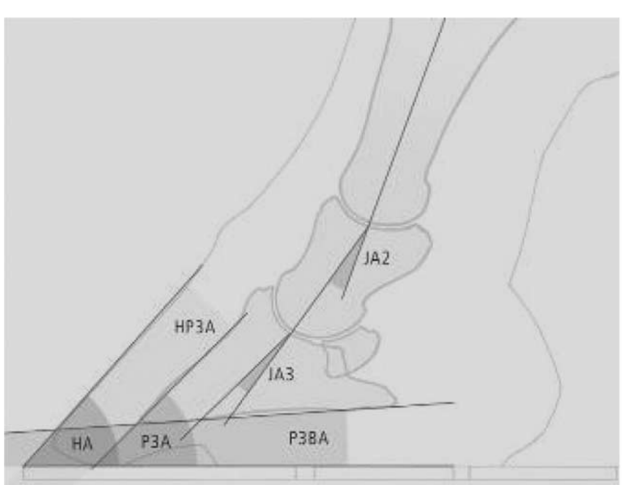
Measurements such as distances and angles that describe the position of P3 in relation to the hoof capsule are marked with two asterisks (**). Of those, P3 to bottom, P3 to toe, P3 to point of break-over, frog to bottom



Parameters (* = invariable):

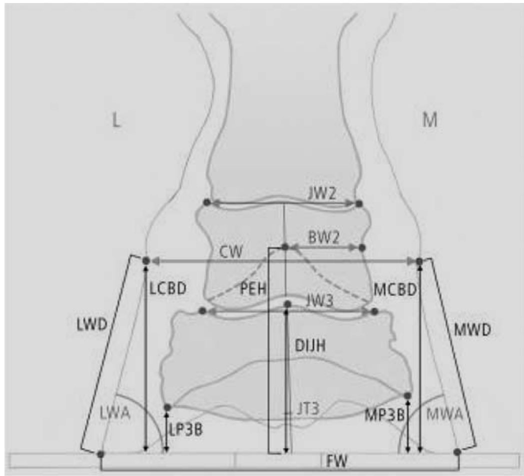
LP2 = Length of P2 (cm) *
LP3 = Length of P3 (cm) *
NW = Navicular Width (cm) *
HP3P = Hoof P3 Distance proximal (cm) *
HP3D = Hoof P3 Distance distal (cm)
FD = Founder Distance (cm)
FL = Foot Length (cm)
DWL = Dorsal Wall Length (cm)
P3B = P3 to Bottom (cm)
P3T = P3 to Toe (cm)
P3PB = P3 to Point of Breakover (cm)
P3F = P3 to Frog (cm)
ST= Sole thickness (cm)
FB = Frog to Bottom (cm)
JH3 = P2/P3 Joint Height (cm)
TFL% = Toe/Foot Length %

Fig. 1. Schematic view of a LM radiograph indicating the 16 measured parameters (distances).



Parameters:
HA = Hoof Angle (°)
P3A = P3 Angle (°)
P3BA = P3/Bottom Angle (°)
JA2 =P1/P2 Joint Angle (°)
JA3 = P2/P3 Joint Angle (°)
HP3A = Hoof P3 Angle (°)

Fig. 2. Schematic view of a LM radiograph indicating the 6 measured parameters (angles).



Parameters (* = invariable):

BW2 = Half Bone Width P2 (cm) *
JW2 = P1/P2 Joint Width (cm) *
JW3 = P2/P3 Joint Width (cm) *
CW = Coronet Width (cm) *
DIJH = P2/P3 Joint Height (cm)
PEH = Height of Processus Extensorius (cm)
LWD = Lateral Wall Length (cm)
MWD = Medial Wall Length (cm)
FW = Foot Width (cm)
LCBD = Lateral Height of Coronet (cm)
MCBD = Medial Height of Coronet (cm)
LP3B = P3 to Bottom lateral (cm)
MP3B = P3 to Bottom medial (cm)
LWA = Lateral Wall Angle (°)
MWA = Medial Wall Angle (°)
JT3 = Joint Tilt of P2/P3 (°)

Fig. 3. Schematic view of a DP radiograph indicating the 16 measured parameters (distances and angles).

in the LM view (Table 1); and P3 to bottom lateral, P3 to bottom medial in the DP view (Table 2) showed the greatest differences before and after hoof trimming.

