The estimation of withers height of ancient horse: New estimation formulations by using the metacarpal measurements of living horse

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SUMMARY

In this study, a total of 150 horses have been used from different modern (living) breeds. They include Arab, Thoroughbred, German-Holstein, Haflinger and Hungarian Warmblood horse breeds. Thirty individuals have been chosen (15 mares and 15 stallions) from each of these breeds. Following the withers height measurements, gender and age of the horses, the radiography of the metacarpals were taken. Metacarpal measurements were taken radiographically in third metacarpal bones of the living horses by using a mobile X-Ray device with DR System Flat Panel detector. Then, regression formulae to be used in the estimation of withers height were determined by using the metacarpal measurements. "Stepwise regression", in particular, was preferred in this analysis. Thus, models possessing the highest coefficient of determination with the least factors were formed. Also, multipliers were obtained according to the height of the withers/ greatest length and lateral length on the outer side model. These formulations and multipliers were models including joint space, muscle and skin, in relation to the formulation and multipliers reported in the very limited and debatable literary data. Therefore, the debatable points and shortcomings of old formulations obtained from montage skeletons were rectified.

Keywords: Withers height, estimation, regression, horse

NEW METHOD TO ESTIMATE THE WITHERS HEIGHT IN HORSE

Animal remains from archaeological excavations do not only provide information on animal species themselves, but also provide important clues about the economical role and human-animal relationships in past societies. Not only because of the nutritional surplus, animal bones from archaeological sites are always a matter of interest to zooarchaeologists because of the facts that they can give insights of the morphological characteristics of past animals, the diseases they were infected and so on [8, 22, 34-37]. For this reason, zooarchaeologists focus on the importance of morphological data while identifying an animal population [33]. It is attempted to estimate the withers height considering the close relationship between the length of the limb bones and the height of the animal. One of the most important methods for this purpose is the use of osteometric measurements [33].

Introduction

The domestication of horse has been regarded as an important revolution of human history [1]. Horses have always played an important role in humanity since the species was first domesticated. The social and historical development of human beings has also acquired a different dimension with the new beginning of the human-horse relationship.

There is no general agreement on the changes in size or about morphological changes brought by the domestication of the species [33]. Environmental impacts such as the effects of climate change are mentioned for some species [12], however, a significant impact of the dependency of animal farming in the later period (e.g. Roman period) can be expected [18].

RÉSUMÉ

L’estimation de la hauteur au garrot du cheval ancien : Nouvelles formulations d’estimation en utilisant les mesures métacarpiennes du cheval vivant


Mots-clés: Hauteur au garrot, estimation, régression, chevaux
The withers height is an important morphological factor in defining the animal population. This is because it allows a direct comparison of the measurements of different elements, as well as a complete understanding to the living animal without the measurement of bone lengths [31]. The measurements of the shoulder height of archaeological animals can be done by using many different formulations according to species [4, 9, 15, 19, 20, 22, 23, 26, 27, 30, 32, 42-44]. However, while applied on archaeological animal bones, it has been reported that different shoulder height formulas applied by different researchers on the same species have not revealed similar results [3, 41]. Meanwhile, among the so many factors affecting the bone length and withers height in horses (nutrition, castration, sexual dimorphism etc.) the factors relating the leg proportions are also considered. Because it is suggested that any element forming the legs in or among the species have considerable differences in the contribution ratios [25]. It is perhaps because of the effect of not having the same leg ratios between some pre- and early historic animals (e.g. horses) and modern animals [25]. Another problem could be the difficulty to distinguish metacarpal and metatarsal bones by some zooarchaeologists. In particular, when ancient remains from archaeological excavations are fragmented. In addition to the problems arising from the leg ratio between modern and ancient horses [25, 40], these formulations were either used in horses [27] which did not show different phenotypic characteristics due to a limited number of materials, a wide range of breeds [27] or not based on height of live animals but based on mounted frames (according to [2, 16, 46]) also carry some handicaps. Therefore, it is stated that estimates should not be exaggerated even if they are underestimated [25].

Although it has been reported that there are morphological differences between modern and ancient animal sizes [25, 40], the use of present-day data has always been inevitable in the identification of visible morphology from archeological horse bones [46].

