

Height at the withers estimation in the horses based on the internal dimension of cranial cavity

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The investigations were carried out on 17 modern half-breed horse skulls and their metacarpal and metatarsal bones. The basal length (BL), total length (TL), internal cranial cavity dimension and maximal length of metacarpus and metatarsus and maximal lateral length of metacarpus and metatarsus were measured according to Kiesewalter and von den Driesch. During height at the withers estimation, the Kiesewalter and Vitt methods were used. The Wyrost and Kucharczyk mathematical formula was modified for height at the withers calculation ($H_{estmd} = 1.016 \times D$) in horses. All height at the withers estimation methods were statistically analysed and compared. The analysis of variance ANOVA proved the lack of significant difference between the investigated values. The results achieved using Wyrost and Kucharczyk modified method are strongly comparable to Kiesewalter methods results computed using the metacarpal and metatarsal bones measurements. The height at the withers calculated on the basis of TL slightly differs from 2 above-mentioned methods. The BL Vitt's method was the least exact. (Folia Morphol 2014; 73, 2: 143–148)

Key words: craniometry, shoulder height, horses, statistical analysis

INTRODUCTION

Height at the withers (withers height) is an important phenotypical parameter in domestic animals [30] and may be used for selection and performance, especially of the horses. Horse performance in history allowed for the assumption that large animals would have been used in cavalry troops and therefore the withers height had significant influence on horse breeding [15, 16, 29]. Withers height estimation is an important indicator in archaeozoological investigation [1, 3–5, 7–9, 11–14, 17, 21, 24–26, 28, 31–35]. Osteometric calculations of withers height in animals (horses, dogs, pigs, cattle and deer) remain the most common method [3–5, 11–14, 28, 31, 35]. Similar methods have been used and modified in anthropology [27]. In archaeozoology, Koundel-

ka [21] introduced the first method of the withers height calculation for the horses' remains. Moreover, Kiesewalter's and Vitt's method of the withers height estimation in horses is used in archaeozoology [2, 6, 9, 23, 34]. All possible methods are estimations only. For instance, the method used by Vitt indicates only the range of withers height values (Table 1). Both methods are not sufficient because of remaining animal bone condition. The majority of animal artifacts is often strongly fragmented, thus the long bones measurements cannot be used. Sometimes the animal skull or part of it (*neurocranium*) still remains intact and the internal dimension of cranial cavity (EB) measurement is accessible [5, 35]. The EB is defined as the distance between the most rostral point of *crista galli* (*ethmoideum*) and the most ventral point of *foramen*

Table 1. Shoulder height in horses estimated using various methods [cm]

Horse number	Kies. LMc	Kies. LMt	Kies. TL	EB	Vitt Mc	Vitt Mt	Vitt BL
1	170.5	166.2	182.25	173.2	160–168	160–168	160–168
2	175.85	169.5	159.84	173.6	< 168	< 168	160–168
3	168.0	172.0	150.12	165.22	160–168	160–168	136–144
4	156.2	151.7	142.29	161.3	144–152	152–160	136–144
5	150.2	149.2	140.9	154.4	128–136	128–136	128–136
6	131.7	131.5	132.84	137.9	136–144	136–144	136–144
7	141.1	140.2	142.8	142.57	136–144	136–144	136–144
8	144.5	142.1	141.7	145.5	144–152	144–152	136–144
9	165.2	163.4	160.2	165.3	160–168	160–168	152–160
10	167.5	162.4	160.2	166.3	160–168	160–168	160–168
11	170.1	169.2	164.2	168.6	< 168	< 168	160–168
12	155.4	153.2	148.3	153.1	144–152	144–152	136–144
13	149.6	148.2	142.5	150.8	136–144	136–144	136–144
14	157.3	153.2	145.3	159.2	136–144	144–152	136–144
15	167.2	169.5	163.1	170.2	160–168	160–168	152–160
16	154.2	153.7	145.3	155.1	144–152	136–144	136–144
17	162.3	162.3	157.2	153.2	160–168	160–168	152–160
Mean value	158.1	156.3	151.7	158.6	–	–	–
Standard deviation	11.9	11.8	12.2	10.7	–	–	–