There was no statistical difference in the FD and in the angles describing the alignment of the digital bones (JA2, JA3) on the LM view; or in JT3 on the DP view (Table 2).

The comparison of the measurements of the ipsilateral and the contralateral (right and left) feet is shown in Tables 3 and 4. There were significant differences between left and right feet in all four sessions. The dorsal wall (DWL) was longer in right feet in 65–77.5% of the horses in the four different sessions. The digital bones (LP2, LP3) were longer and the distal sesamoid bone was wider (NW) on the left side in the LM view (Table 3).

In the DP view (Table 4) most of the parameters were bigger on the left side compared to the right before and after hoof trimming.

On the LM view LP2, LP3, NW, DWL, HP3D, P3T and FL; on the DP view JW2, CW, FW and PEH showed significant positive correlations with the horse's height ($P < 0.05$ in all sessions). The coefficients of correlation of these parameters for all sessions are listed in Table 5. The FD and P3F showed absolutely no correlation ($P > 0.05$) with the height of the horse. There was no correlation between the radiographic measurements of the foot and the age of the horse or the shoeing interval.

FD was only significantly correlated with HP3P, coefficient of correlation (r) < 0.32 in all four sessions. FB and P3F were not significantly correlated with any of the invariable parameters. HA and P3A were negatively correlated with LP3 and HP3P, r between −0.39 and −0.15.

To evaluate the accuracy of the measurements, the difference between the lateral and medial distance from P3 to bottom (LP3B − MP3B = ΔP3B) was calculated and correlated to JT3. ΔP3B showed a significant correlation with JT3, r between 0.36 and 0.49. In the same way the difference between the lateral and medial height of coronet (LCBD − MCBD = ΔCBD) and the difference between the lateral and medial wall length (LWD − MWD = ΔWD) were compared. Both correlate highly significantly ($P < 0.01$), $r > 0.86$ for all four sessions. There is, however, no correlation between either ΔP3B or JT3 and ΔCBD and ΔWD, respectively.

The FD showed a wide range in the different sessions: A (0.5–2.1 cm), B (0.4–2.1 cm), C (0.4–2.0 cm), D (0.3–2.1 cm). The maximal difference seen in the same hoof between two sessions was 0.69 cm. The greatest difference found between the left and the right front feet of the same horse in the same session was 0.8 cm.

P3F shows ranges of A (1.0–2.6), B (1.0–2.9), C (1.0–2.6), D (1.1–3.5). The maximum intra-individual difference between two sessions was 1.75 cm. The maximum difference found between the front feet of the same horse in the same session was 1.3 cm.

4. Discussion

The trimming procedure has an important influence on the conformation of the hoof. This is visible on both radiographic projections, although it is especially pronounced on the LM view in the region of the toe.

The trimming procedure shortens the DWL by about 1.0 cm (10% of the length before trimming) and has a dramatic effect on the position of P3 in relation to the hoof capsule: P3B is reduced by about 0.7 cm (30%), P3T by about 0.7 cm (19–22%) and P3PB is shortened by about 1.1 cm (30%) through trimming. The angle parameters reflect these changes: the HP3A increases

