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Hoof size as related to body size in the horse (*Equus caballus*)

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The study was conducted to find out the most reliable parameter of the hoof size in relation to the horse body size, exemplified in mares. The mares of four breeds belonging to different origin types were examined: Purebred Arabian, halfbred Anglo-Arabian, primitive Polish Konik and Polish Cold-Blood, 77 mares in total. The mares were four to 13 years old, classified into three age groups. Three body measurements were taken: height at withers, chest circumference and cannon circumference. The boniness index (cannon circumference to height at withers ratio) was also defined. After trimming, three left fore hoof measurements were taken: toe length, solar length and hoof width. Total length and width were calculated as a hoof solar size measure. On the basis of the parameters obtained, nine fore hoof to body dimension ratios were defined. To evaluate the results, least squares means analysis was used and correlation coefficients between body parameters (1), between hoof parameters (2), as well as between body and hoof parameters (3) were identified. The results show the hoof to body dimension ratios grow according to the increasing cannon circumference to height at withers ratio. The hoof width to chest circumference ratio was found to be a useful parameter of the hoof size. The means (%) obtained (5.93±0.10, 6.41±0.08, 6.56±0.11 and 7.26±0.09 in Purebred Arabian, Anglo-Arabian, Polish Konik and Polish Cold-Blood horses, respectively) are suggested as standards to which individual ratios in mares of similar breeds may be compared judging the horse's conformation. The age hardly affected the hoof solar size to height at withers ratio in mares four to nine years old.

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The hoof size is influenced, apart from genetic factors, by many environmental effects, of which nutrition is the most important. It has been documented that weanlings fed *ad libitum* with balanced ration had bigger hoof sole border than those which had limited access to the same feed [Butler and Hintz 1977]. Heritability coefficient of hoof conformation traits ranges from 0.16 for heel height to 0.27 for hoof shape [Ducro *et al*. 2009a]**.** Normal functioning of the hoof depends to a large degree on its size. The hoof should be a strong support for the horse's body mass. Thanks to the concave sole, wedge-shaped frog and the sharp-angled toe, it reduces slipping. The hard hoof capsule protects soft inner structures. Concussion forces occurring during movement, particularly high in fast gaits and jumps on hard surface, are reduced by the elastic structures in the hoof. A too small hoof is not able to fulfill these functions effectively and contributes to foot lameness [Redden 1997]. The rider considerably increases the natural fore hoof strain and concussion in the movement [Clayton 1997, Summerly *et al*. 1998, Clayton *et al*. 1999]. Draught use of the horse additionally loads the hooves, as well. The relation between the foot conformation and sport performance or movement traits is pointed out in the recent publications by Ducro *et al*. [2009 ab] and van Heel *et al*. [2010]. However, the importance of the size of the hoof has not been investigated extensively.

Despite all the arguments for big hooves, in some breeds they were once considered as incorrect. According to Butler [1995], some American breeds were even selected for small feet for aesthetic reasons. On the other hand, in many breeds the hoof size is not the official selection criterion (e.g. in Poland) and that is the reason for which the small hooves appear more frequently in the population. Instead, in show horse breeds there is a tendency to lengthen the hooves to achieve flashy gaits. It has been documented that lengthening of the hoof increases the maximum height of the hoof in the flight, increases the vertical velocity of the hoof and delays the breakover [Balch *et al.* 1994]. Some breed and show associations specify the maximum hoof length (measured on the dorsum of the front wall) with regard to the horse body weight to prevent horse abuse [Lessiter 1996]. However, it does not concern the natural size of the capsule but the method of trimming.

Apart from the length, the hoof size is usually judged subjectively. There is no commonly assumed parameter which would show univocally whether the hoof is big or small relative to the horse's size. It is necessary to point which hoof is considered since in spite of high correlation between the fore and rear hoof dimensions, differences related to specific functions of fore and hind limbs are known [Back *et al*. 1995, Gustĺs *et al*. 2004]. The hoof absolute size is measured in various ways. The width is the most characteristic hoof dimension with respect to the breed [Stachurska *et al*. 2008]. The horse body size may also be specified in various parameters. The body weight seems to be the most convenient, but not very useful because of limited access to the animal scale. Estimating the horse body weight with a tape is not accurate since horse types and breeds are widely differentiated. For instance, chest circumference

in horses of same weight but different type can differ. The horse condition may also affect the result.

Turner [1992] suggested to use the maximum body weight (*B*, lb) to coronary rim circumference (*C*, inch) ratio as follows: $B = 78 \times C^2 / 12.56$. If in the formula we use centimeters and kilograms as units, a horse of 550 kg body weight should have the coronary rim of at least 35 cm. However, accurate measuring of the coronary rim also seems difficult. Sasimowski *et al*. [1994] found the hoof ground surface outline to height at withers and to body weight ratios varied considerably in different breeds of small horses and ponies: from 64.3 to 79.4% and from 26.9 to 32.9%, respectively. Kummer *et al*. [2005] found some mild positive correlations between the hoof parameters and the horses' height at withers.