Kies. LMc — withers height estimation method based on lateral metacarpal measurement; Kies. LMt — withers height estimation method based on lateral metatarsal measurement; Kies. TL — withers height estimation method based on total length measurement; EB — withers height estimation method based on internal dimension of cranial cavity measurement; Vitt Mc — withers height estimation based on metacarpal measurement; Vitt Mt — withers height estimation based on metatarsal measurement; Vitt BL — withers height estimation based on basal length measurement

magnum (basion) [5, 7, 35]. Exact measurement points indicates Figure 1. Wyrost and Kucharczyk [34] designed a new mathematical formula for withers height estimation in dogs, using the EB. This method is accurate in brachycephalic, dolichocephalic and mesaticephalic dogs [5]. Wustinger et al. [33] successfully modified and used the Wyrost and Kucharczyk's formula in roe deer (*Capreolus capreolus*) withers height estimation based on the EB. These authors demonstrated clearly the possible use of Wyrost and Kucharczyk's formula in wild-living animals' archaeological investigations. In our work, the Wyrost and Kucharczyk's mathematical formula of withers height estimation was modified for use in horses. The modified formula efficiency and its accuracy in horse's withers height calculation were proved to be accurate.

MATERIALS AND METHODS

The investigation was carried out on 17 modern saddle type half-breed horse skulls (thoroughbred × × Wielkopolski breed) and their metacarpal and metatarsal bones, both right and left. This material

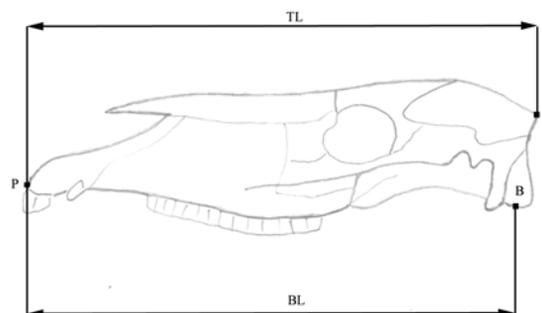


Figure 1. Craniometric measurements used in height at withers estimations; P — prosthion; B — basion; A — acrocranium; TL — total length of the skull; BL — basal length of the skull.

came from comparative collection of Department of Biostructure and Animal Physiology, Faculty of Veterinary Medicine, Environmental and Life Sciences University in Wrocław and Department of Anatomy, Faculty of Veterinary Medicine, University of Warmia and Mazury in Olsztyn. The morphometric investigations do not include the live horses. The basal length of skull (BL, *prosthion-basion*), total length of skull (TL, *prosthion-acrocranium*) (Fig. 1), and EB

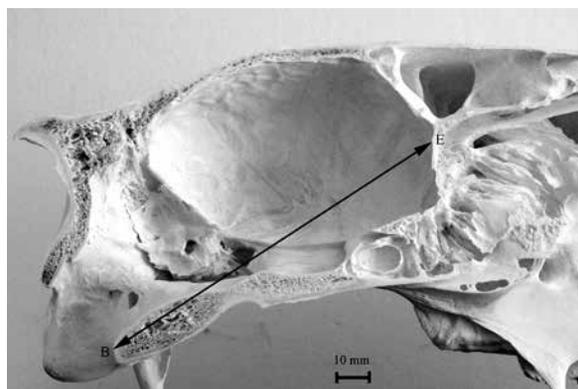


Figure 2. Craniometric measurements used in height at withers estimations; E — *ethmoideum* — the most rostral point of the *crista galli* in the median plane of the skull; B — *basion*.

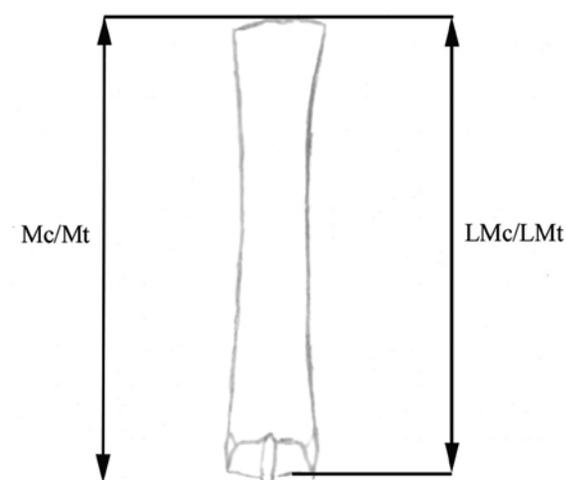


Figure 3. Osteometric measurements used in height at withers estimations; Mc/Mt — maximal length of the metacarpal/metatarsal bone; LMc/LMt — maximal lateral length of the metacarpal/metatarsal bone.

(*ethmoideum-basion*) (Fig. 2) were measured according to the craniometrical points introduced by von den Driesch [5, 7, 35].