Table 1
Descriptive statistics for the LM view

Parameter	Left		Right		ANOVA for session	Influence of the trimming procedure	Percentage: reduction/before trimming (%)
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD			
	A	C	A	C			
	B	D	B	D			
LP2 = length of P2 (cm)*	4.6 ± 0.24	4.7 ± 0.24	4.7 ± 0.25	4.7 ± 0.20	*x*	−0.1 to 0.1	−2 to 2
	4.7 ± 0.23	4.6 ± 0.23	4.7 ± 0.24	4.7 ± 0.26			
LP3 = length of P3 (cm)*	5.8 ± 0.35	5.8 ± 0.36	5.9 ± 0.38	5.9 ± 0.37	0.01	0.1	2
	5.7 ± 0.36	5.8 ± 0.37	5.8 ± 0.37	5.8 ± 0.37			
NW = navicular width (cm)*	1.7 ± 0.15	1.7 ± 0.14	1.8 ± 0.19	1.8 ± 0.18	*x*	0	0
	1.7 ± 0.14	1.7 ± 0.15	1.8 ± 0.17	1.8 ± 0.17			
HP3P = hoof P3 distance proximal (cm)*	1.9 ± 0.14	1.8 ± 0.14	1.9 ± 0.18	1.9 ± 0.15	0.012	−0.1 to 0	−5 to 0
	1.9 ± 0.15	1.9 ± 0.14	1.9 ± 1.57	1.9 ± 0.15			
HP3D = hoof P3 distance distal (cm)**	1.7 ± 0.17	1.7 ± 0.13	1.8 ± 0.20	1.7 ± 0.19	<0.0001	0.1	6
	1.6 ± 0.17	1.6 ± 0.13	1.7 ± 0.20	1.7 ± 0.16			
FD = founder distance (cm)**	1.0 ± 0.35	1.1 ± 0.34	1.1 ± 0.35	1.1 ± 0.34	*x*	−0.1 to 0	−10 to 0
	1.1 ± 0.39	1.1 ± 0.36	1.1 ± 0.35	1.1 ± 0.34			
FL = foot length (cm)	12.9 ± 0.92	13.1 ± 0.95	13.0 ± 1.11	13.1 ± 0.98	<0.0001	0.2–0.5	2– 4
	12.7 ± 0.92	12.7 ± 0.87	12.5 ± 1.05	12.7 ± 0.95			
DWL = dorsal wall length (cm)	10.5 ± 0.77	10.6 ± 0.75	10.8 ± 0.77	10.8 ± 0.73	<0.0001	1.0–1.1	10
	9.5 ± 0.61	9.5 ± 0.59	9.7 ± 0.68	9.7 ± 0.65			
P3B = P3 to bottom (cm)**	2.3 ± 0.32	2.3 ± 0.35	2.3 ± 0.36	2.3 ± 0.36	<0.0001	0.7	30
	1.6 ± 0.23	1.6 ± 0.26	1.6 ± 0.26	1.6 ± 0.27			
P3T = P3 to toe (cm)**	3.1 ± 0.44	3.2 ± 0.39	3.2 ± 0.53	3.2 ± 0.47	<0.0001	0.6–0.7	19–22
	2.5 ± 0.30	2.5 ± 0.25	2.5 ± 0.39	2.5 ± 0.32			