In the analysis of the hoof size relative to the body size, besides various types of horses, the age of animals should be taken into account. The size of the hoof raises up to the age of six years and bigger hooves in older horses grow slower. The hoof wall length grows 0.5 mm daily in sucklings and 0.2 mm in adults [Butler 1995]. In addition to the size, the shape of the capsule is important in fulfilling the functions of the hooves.

The study aimed at determining the fore hoof to body dimension ratios and correlations between these two groups of values. Another objective was to define the most reliable parameter of the hoof size in relation to the body size, which could be easily used in judging the horse's conformation and applied in the selection improving the hoof size.

Material and methods

The mares of four breeds belonging to different origin types were examined: Purebred Arabian (PA, n=18) and halfbred Anglo-Arabian (AA, n=25) of warmblood type, Polish Konik (PK, n=12) of primitive type and Polish Cold-Blood (PCB, n=22), 77 mares in total. The mares were the property of big Polish studs: Janów Podlaski, Florianka (Roztocze National Park in Zwierzyniec) and Nowe Jankowice. The study was performed exemplified in the mares in order to investigate homogenous groups big enough for statistical analysis. The mares were classified to three age groups: 4-6, 7-9 and 10-13 year olds. To determine the size and boniness of the horse, the following body traits were measured:

– height at withers (with a stick, 1 cm accuracy);
– chest circumference (with a tape, 1 cm accuracy);
– left fore cannon circumference (with a tape, 0.5 cm accuracy).

Index of boniness (%) was calculated as the left cannon circumference to the height at withers ratio.

In all the mares the following traits of the left fore hoof were measured with a caliper, after trimming, with a 1 mm accuracy:

– toe length (from the coronary rim to the centre of the toe);
– hoof solar length (from the centre of the toe to the heel buttress line not including the heel bulb);
– hoof width (at the solar side at the widest part of the hoof).

To assess the solar size of the hoof, the total hoof solar length and width was calculated. Based on the hoof and body dimensions, nine following ratios (%) illustrating the relative hoof size, were determined:

– toe length to height at withers;
– hoof solar length to height at withers;
– hoof width to height at withers;
– total hoof solar length and width to height at withers;
– toe length to chest circumference;
– hoof solar length to chest circumference;
– hoof width to chest circumference;
– total hoof solar length and width to chest circumference;
– total hoof solar length and width to cannon circumference

Least squares means analysis of variance of the body and hoof traits, as well as the hoof to body dimension ratios, was performed with the SAS programme [2003] considering the breed and age of the horse as constant factors and the error effect as random factor. The results of the analysis are presented in Least Squares Means (LSM) and Standard Errors (SE). Correlation coefficients (*r*) between body traits (1), between hoof traits (2), and between body and hoof traits (3) in breeds in total were calculated with Pearson's procedure.

Results and discussion

The data presented in Table 1 show considerable differences in body and fore hoof parameters between breeds. The breeds are arranged in Tables according to the growing boniness index. In the resulting order, bigger PA mares are placed first and smaller PK mares as third, since the former had relatively thinner cannons than the latter. The same arrangement was applied while analysing the hoof to body traits ratios. The hooves of PCB differed the most in the absolute size.

The body dimensions were highly correlated with one another, particularly the chest with cannon circumferences (Tab. 2). The correlations within hoof traits came out to be even higher.

Taking into account three body dimensions, the cannon circumference correlations with the hoof size were the highest, the chest circumference correlations with the hoof traits were lower and respective height at withers correlations the lowest (Tab. 3). Considering hoof dimensions relative to the body traits, the highest *r* values concerned the hoof width, as well as the total hoof solar length and width. All the *r* values were found significant.

Table 1. Least squares means (LSM) and standard errors (SE) for body parameters and hoof parameters

Breed	N	Body parameters								Hoof parameters							
		height at withers (cm)		chest circum-ference (cm)		cannon circum-ference (cm)		index of boniness (%)		toe length (mm)		hoof solar length (mm)		hoof width (mm)		total hoof solar length and width (mm)	
		LSM	SE	LSM	SE	LSM	SE	LSM	SE	LSM	SE	LSM	SE	LSM	SE	LSM	SE
PA	18	149.4	0.9	185.5	1.8	18.3	0.2	12.3	0.1	78.3	1.8	113.5	1.6	110.3	1.5	223.8	2.6
AA	25	161.1	0.7	193.9	1.4	20.5	0.2	12.7	0.1	86.4	1.4	125.5	1.2	124.3	1.2	249.9	2.0
PK	12	134.8	1.1	169.6	2.0	17.7	0.2	13.1	0.1	79.2	2.0	121.3	1.7	111.1	1.6	232.4	2.7
PCB	22	159.2	0.9	227.6	1.6	26.5	0.2	16.7	0.1	105.0	1.7	160.9	1.4	164.8	1.4	325.7	2.3

PA – Purebred Arabian; AA –Anglo-Arabian; PK – Polish Konik; PCB – Polish Cold-Blood.
N – number of horses.
All interbreed differences significant at P≤0.01except for those between PA and PK in toe length and hoof width.