Maximal length of the metacarpal bone (Mc) and metatarsal bone (Mt) and maximal lateral length of the metacarpal bone (LMc) and metatarsal bone (LMt) according to Kiesewalter were measured [7]:

- maximal length of the 3rd metacarpal bone and the 3rd metatarsal bone (Mc/Mt) (Fig. 3);
- maximal lateral length of the 3rd metacarpal bone and the 3rd metatarsal bone (LMc/LMt) according to Kiesewalter (Fig. 3).

The withers height estimation methods:

- Kiesewalter's method is based on LMc, LMt and TL measurements; the osteometric results should be

multiplied by 6.41 (LMc), 5.33 (LMt) and 2.7 (TL) as a multiplication factors;

- Vitt's method is based on Mc, Mt and BL measurements; the osteometric results should be compared with the values introduced by Vitt in order to estimate the range value of withers height;
- Wyrost and Kucharczyk's method is based on the EB measurement; the EB (D) is the distance between *ethmoideum-basion* (Fig. 2); the osteometric results should be computed using the modified Wyrost and Kucharczyk's mathematical formula: $H_{estmd} = 1.016 \times D$, where H_{estmd} is the estimated value of withers height, and D is the internal dimension of cranial cavity [35].

The withers height was estimated according to Kiesewalter's and Vitt's methods. Next, the results were compared with withers height calculations achieved according to modified Wyrost and Kucharczyk's mathematical formula. Statistical analysis consisted of 4 parts. The 1st part (descriptive statistics) consisted in the mean value, median, standard deviation (SD), maximum, minimum, Kolmogorov-Smirnov test (k-s test) and statistical significance estimation. The 2nd part was the withers height achieved on the basis of TL, EB, LMc/LMt measurements comparison using analysis of variance one-way variance analysis (ANOVA). The 3rd part was devoted to Pearson's correlation coefficient (r) analysis. Finally, the 4th part was the regression analysis. During the statistical analysis Prism[®] Software was used.

RESULTS

Accessible osteometric measurements (BL, TL, EB, Mc/Mt, LMc/LMt) were used in withers height estimation (Table 1). The mean value of withers height estimated on the basis of LMc is 158.1 cm, subsequently for LMt = 156.3 cm and TL = 151.7 cm. SD for the above-mentioned values equals: LMc = 11.9, LMt = 11.8 and TL = 12.2. The mean value of withers height calculated on the basis of EB is 158.6 cm and SD = 10.7. Descriptive statistics results are presented in Table 2. All the parameters are close to normal distribution, therefore the parametric statistical tests were used in further part of statistical analysis. The ANOVA proved the statistical significance $F(3, 48) = 9.86$; $p = 0.001$. Multiple comparison with Bonferroni correlation use stated the higher withers height results achieved using EB method than TL Kiesewalter's method, TL: $p = 0.007$, and similar assumption for LMc Kiesewalter's method results

Table 2. Descriptive statistics for wither height estimation methods in horses [cm]

Statistics	Kiesewalter's method			EB
	LMc	LMt	TL	
Mean value	158.1	156.3	151.7	158.6
Median	157.3	153.7	148.3	159.2
Standard deviation	11.9	11.8	12.2	10.7
Minimum	131.7	131.5	132.8	137.9
Maximum	175.9	172.0	182.3	173.6
K-S test results	0.57	0.68	0.70	0.60
Statistical significance	0.907	0.747	0.704	0.868

LMc — lateral length of metacarpal bone; LMt — lateral length of metatarsal bone; TL — total length; EB — internal cranial cavity dimension

Table 3. Pearson's correlation coefficient (r) between investigated methods

Method	Kies. Mc	Kies. Mt	Kies. TL	EB
Kies. Mc	–	0.98*	0.83*	0.96*
Kies. Mt	0.98*	–	0.80*	0.92*
Kies. TL	0.83*	0.80*	–	0.81*
EB	0.96*	0.92*	0.81*	–

*p < 0.001; Kies. Mc — withers height estimation method based on length of metacarpal measurement; Kies. Mt — withers height estimation method based on length of metatarsal measurement; Kies. TL — withers height estimation method based on total length measurement; EB — withers height estimation method based on internal dimension of cranial cavity measurement

Table 4. Regression analysis of chosen withers height estimation methods

Method	F(1, 15)	P	R ²	Beta	P
Kies. Mc	156.34		0.907	0.955	
Kies. Mt	79.89	< 0.001	0.831	0.918	< 0.001
Kies. TL	29.34		0.639	0.813	

Kies. Mc — withers height estimation method based on length of metacarpal measurement; Kies. Mt — withers height estimation method based on length of metatarsal measurement; Kies. TL — withers height estimation method based on total length measurement

and TL Kiesewalter's method, TL: p = 0.012. Other differences lacked of statistical significance. The Pearson's correlation coefficient (r) analysis between investigated withers height estimation methods is shown in Table 3. The single-sign regression analysis was carried out for 3 Kiesewalter's methods (LMc, LMt and TL) in order to EB withers height estimation method results projection. The regression analysis of the above-mentioned withers height estimation methods proved statistical significance (Table 4).