P3PB = P3 to point of break-over (cm)**	3.6 ± 0.47	3.6 ± 0.45	3.6 ± 0.59	3.7 ± 0.54	<0.0001	1.1	30
	2.5 ± 0.40	2.5 ± 0.41	2.5 ± 0.49	2.6 ± 0.47			
P3F = P3 to frog (cm)**	1.8 ± 0.33	1.8 ± 0.31	1.9 ± 0.39	1.8 ± 0.42	<0.0001	−0.3	−16
	2.1 ± 0.32	2.1 ± 0.35	2.2 ± 0.38	2.1 ± 0.45			
ST = sole thickness (cm)**	1.5 ± 0.27	1.5 ± 0.31	1.5 ± 0.26	1.5 ± 0.30	<0.0001	0.2	13
	1.3 ± 0.17	1.3 ± 0.22	1.3 ± 0.21	1.3 ± 0.22			
FB = frog to bottom (cm)**	1.2 ± 0.31	1.2 ± 0.34	1.3 ± 0.36	1.2 ± 0.38	<0.0001	0.2–0.3	17–23
	1.0 ± 0.29	0.9 ± 0.25	1.0 ± 0.30	0.9 ± 0.29			
JH3 = P2/P3 joint height (cm)	5.3 ± 0.48	5.3 ± 0.51	5.4 ± 0.53	5.3 ± 0.55	<0.0001	0.4–0.5	8–9
	4.8 ± 0.37	4.8 ± 0.41	4.9 ± 0.43	4.9 ± 0.45			
TFL% = toe/foot length (%)	68.6 ± 4.97	68.2 ± 4.03	68.9 ± 5.46	68.8 ± 4.91	<0.0001	3.9–4.7	6–7
	63.9 ± 4.27	63.8 ± 3.50	65.0 ± 4.45	64.2 ± 4.24			
HA = hoof angle (°)	52.3 ± 3.69	51.8 ± 3.55	51.8 ± 3.69	51.5 ± 3.67	<0.0001	−2.5 to −2.9	−5 to 6
	54.8 ± 3.17	54.7 ± 2.68	54.7 ± 3.00	54.2 ± 2.99			
P3A = P3 angle (°)	49.5 ± 4.05	49.0 ± 3.98	49.0 ± 3.84	48.8 ± 3.52	<0.0001	−1.8 to −2.2	−4
	51.3 ± 3.58	51.0 ± 3.11	51.2 ± 3.57	50.9 ± 3.11			
P3BA = P3/bottom angle (°)**	4.0 ± 2.09	4.0 ± 2.10	4.7 ± 2.25	4.3 ± 2.34	<0.0001	−1.4 to −1.9	−30 to −44
	5.4 ± 2.16	5.4 ± 1.88	6.1 ± 2.24	6.4 ± 2.13			
JA2 = P1/P2 joint angle (°)	5.6 ± 3.33	5.3 ± 3.72	6.4 ± 3.77	6.6 ± 3.78	*x*	0.1–0.6	2–11
	5.2 ± 3.65	4.7 ± 3.25	6.3 ± 3.49	6.5 ± 3.12			
JA3 = P2/P3 joint angle (°)	6.5 ± 7.30	8.5 ± 7.48	7.9 ± 6.73	8.2 ± 7.54	*x*	0.9–2.9	14–41
	5.6 ± 7.19	5.8 ± 6.71	5.0 ± 7.14	6.1 ± 6.86			
HP3A = hoof P3 angle (°)**	−2.8 ± 1.39	−2.8 ± 1.28	−2.8 ± 1.37	−2.7 ± 1.59	0.0001	−0.7 to −0.9	−25 to −48
	−3.5 ± 1.63	−3.7 ± 1.68	−3.5 ± 1.76	−3.4 ± 1.47			