Table 2. Correlation coefficients (*r*) between individual traits within the body (1) and hoof (2) parameters

1. Between body parameters		
	height at withers	chest circumference
Chest circumference	0.644	
Cannon circumference	0.572	0.921

2. Between hoof parameters		
	toe length	hoof solar length
Hoof solar length	0.862	
Hoof width	0.846	0.937

All coefficients significant at P≤0.01.

Table 3. Correlation coefficients (*r*) between body and hoof parameters (3)

Trait	Toe length	Hoof solar length	Hoof width	Total hoof solar length and width
Height at withers	0.474	0.410	0.505	0.469
Chest circumference	0.797	0.814	0.882	0.865
Cannon circumference	0.837	0.926	0.953	0.956

All coefficients significant at P≤0.01.

All ratios relating the hoof dimensions to the withers height, chest circumference and cannon circumference varied with regard to the breed (Tab. 4). The ratios grew according to the growing index of boniness in particular breeds. In PA the ratios were lower than in AA and in the latter turned out to be lower than in PK mares. The ratios in question were the highest in PCB mares. These trends were regular apart from the toe length and hoof solar length to chest circumference ratios similar in PK and PCB mares, as well as the total hoof solar length and width to cannon circumference smaller in heavy-boned PCB than in PK mares. Most differences in the ratios between breeds were significant except for the toe length to chest circumference and the total hoof solar length and width to cannon circumference. Regarding the former ratio, PA differed from other breeds, while with respect to the latter ratio, significantly different were PK mares.

The hoof to body dimension ratios were similar in consecutive age groups (Tab. 5). There were significant differences solely between 4-6 and 7-9-year old mares in the hoof solar length to the height at withers ratio, as well as in the total hoof solar length and width compared to the height at withers.

The hoof to body dimensions ratios increasing in breeds along with the index of boniness show the hoof size is related to this trait. The index of boniness describes the type of the horse by relating the cannon thickness to the height at withers. The cannon measured should not show pathological alterations. It reflects total *ossa metacarpus* and tendons circumference. Since the bone perimeter is the main factor defining the thickness of the cannon, it may be found that the hoof size related to the index of boniness results mainly from the bone dimension. Thus, there is no uniform ratio for *Equus caballus* but the hoof size should be considered with respect to the type of the horse. This is in accordance with Butler [1995] who reported that the hoof size correlated with the bone dimension. In the present study the total hoof solar length and width to cannon circumference ratio was one of the least differentiated hoof to body traits ratios with regard to the horse breed. This proportion closely related to the bone thickness and simultaneously being less variable than other ratios, additionally documents the Butler's [1995] finding. The ratio in question was higher only in PK mares. It may be suggested that thinner bones and greater hooves result from the specific origin of this primitive breed descendent from the Tarpan (*Equus caballus gmelini*) – Pruski [1959].

Table 4. Least squares means (LSM) and standard errors (SE) for hoof to body parameter ratios (%) and significance of differences between breeds

Breed	N	Toe length to height at withers		Hoof solar length to height at withers		Hoof width to height at withers		Total hoof solar length and width to height at withers		Toe length to chest circumference		Hoof solar length to chest circumference		Hoof width to chest circumference		Total hoof solar length and width to chest circumference		Total hoof solar length and width to cannon circumference	
		LSM	SE	LSM	SE	LSM	SE	LSM	SE	LSM	SE	LSM	SE	LSM	SE	LSM	SE	LSM	SE
PA	18	5.24	0.13	7.60	0.11	7.39	0.11	15.00	0.19	4.22	0.10	6.11	0.11	5.93	0.10	12.06	0.19	12.20	0.13
AA	25	5.36	0.10	7.79	0.10	7.72	0.08	15.51	0.15	4.46	0.08	6.48	0.10	6.41	0.08	12.90	0.15	12.22	0.10
PK	12	5.89	0.14	9.00	0.12	8.25	0.12	17.26	0.20	4.67	0.11	7.17	0.12	6.56	0.11	13.72	0.20	13.13	0.14
PCB	22	6.61	0.11	10.12	0.10	10.37	0.10	20.49	0.17	4.62	0.09	7.08	0.09	7.26	0.09	14.36	0.17	12.32	0.12
Total	77	5.77	0.06	8.63	0.05	8.43	0.06	17.07	0.09	4.49	0.05	6.71	0.05	6.54	0.05	13.26	0.09	12.47	0.07
PA – AA		ns		ns		*		**		*		**		**		**		ns	
PA – PK		**		**		**		**		**		**		**		**		**	
PA – PCB		**		**		**		**		**		**		**		**		ns	
AA – PK		**		**		**		**		ns		**		ns		**		**	
AA – PCB		**		**		**		**		ns		**		**		**		ns	
PK – PCB		**		**		**		**		ns		ns		**		*		**	