Combining the necessary considerations in calculations and the errors in the original publication of Kiesewalter (especially the humerus factor) [26], von den Driesch and Boessneck [46] offered a series of multipliers by different researchers which allow estimating the wither height.

Estimation of the withers height of the horses from the lengths of the long bones is based on two systems [24]. These systems are set forth by Kiesewalter [26] and Vitt [44], based on a simple multiplication factor obtained from the long bone to the height of the body [25]. The most significant difference between the two systems is that the lateral length of the metacarpal bone on the outer side (L1) or greatest length (GL) of the same bone is differently based on both systems. The fact that the Kiesewalter [26] method, which is widely used in zooarchaeological studies in particular, is based on the assembled skeletons (according to the explanation of Forest [16], von den Driesch and Boessneck [46], Ambros and Müller [2]), leads to a discussion of how accurately the estimate can be made.

Because, it is pointed out that some other anatomical formations of horses such as joint cartilage, articular cavity, hooves, the ligaments, muscles and skin of the withers region are not used to estimate the withers height. Suggests that, the factors obtained by this estimation do not include all the anatomical structures [25].

The reconsideration of these formulations will only be possible through the use of living individuals, including all anatomical structures, with sufficient and different phenotypic distribution of distinct breed. For this purpose, we have used enough modern examples of different horse breeds. There are many factors in metacarpal preference. It is reported that, if the distal epiphysis of the Mc-III is 10-15 months old [6, 7, quoted 17], the length of the horse Mc-III is not affected by subsequent training conditions [48]. Also, beside having paleo-environmental differences on metapodia [5], it is also important that problems relating the locomotor system occur mostly on forelimbs specially at lower extremities [39]. In the case of young race horses, metacarpal is the bone in which changes in shape are observed the most in response to training [10, 28, 29, 47]. For this purpose, the modern horses were taken over the developed bone and it is attempted to present the formulations with the highest determinative properties.

Materials and Methods

In this study, a total of 150 horses have been used from different modern (living) breeds. They include Arab, Thoroughbred, German-Holstein, Haflinger and Hungarian Warm blood horse breeds. Thirty individuals have been chosen (15 mares and 15 stallions) from each of these breeds. The withers height measuring stick was placed on the ground perpendicularly and it was measured at the left hand side of the horse. Following the withers height measurements of the horses, the radiography of the metacarpals was taken. A mobile X-ray device with DR System Flat Panel detector was used in the research method called “Metacarpal radiogrammetry” [24]. The most accurate result of the metacarpal radiographs was dorso-palmar filming with the optimum focal distance from 1 meter to 90 degrees, with the horizontal angle of the cassette kept close to the extremity [47] not exceeding 5°. In this way, the accuracy of the measurements from the obtained images has been verified [47].

Radiographic images have been taken both from the right and left metacarpus and measurements were taken on them (Fig.1).
MORPHOMETRIC MEASUREMENTS FROM THE RADIOPHGRAPHIC IMAGES OF LIVING HORSES [45]

1-Greatest length (GL)
2-Greatest length of the lateral part (GL1)
3-Lateral length on the outer side (L1)
4-Medial length on the inner side (ML)
5-Breadth of the proximal end (Bp)
6-Smallest breadth of the diaphysis (SD)
7-Smallest depth of the diaphysis (DD)
8-Greatest breadth of the distal end (Bd)

The “stepwise regression” analysis was used to construct these regression formulas. In this way, p = 0.05 was taken as a criterion to add a model, whereas p = 0.1 was taken as a criterion in order to remove from the model. Although it is always possible to numerically increase the reliability in the created regression formulas, it was aimed to obtain the highest possible reliability of these formulations using minimum factors. This allowed the calculation of the withers height with the highest reliability and fewer factors.

Withers height and metacarpal measurements were assessed for the presence of sexually dimorphism with both general and race-level asymmetry (homotypic variation) [11, 48]. For this purpose, the LSM-Least Square Means test was applied to see if there was racial and gender effect on factors (multiplier or formulation) and the withers height, and metacarpal osteometric measurements from the living modern horse.

The deterministic states of the formulations available in contemporary literatures about horses have been evaluated along with the resulting multipliers and formulations in this research.