Mean and standard deviation (SD) of the invariable (*) and variable parameters. Measurements divided by side and session. A: First shoeing, before trimming; B: First shoeing, after trimming; C: Second shoeing, before trimming; D: Second shoeing, after trimming. ANOVA (Bonferroni/Dunn) *P*-values for sessions ($x > 0.05$). Influence of the trimming procedure and the percentage (reduction/before trimming) are mentioned for all LM parameters. Parameters that describe the position of the third phalanx in relation to the hoof capsule are marked with two asterisks (**).

by about 0.8° (25–48%), the HA is increased by about 3° and the P3A is increased by about 2°. The rasping of the dorsal hoof wall is responsible for the significantly smaller HP3D after trimming. These differences illustrate the change in the conformation around P3 and underline the influence of the trimming procedure in this region.

Compared to the palmar region of the hoof, which is worn down by the constant movement caused by the hoof mechanism, the toe region has to be shortened to a remarkable extent. This circumstance provides an ideal opportunity to influence hoof shape and hoof pastern axis through the trimming procedure. Shortening

Table 2
Descriptive statistics for the DP view

Parameter	Left		Right		ANOVA for session	Influence of the trimming procedure	Percentage: reduction/before trimming (%)
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD			
	A	C	A	C			
	B	D	B	D			
BW2 = half bone width P2 (cm)*	2.7 ± 0.11	2.8 ± 0.11	2.7 ± 0.14	2.7 ± 0.14	0.02	−0.1 to 0	−4 to 0
	2.8 ± 0.13	2.8 ± 0.11	2.7 ± 0.13	2.7 ± 0.14			
JW2 = P1/P2 joint width (cm)*	5.4 ± 0.24	5.4 ± 0.24	5.2 ± 0.23	5.2 ± 0.23	0.0051	0	0
	5.4 ± 0.29	5.4 ± 0.24	5.2 ± 0.26	5.2 ± 0.24			
JW3 = P2/P3 joint width (cm)*	5.6 ± 0.27	5.6 ± 0.29	5.3 ± 0.26	5.3 ± 0.28	0.041	−0.1 to 0	−2 to 0
	5.6 ± 0.33	5.6 ± 0.31	5.4 ± 0.29	5.4 ± 0.25			
CW = coronet width (cm)*	10.6 ± 0.57	10.7 ± 0.56	10.2 ± 0.54	10.2 ± 0.51	*x*	−0.1 to 0	−1 to 0
	10.7 ± 0.61	10.7 ± 0.57	10.3 ± 0.60	10.3 ± 0.55			
DIJH = P2/P3 joint height (cm)**	5.3 ± 0.45	5.3 ± 0.50	5.1 ± 0.49	5.1 ± 0.51	<0.0001	0.4–0.6	8–11
	4.8 ± 0.38	4.7 ± 0.39	4.7 ± 0.39	4.6 ± 0.43			
PEH = height of processus extensorius (cm)**	7.4 ± 0.49	7.4 ± 0.57	7.1 ± 0.60	7.0 ± 0.62	<0.0001	0.4–0.6	6–8
	6.8 ± 0.44	6.8 ± 0.52	6.6 ± 0.50	6.6 ± 0.61			
LWD = lateral wall length (cm)	6.7 ± 0.64	6.5 ± 0.67	6.5 ± 0.65	6.4 ± 0.66	<0.0001	0.2–0.4	3–6
	6.3 ± 0.61	6.3 ± 0.52	6.2 ± 0.66	6.0 ± 0.59			
MWD = medial wall length (cm)	6.8 ± 0.70	6.7 ± 0.61	6.8 ± 0.63	6.7 ± 0.64	<0.0001	0.3–0.5	4–7
	6.4 ± 0.57	6.4 ± 0.61	6.3 ± 0.62	6.2 ± 0.58			
FW = foot width (cm)	14.0 ± 1.04	14.1 ± 1.08	13.6 ± 0.96	13.6 ± 0.98	<0.0001	0.5–0.6	4
	13.5 ± 1.14	13.5 ± 0.98	13.1 ± 0.97	13.1 ± 0.98			
LCBD = lateral height of coronet (cm)	6.5 ± 0.63	6.2 ± 0.69	6.3 ± 0.66	6.1 ± 0.66	<0.0001	0.1–0.4	2–7
	6.1 ± 0.57	6.1 ± 0.52	6.0 ± 0.64	5.7 ± 0.58			
MCBD = medial height of coronet (cm)	6.6 ± 0.71	6.5 ± 0.60	6.5 ± 0.61	6.5 ± 0.65	<0.0001	0.3–0.5	5–8
	6.2 ± 0.59	6.2 ± 0.61	6.1 ± 0.62	6.0 ± 0.57			
LP3B = P3 to bottom lateral (cm)**	2.6 ± 0.38	2.5 ± 0.40	2.5 ± 0.41	2.5 ± 0.37	<0.0001	0.5–0.6	20–24
	2.0 ± 0.32	2.0 ± 0.36	2.0 ± 0.34	1.9 ± 0.36			
MP3B = P3 to bottom medial (cm)**	2.4 ± 0.38	2.3 ± 0.40	2.3 ± 0.37	2.2 ± 0.43	<0.0001	0.4–0.6	18–25
	1.8 ± 0.27	1.8 ± 0.30	1.8 ± 0.29	1.8 ± 0.34			
LWA = lateral wall angle (°)	75.1 ± 3.36	74.4 ± 3.81	73.8 ± 3.95	72.0 ± 4.53	0.0002	−0.7 to −2.4	−1 to −3
	75.8 ± 3.44	76.1 ± 3.48	74.3 ± 3.97	74.4 ± 3.93			
MWA = medial wall angle (°)	75.1 ± 6.16	74.6 ± 5.14	75.6 ± 4.72	76.6 ± 5.70	<0.0001	−0.8 to −2.3	−1 to −3
	77.0 ± 5.72	76.6 ± 5.18	77.9 ± 4.61	77.4 ± 4.97			
JT3 = joint tilt of P2/P3 (°)	1.4 ± 1.56	1.2 ± 1.56	1.9 ± 1.75	2.0 ± 1.78	*x*	−0.1 to 0.4	−7–20
	1.5 ± 1.45	1.4 ± 1.49	1.9 ± 1.65	1.6 ± 1.52			