PA – Purebred Arabian; AA –Anglo-Arabian; PK – Polish Konik; PCB – Polish Cold-Blood.
N – number of horses.
**Interbreed difference significant at P≤0.01; *interbreed difference significant at P≤0.05; ns – interbreed difference not significant.

Few significant differences found in the ratios between particular age groups indicate that the age hardly affects the relative hoof size in mares since four years old. Since the studied age of 4-6 years, the relative hoof size was rather constant. Only the solar length, as well as the total hoof solar length and width relative to the height at withers in 7-9 year old mares still grew compared to 4-6 year old animals.

Apart from the cannon circumference which correlated with hoof dimensions the most, the hoof dimensions were much more correlated with the chest circumference than with the height at withers. Moreover, the correlation of the chest circumference with the cannon circumference occurred 1.6 times higher than that with the height at withers (Tab. 2). Thus, it turns out that for the purpose of this investigation, the chest circumference is more suitable measurement of body size than the height at withers. As it has been mentioned, the hoof width is the most characteristic dimension of the hoof [Stachurska *et al*. 2008]. Out of hoof dimensions studied presently, the highest correlations with the body size measurements also concern the hoof width. Hence, it is suggested to accept the hoof width to chest circumference ratio as a relative measure of the hoof size. The LSMs of the ratio (%) were 5.93±0.10, 6.41±0.08, 6.56±0.11 and 7.26±0.09 in PA, AA, PK and PCB mares, respectively (Tab. 4). The means are suggested as standards to which individual ratios in mares of similar breeds may be compared for selection reasons. Up to date, only visual estimation was performed, i.e. no objective measure was known to judge whether the hoof size is appropriate for the horse body size. The sex dimorphism in horses is not distinct,

Table 5. Least squares means (LSM) and standard errors (SE) for hoof to body parameters ratio (%) of age groups

Breed	N	Toe length to height at withers		Hoof solar length to height at withers		Hoof width to height at withers		Total hoof solar length and width to height at withers		Toe length to chest circumference		Hoof solar length to chest circumference		Hoof width to chest circumference		Total hoof solar length and width to chest circumference		Total hoof solar length and width to cannon circumference	
		LSM	SE	LSM	SE	LSM	SE	LSM	SE	LSM	SE	LSM	SE	LSM	SE	LSM	SE	LSM	SE
4-6-year-olds	43	5.64	0.08	8.49[a]	0.07	8.27	0.07	16.76[a]	0.12	4.42	0.06	6.64	0.07	6.46	0.06	13.11	0.12	12.49	0.09
7-9-year-olds	19	5.79	0.11	8.77[a]	0.10	8.50	0.10	17.28[a]	0.17	4.51	0.09	6.82	0.10	6.60	0.09	13.43	0.17	12.43	0.12
10-13-year-olds	15	5.87	0.13	8.63	0.11	8.53	0.11	17.16	0.20	4.55	0.11	6.66	0.11	5.58	0.10	13.24	0.20	12.48	0.14

N – number of horses.
[a]Within columns LSMs marked with the same superscripts differ significantly at P≤0.05

hence it may be expected that in males the ratios approximate those of females. For the advantages of big hooves in horses it is suggested to consider the hooves as big and favourable if the ratio exceeds the mean. Since the dimensions constituting the ratio are easy to measure, the ratio may be commonly used in estimating the horse's conformation.

Another less variable ratio was the toe length to chest circumference. Solely PA mares differed from those of other breeds, having relatively shorter toes and bigger chest circumference. However, the correlations with the toe length were lower than with the hoof width (Tab. 3), hence this ratio seems to be less applicable to measure the relative hoof size.

To conclude, the results of this study show that the hoof width to chest circumference ratio is a suitable parameter of the hoof size. The hoof to body dimension ratios grow along with the increasing ratio of cannon circumference to height at withers. The age hardly affects the hoof solar size to height at withers ratio in horses since four to nine years old.

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