FORMULATIONS IN THE LITERATURES:

Withers height= Lateral length on the outer side (L1) x 6.41 [26, 46]
Withers height= Greatest length (GL) x 6.49 [27]
Withers height= Lateral length on the outer side (L1) x 6.48 (Draft horses) [14]
Withers height= Lateral length on the outer side (L1) x 5.81 (Arabian horses) [14]
Withers height= Lateral length on the outer side (L1) x 5.77 (Przewalski’s horses) [14]
Withers height= Lateral length on the outer side (L1) x 6.24 (Small Ponys) [14]

Results

Withers heights of 150 horses in this study are given in table I.

As a result of this study, it was determined that the difference between osteometric values of the right and left Mc-III was not statistically significant in both racial and regardless of race. Only in Arabian horses, the importance

<table>
<thead>
<tr>
<th>Horse Breeds</th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARABIAN</td>
<td>30</td>
<td>153.2</td>
<td>3.54</td>
<td>143.0</td>
<td>159.0</td>
</tr>
<tr>
<td>THOROUGHBRED</td>
<td>30</td>
<td>159.3</td>
<td>3.32</td>
<td>150.0</td>
<td>167.5</td>
</tr>
<tr>
<td>GERMAN-HOLSTEIN</td>
<td>30</td>
<td>168.1</td>
<td>4.91</td>
<td>158.5</td>
<td>176.5</td>
</tr>
<tr>
<td>HAFLINGER</td>
<td>30</td>
<td>141.0</td>
<td>3.43</td>
<td>137.0</td>
<td>152.0</td>
</tr>
<tr>
<td>HUNGARIAN WARMBLOOD</td>
<td>30</td>
<td>165.7</td>
<td>6.53</td>
<td>151.5</td>
<td>176.5</td>
</tr>
<tr>
<td>GENERAL HORSES</td>
<td>150</td>
<td>157.5</td>
<td>10.72</td>
<td>137.0</td>
<td>176.5</td>
</tr>
</tbody>
</table>

Table I: Withers heights in modern horse breeds (cm)
### Table II: Race, gender, and race×gender effects found on the characteristics of modern horses.