Mean and standard deviation (SD) of the invariable (*) and variable parameters. Measurements divided by sides and session. A: First shoeing, before trimming; B: First shoeing, after trimming; C: Second shoeing, before trimming; D: Second shoeing, after trimming. ANOVA (Bonferroni/Dunn) *P*-values for sessions ($x > 0.05$). Influence of the trimming procedure and the percentage (reduction/before trimming) are mentioned for all DP parameters. Parameters that describe the position of the third phalanx in relation to the hoof capsule are marked with two asterisks (**).

Table 3
Paired *t* test *P*-values for parameters with significant differences between left and right side for LM view

Parameter	ANOVA for side	Percentage	
		Left bigger	Right bigger
LP2	<0.0001	57.5–80	20–42.5
LP3	<0.0002	65–72.5	27.5–35
NW	<0.0001	77.5–90	10–22.5
DWL	0.0002	22.5–35	65–77.5
P3BA	0.013	35–50	50–65
JA2	0.023	32.5–37.5	62.5–67.5

The ranges of percentile distribution in the four different sessions are shown.

the distance from point of break-over to the tip of P3 decreases the strain on the deep digital flexor tendon and reduces the pressure of the deep digital flexor tendon on the palmar cortex of the navicular bone (Page and Hagen, 2002). The longer the digital break-over on the hoof (horizontal distance from the tip of P3 to the break-over point of the shoe), the greater the tension on the laminar attachment and the more the horn tubules are bent (Redden, 2003a).

Ovnicek et al. (2003) determined the point of break-over relative to the apex of the frog. This would be a very practical method, but according to the results in Session B and D of the present study, the position of the frog apex is very variable, even within individuals. The position of the frog's apex depends on how it is trimmed and on hoof condition; flat hooves with low heels tend to have elongated frog apexes (Ovnicek et al., 2003). Therefore, using the apex of the frog for determination of the point of break over is not reliable.

Table 4
Paired *t* test *P*-values for parameters with significant differences between left and right side for DP view

Parameter	ANOVA for Side	Percentage	
		Left bigger	Right bigger
BW2	<0.0001	72.5–80	20–27.5
JW2	<0.0001	95	5
JW3	<0.0001	80–92.5	7.5–20
CW	<0.0001	90–97.5	2.5–10
DIJH	0.0089	60–72.5	27.5–40
PEH	<0.0001	72.5–80	20–27.5
LWD	0.015	57.5–77.5	22.5–42.5
FW	<0.0001	72.5–87.5	12.5–27.5
LCBD	0.002	60–82.5	17.5–40
LWA	0.007	60–67.5	32.5–40
JT3	0.03	42.5–50	50–57.5

The ranges of percentile distribution in the four different sessions are shown.