DISCUSSION

The withers height estimation belongs to the basic methods used in archaeozoology [22, 26]. The accessible literature is a source of various methods based on cranial and postcranial skeleton measure-

ments, but all of these are estimative in character. The crucial point of these investigations was the Wyrost and Kucharczyk's mathematical formula comparison to other withers height estimation methods used in horses (Kiesewalter's methods). The mean values of withers height calculated on the basis of the 3rd metacarpal bones measurements (LMc) equals 158.1 cm and subsequently 156.3 cm on the basis of the 3rd metatarsal bone (LMt). The mean value of withers height calculated on the basis of EB is 158.6 cm. The value is greater than Kiesewalter's methods results, but SD = 10.7 for EB based method is lower than Kiesewalter's methods results (LMc = 11.9, LMt = 11.8). Low SD indicates that the data points tend to be very close to the mean value of parameter.

Moreover, the Wyróst and Kucharczyk's mathematical formula used in dogs' withers height estimation proved its high accuracy to the known and intravital measured withers height [5]. Similar results brought the investigations carried out in roe deer (*Capreolus capreolus*) [33]. The modified Wyróst and Kucharczyk's mathematical formula probably gives more exact results in horses, too. The withers height mean value computed on the basis of the skull TL is lower than in other methods (151.7 cm; SD = 12.2), and therefore the least exact. Although the lowest mean value and the highest SD calculated for the latter method, the regression analysis proved strong correlation between all 4 investigated wither height estimation methods.

Lack of statistical differences between LMc, LMt and EB together with high square correlation coefficient indicates linear function of the values and allow to state the usage of the EB in withers height estimation.

Additionally, Pearson's correlation coefficient (r) indicates the withers height, calculated with modified Wyróst and Kucharczyk's formula (EB) use, is much more comparable to the results achieved with the metapodial bones osteometry (LMc and LMt), than to the withers height calculated on the basis of skull TL (Table 3).

The highest correlation proved the withers height estimated on the 3rd metacarpal bones measurements (LMc) and the EB. Similar significant correlations according to horse withers height, horse crupper height, girth, circumference of the metacarpus, live weight and the greatest length of the autopodium skeletons (*manus/pedis skeleton*) observed Komosa and Godynicki [18] in intravital and post mortal investigations. Moreover, the horse size coefficient calculated on the basis of the 3rd metacarpal and the 3rd metatarsal bones, together with the proximal phalanges, play the biggest role while assessing the height of a certain animal [19]. Latter assumption is an important proof of strong correlation between the metapodial bones and estimated withers height. The metacarpal bones based withers height and the same value based on EB is also strongly correlated ($r = 0.96$, $R^2 = 0.907$), therefore the EB based withers height method is more accurate than the skull TL based methods.

Intact cranial and postcranial horse skeleton remains occur rare, thus the EB measurement possibility seems to be more applicative in archaeozoological practice due to the artifacts conditions [2, 5–8, 34].

Finally, Vitt methodology (based on BL and metapodial measurements) allows for the range values of withers height estimation. It would not allow for any statistical comparisons, but can confirm the results achieved with other methods. The range of values was lower than the withers height calculated on the basis of other method every time. The BL Vitt's method is the least exact. It seems to be that the *neurocranium* is more invariable part of the horse skull than the *splanchnocranium*.

The morphological investigation of horse skull indicates breed variability [10, 20]. Arabian horses and thoroughbreds skull length values are similar, but Arabians have smaller and lighter head of these 2 breeds [10]. These authors suggest that this assumption is caused by relatively shorter facial length. The internal dimension of cranial cavity, as one of the *neurocranium* measurements, should be less variable than TL and therefore breed influence independent. The usefulness of presented mathematical formula should be confirmed in various horse breeds.

CONCLUSIONS

The investigations of withers height values estimated on the basis of internal dimension of the cranial cavity proved high accuracy of modified method. During the statistical analysis, the results achieved using TL and LMc/LMt methods introduced by Kiesewalter (1888) and modified Wyróst's and Kucharczyk's formula, the lack of statistically important differences and strong correlations were stated. The internal dimension of cranial cavity measurement is a valuable tool, which can be used in the height at withers estimations both in archaeozoological and morphological analyses, especially when other methods (craniometry or/and long bones measurements) are not accessible due to the skeletal material preservation status.

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