<table>
<thead>
<tr>
<th>Features/measurements</th>
<th>ARABIAN</th>
<th>THOROUGHBRED</th>
<th>GERMAN-HOLSTEIN</th>
<th>HAFLINGER</th>
<th>HUNGARIAN WARMBLOOD</th>
<th>SEM</th>
<th>Sex</th>
<th>SIGNIFICANT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Withers height</td>
<td>153.22&lt;sup&gt;c&lt;/sup&gt;</td>
<td>159.33&lt;sup&gt;c&lt;/sup&gt;</td>
<td>168.12&lt;sup&gt;b&lt;/sup&gt;</td>
<td>141.03&lt;sup&gt;a&lt;/sup&gt;</td>
<td>165.68&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.369</td>
<td>Male</td>
<td>158.13</td>
</tr>
<tr>
<td>Factor 1 (Withers height/GL)</td>
<td>0.554&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.540&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.581&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.579&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.577&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.001</td>
<td>Female</td>
<td>0.565</td>
</tr>
<tr>
<td>Factor 2 (Withers height/L1)</td>
<td>0.571&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.557&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.601&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.598&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.596&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.001</td>
<td>Race</td>
<td>0.583</td>
</tr>
<tr>
<td>Greatest length (GL)</td>
<td>276.60&lt;sup&gt;c&lt;/sup&gt;</td>
<td>295.47&lt;sup&gt;a&lt;/sup&gt;</td>
<td>289.58&lt;sup&gt;b&lt;/sup&gt;</td>
<td>243.65&lt;sup&gt;d&lt;/sup&gt;</td>
<td>287.13&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.781</td>
<td>Gender</td>
<td>280.46</td>
</tr>
<tr>
<td>Greatest length of the lateral part (GL1)</td>
<td>272.33&lt;sup&gt;c&lt;/sup&gt;</td>
<td>291.27&lt;sup&gt;c&lt;/sup&gt;</td>
<td>284.42&lt;sup&gt;b&lt;/sup&gt;</td>
<td>239.12&lt;sup&gt;d&lt;/sup&gt;</td>
<td>282.19&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.768</td>
<td>Race×Gender</td>
<td>275.81</td>
</tr>
<tr>
<td>Lateral length on the outer side (L1)</td>
<td>268.53&lt;sup&gt;c&lt;/sup&gt;</td>
<td>286.42&lt;sup&gt;a&lt;/sup&gt;</td>
<td>280.04&lt;sup&gt;b&lt;/sup&gt;</td>
<td>236.05&lt;sup&gt;d&lt;/sup&gt;</td>
<td>278.22&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.757</td>
<td>Male</td>
<td>271.59</td>
</tr>
<tr>
<td>Medial length on the inner side (ML)</td>
<td>267.19&lt;sup&gt;c&lt;/sup&gt;</td>
<td>285.69&lt;sup&gt;a&lt;/sup&gt;</td>
<td>279.72&lt;sup&gt;b&lt;/sup&gt;</td>
<td>235.99&lt;sup&gt;d&lt;/sup&gt;</td>
<td>277.72&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.777</td>
<td>Female</td>
<td>271.29</td>
</tr>
<tr>
<td>Breadth of the proximal end (Bp)</td>
<td>67.74&lt;sup&gt;c&lt;/sup&gt;</td>
<td>74.32&lt;sup&gt;b&lt;/sup&gt;</td>
<td>77.57&lt;sup&gt;a&lt;/sup&gt;</td>
<td>64.80&lt;sup&gt;d&lt;/sup&gt;</td>
<td>76.91&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.277</td>
<td>Male</td>
<td>73.15</td>
</tr>
<tr>
<td>Smallest breadth of the diaphysis (SD)</td>
<td>39.57&lt;sup&gt;c&lt;/sup&gt;</td>
<td>41.35&lt;sup&gt;b&lt;/sup&gt;</td>
<td>45.10&lt;sup&gt;a&lt;/sup&gt;</td>
<td>40.03&lt;sup&gt;d&lt;/sup&gt;</td>
<td>44.87&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.190</td>
<td>Female</td>
<td>42.57</td>
</tr>
<tr>
<td>Smallest depth of the diaphysis (DD)</td>
<td>31.27&lt;sup&gt;b&lt;/sup&gt;</td>
<td>34.55&lt;sup&gt;c&lt;/sup&gt;</td>
<td>33.93&lt;sup&gt;a&lt;/sup&gt;</td>
<td>28.73&lt;sup&gt;d&lt;/sup&gt;</td>
<td>34.05&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.163</td>
<td>Race</td>
<td>32.86</td>
</tr>
<tr>
<td>Greatest breadth of the distal end (Bd)</td>
<td>59.45&lt;sup&gt;c&lt;/sup&gt;</td>
<td>63.64&lt;sup&gt;b&lt;/sup&gt;</td>
<td>67.16&lt;sup&gt;c&lt;/sup&gt;</td>
<td>57.81&lt;sup&gt;d&lt;/sup&gt;</td>
<td>66.30&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.211</td>
<td>Gender</td>
<td>63.86</td>
</tr>
</tbody>
</table>

***: P<0.001; **: P<0.01; *: P<0.05; NS: Not significant

The differences between the average of the minimum squares indicated by the different letters on the same line are significant (P<0.05)

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**Table II**: Race, gender, and race×gender effects found on the characteristics of modern horses.
level of 0.05 was determined in DD (smallest depth of the diaphysis) and the P value was not evaluated statistically because it was very close to the insignificant level.

The mean of the right and left bones was used as a measurement value in all statistical calculations, since no statistically significant difference was found between the osteometric values of the right and left McIII.

Regardless of different races, there was no statistically significant difference in withers height measurements between male and female horse in general. However, LSM (Least Square Means) test was applied to determine whether racial and gender effects were present on multipliers by withers and metacarpal osteometric measurements from modern horses (Table II). When racial assessments were done, it was observed that race, gender, and race x gender (race/gender interaction) effects on the withers height as well as metacarpal measurements were at different levels for each race. The effect of the race was observed at p < 0.001 the level on the metacarpal measurements along with the wither height multipliers 1 and 2.