Table 5
Correlation coefficients (Pearson) between the withers height and the parameters of the LM and DP view with $P < 0.05$ in all four sessions

Parameter	A	B	C	D
LP2	0.64	0.6	0.58	0.59
LP3	0.49	0.49	0.51	0.52
NW	0.44	0.38	0.37	0.39
DWL	0.41	0.45	0.42	0.43
HP3D	0.38	0.4	0.43	0.39
P3T	0.47	0.48	0.53	0.5
FL	0.52	0.49	0.52	0.48
JW2	0.43	0.46	0.4	0.42
CW	0.42	0.48	0.43	0.48
FW	0.46	0.48	0.47	0.49
PEH	0.38	0.39	0.36	0.38

Changes of the hoof angle influence the loading pattern of the superficial flexor tendon, the deep flexor tendon, the inferior check ligament and the suspensory ligament (O'Grady and Poupard, 2003). The strain on tendons and ligaments will be affected although in the present study we detected small changes of the hoof angle.

According to the results of this study, the length of P3 is associated with the angle of the hoof. Horses with long P3 tend to have flatter hooves. In addition, horses with a large HP3P tend to have smaller HA and P3A. This very mild correlation could be explained by the increased tension on the laminar structures of the dorsal hoof wall in hooves with acute hoof angles, leading to thickening of the soft-tissues dorsal to P3 (Linford et al., 1993).

The foot length (FL) undergoes a relatively moderate reduction of about 5–6 mm by the trimming procedure. This is because simultaneous trimming of the toe and heel region causes an extension of the surface area of the hoof in a palmar direction, thus compensating some of the length lost at the toe. This is underlined by the regression by 4–5% of the TFL% before and after trimming.

Sole thickness is a parameter which stays relatively constant; net growth between trimming is small (0.2 cm on average) so little trimming is required – this equilibrium may be due to the natural wear, which is not limited by a shoe as it is on the wall.

On the DP view, the consequence of cutting and rasping the horn walls is shown by the simultaneous shortening of the medial and lateral walls by about 5–6 mm and a reduction in FW of about 5 mm. The horn growth in this region is well illustrated by the fact that in spite of a sufficient lateral and medial extension on the shoes at the beginning, there is often a remarkable overgrowth of the horn over the outer boundary of the shoe in the palmar region of the hoof 6–8 weeks after shoeing.

Generally, this study shows what a large influence the trimming procedure has on hoof conformation. Such changes are often underestimated and could well be the explanation for mild irregularities or the short and choppy gait seen shortly after trimming and shoeing. The abrupt alteration of loading patterns in joints, tendons and ligaments needs more time for adaptation.

In both views, as expected, ANOVA of the invariable parameters showed no or small significant differences between the sessions. The differences between sessions are maximal about 0.1 cm and could therefore be neglected. The high reproducibility of the invariable measurements confirm the accuracy of the radiographic technique applied in this study, which is described in detail by Kummer et al. (2004) and evaluated by Vargas et al. (2004).

In the LM and DP views, the significant changes ($P < 0.0001$) between the variable measurements before and after trimming in both trimming sessions were very similar. The reason for the lack of significant changes in JA2 and JA3, is likely to be that these angles are mainly influenced by the loading pattern of the interphalangeal joints – the effect of trimming was too minimal to produce significant differences.

There are few studies directly comparable to the one presented here. Two studies, Linford et al. (1993) and Kane et al. (1998), investigated a population of Thoroughbred racehorses. Their values were consistently lower than those measured in this study. This circumstance can be explained by the very different occupation, height, body size and weight, shoeing strategies, and genetic of Thoroughbreds. Turner (1992) also found lower values – DWL in his study averaged 8.9 cm, compared to 9.5 cm seen in this study (after trimming). However, he did not precisely define the most proximal end of his measurements, so the results are somewhat difficult to compare. From his studies, he also concluded that other factors apart from size and trimming status that can have an effect on hoof parameters, particularly DWL, are the horse's use and its weight.

The correlation between weight and DWL was also studied by Balch et al. (1991), who published guidelines relating weight to DWL. The measurements of Verschooten et al. (1989), comparing parameters of sound horses and horses with navicular disease, were clearly larger than the ones presented here; a possible explanation is that they did not consider the influence of the magnification through the radiographic technique. The fact that their angles correlate to the ones of this study, justifies this assumption. Angle parameters generally showed greater similarities between studies. The HA measurements in the studies by Cripps and Eustace (1999), Verschooten et al. (1989) and Kane et al. (1998) are comparable with this study's pre-trimming measurements.

FD is a parameter first described by Cripps and Eustace (1999). Their measurements were based on a marker with the most proximal end at the point below the coronary band, where the wall horn began to yield to moderate digital pressure. In the present study, the marker was positioned with the proximal end at the hairline. The different position of the marker explains the larger measurements seen here. The differences between left and right feet and the differences between the sessions were not statistically significant ($P > 0.05$). Generally, differences in FD (apart from the effect of marker placement) may be due to variations in limb loading, or as a consequence of laminitis. However, the degree of natural variation indicates that this parameter is only of limited usefulness in the early stages of laminitis.

A distinct degree of anatomical asymmetry is apparent from this study's measurements. On the left side, the invariable bony structures in the LM view LP2, LP3 and NW were significantly larger than on the right side. However, the DWL was significantly smaller ($P < 0.0001$) on the left side and the P3BA was decreased (Table 3). The measurements from the DP view parallel this finding (Table 4) and confirm the observations of Perreaux (2002). He postulated a diagonal asymmetry pattern, whereby the foal's position in utero determines its future conformation. This predisposition is exacerbated by the fact that horses at rest usually stand with the larger foot (usually also the flatter foot) slightly further forward and the smaller foot slightly back. Seventy two percent of the horses over 165 cm at the withers have two different fore feet, the larger foot on the left side grows faster at the toe than the smaller right foot, whereas the smaller foot grows faster at the heel (Perreaux, 2002). Perreaux (2002) and Meij and Meij (1980) postulated that 70–80% of the horses are 'left-handed', with a weaker right rein, and a strong preference for the left side. The percentile distribution observed in this study is absolutely in line with Perreaux (2002) and Meij and Meij (1980). The significant asymmetries seen in this and other studies could well be linked to an incidence of lameness.

Generally, the horses show only very mild correlations between the height at the withers and some invariable parameters (LP2, LP3). Significant correlations ($P < 0.05$) have also been found for some variable parameters, both before and after trimming. But most of them show $r < 0.5$ and therefore has no practical relevance. These findings were expected because of the limited size range of horses investigated in the present study (162–172 cm). Some of the correlations were described earlier in the study by Cripps and Eustace (1999).

A correct mediolateral hoof balance is essential for an equal medial and lateral loading pattern. Examining the form of the hoof capsule is very often insufficient for assessing the mediolateral orientation of the bony structures. A lot of horses have differences in medial and lateral coronet height. However, these differences, as well as those between lateral and medial wall length do not correlate with JT3. In these cases, the mediolateral position of P3 and JT3 could only be defined by evaluating a DP radiograph and comparing MP3B and LP3B, the difference between which shows a good correlation to JT3. Therefore, the shape of the horn capsule gives no indication on the mediolateral position of P3 and the coffin joint. Forms of lameness associated with inappropriate mediolateral balance include laterally distorted hooves, sheared heels, chronic heel soreness, quarter and heel cracks, bar cracks, side-bones and deep thrush (Balch et al., 1995). To solve the primary problem behind these lamenesses, the central point of treatment must be optimising the mediolateral balance of P3 according to a radiographic study.

5. Conclusion

In conclusion, this study describes radiographic measurements of the front hooves of a defined population of Warmblood horses that had no recent history or obvious clinical signs of lameness. On both views (LM and DP), about 70% of the horses had larger and flatter hooves on the left side. In addition, these measurements accurately quantify the effect of trimming on the hoof conformation of horses aged between 6 and 12 years and with a withers height of 162–172 cm.

The findings regarding the database of measurements in Tables 1 and 2, may be helpful in the diagnosis of several hoof problems and provide guidelines for correct trimming or corrective treatment of abnormal, deformed hooves.

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