It was found that there was no gender effect on withers height and factors 1 and 2 at the race level, but there was an effect on other metacarpal measurements at p<0.05 and p<0.001 levels. However, regardless of racial variation, the difference between the greatest breadth of the distal end (Bd) of the female and male individuals and greatest breadth of the distal end is generally significant at p<0.05 and p<0.01 levels. It was determined that the differences between the values other than these are not statistically significant. This is probably showing the presence of racial effect.

Being the most commonly used multiplication factor in literature data, the ratio of wither height / GL (factor 1) or wither height / L1 (factor 2), was also obtained in our research according to both horse in general and horse races. Only the racial effect (p<0.001) was found on these factors.

Because of the absence of the gender and race × gender interaction effects on the withers height, which has a meaning for the whole of the living animal without bone lengths, estimations were calculated using metacarpal measurements.

Constructed statistical modeling (stepwise regression analysis) was based on longitudinal lengths of the bone (GL, GL1, L1 and ML). However, it was observed that the coefficient of determination ($R^2$), which indicates how strong the estimate of the obtained regression is, has a low or moderate determinant based on a single measurement. Therefore, it was determined that these measurements were high when other osteometric measurements (transverse measurements of the bone, e.g. SD) were incorporated into these measurements. This is showing the effectiveness of transversal measurements of the bone in the formulations which are going to be created. In particular, SD (smallest breadth of the diaphysis) was the most effective of these measurements. A regression formula was obtained, which has GL or L1 with the highest detection coefficient ($R^2$) as well as SD measurement (Table III).

Since it was based on making the wither estimation with the least reliability and the highest reliability in the statistical modeling, the estimation coefficient ($R^2$) was excluded in the analysis with other measures because it was low. When each racial is evaluated separately for wither height estimation, a different result has been obtained from the general horse regardless of racial variation. In the regression equations, the coefficient of determination ($R^2$) was observed to be low due to the insufficient number of animals in each horse race. Therefore, all the evaluations were done on the horse in general (regardless of any distinct race).

Similar values to those in table IV were obtained when a factor of the withers height and the ratio of GL and L1 were obtained. This is similar to the most commonly used factors (wither height / GL or L1) in the literature data. On these factors, the effect of the race was observed at p<0.001

<table>
<thead>
<tr>
<th>Measurements</th>
<th>Regression formula</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>GL</td>
<td>Withers height= 39.729+(0.423*GL)</td>
<td>0.674</td>
</tr>
<tr>
<td>L1</td>
<td>Withers height= 39.851+(0.436*L1)</td>
<td>0.669</td>
</tr>
<tr>
<td>GL, SD</td>
<td>Withers height= 11.399+(0.327<em>GL)+(1.304</em>SD)</td>
<td>0.802</td>
</tr>
<tr>
<td>L1, SD</td>
<td>Withers height= 10.832+(0.337<em>L1)+(1.322</em>SD)</td>
<td>0.801</td>
</tr>
</tbody>
</table>

Table III: Regression (stepwise) formulas used in predicting withers height in modern horses regardless of race

<table>
<thead>
<tr>
<th>Calculation of the factors</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Withers height / GL (Greatest length) (factor 1)</td>
<td>Withers height= 0.566*GL</td>
</tr>
<tr>
<td>Withers height / L1 (Lateral length on the outer side) (factor 2)</td>
<td>Withers height = 0.584*L1</td>
</tr>
</tbody>
</table>

Table IV: Multipliers obtained with the withers height / GL or L1 for general horses
while the effect of gender or race × gender interaction was not found. Therefore, the obtained factors at race level are given in Table V. Statistically, it is not possible to determine the reliability of these generated factors. It is a factor to be compared with the factors in zooarchaeological data. The coefficient of determination ($R^2$) cannot be obtained statistically because the result of the regression analysis is not obtained along with the contribution to the calculation of the wither height estimation with the least factors.

Using the obtained regression formulas and multipliers in the study, the difference in the estimation of the withers height of the living horses was evaluated (Table VI). Using the regression formulas and multipliers generated by using metacarpal measurements (GL, L1 and SD), the difference between the mean estimated wither heights was found to be 0.06 cm (Table VI). This value was quite low in terms of the estimated real value.

In our study, the regression coefficients and multipliers revealed that the withers height is increased to "cm" as a result of using the “mm” value of the metacarpal measurements directly. For example if the multiplier (factor) 1 is used as 5.66, then the wither height is resulted in mm. This is also preferred that the obtaining result is more suitable for use on the cm.

**Discussion**

Withers height is an important morphological factor in terms of defining the animal population. For this reason, visual morphological feature is most emphasized by zooarchaeologists. This is because it allows a direct comparison of the measurements of different individuals, as well as the complete idea on a living animal as a whole without the bone lengths [33]. The withers height is considered to be a more indicative indicator of the size of the animal population [18] along with many known factors (e.g., nutrition, castration, sexual dimorphism) that may affect the relationship between bone length and withers height [25]. Because length measurements from different bones can be used as a single example when they are converted into withers height [33].

The use of modern horse data for estimating the withers height may be very useful with some related problems [25, 40] as well as the intra-population variation of computational errors [46]. For the modern breeds, 200 to 250 mm difference range is an acceptable condition [46].

Except for leg-related problems [25, 40] between modern horses and ancient horses, estimating the withers height of past horses is still possible with the help of modern horse data. Predictive formulations based on the mounted skeletons (according to Forest [16], von den Driesch and Boessneck [46], Ambros and Müller [2]) or estimating formulations not based on a broad range of phenotypic properties may result in lower values for the withers height [25]. This is because, joint space as well as anatomical formations such as joint cartilage, synovial capsule, ligament, skin, muscle, hoof etc. are not considered in these calculations [25]. An estimating calculation of all these anatomical formations and parts are at the base of this research. Correlation between the radiographic bone images taken from living horses according to the normal posture of the feet and the withers height was seen as a correct approach. The metacarpal bones

<table>
<thead>
<tr>
<th>Factors</th>
<th>TOTAL</th>
<th>ARABIAN</th>
<th>THOROUGHBRED</th>
<th>GERMAN-HOLSTEIN</th>
<th>HAFLINGER</th>
<th>HAUNGARIAN WARMBLOOD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factor 1 (Withers height / GL)</td>
<td>0.566</td>
<td>0.554</td>
<td>0.540</td>
<td>0.581</td>
<td>0.579</td>
<td>0.577</td>
</tr>
<tr>
<td>Factor 2 (Withers height / L1)</td>
<td>0.584</td>
<td>0.571</td>
<td>0.557</td>
<td>0.601</td>
<td>0.598</td>
<td>0.596</td>
</tr>
</tbody>
</table>

**Table V:** Multipliers obtained with the withers height / GL or L1 according to races

<table>
<thead>
<tr>
<th>Regession formula and factors</th>
<th>Live WH (cm)</th>
<th>Estimated WH (cm)</th>
<th>Difference (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>39.729+(0.423*GL)</td>
<td>157.48</td>
<td>157.53</td>
<td>0.05</td>
</tr>
<tr>
<td>11.396+(0.327<em>GL)+1.304</em>SD</td>
<td>157.48</td>
<td>157.46</td>
<td>-0.02</td>
</tr>
<tr>
<td>39.850+(0.436*L1)</td>
<td>157.48</td>
<td>157.50</td>
<td>0.03</td>
</tr>
<tr>
<td>10.829+(0.337<em>L1)+(1.322</em>SD)</td>
<td>157.48</td>
<td>157.53</td>
<td>0.05</td>
</tr>
<tr>
<td>Factor 1: 0.566*GL</td>
<td>157.48</td>
<td>157.62</td>
<td>0.14</td>
</tr>
<tr>
<td>Factor 2: 0.584*L1</td>
<td>157.48</td>
<td>157.59</td>
<td>0.12</td>
</tr>
<tr>
<td>Mean</td>
<td>157.48</td>
<td>157.54</td>
<td>0.06</td>
</tr>
</tbody>
</table>

**Table VI:** Differences in withers height estimation of the living horses using the obtained regression formulas and multipliers
were preferred for this study because of their high availability in archaeological sites as well as the fact that the length of the horse McIII is not affected by subsequent training conditions [48] following the fusion of distal epiphysis of the McIII at 10-15 months [6, 7, quoted 17] or older than this age.

It is reported that there are morphological differences between the right and left homotypic bones of the same individual [11, 13, 21, 38]. Expressed as a homotypic variation, this asymmetry is reported to be a condition that affects the performance on right and left turns in racing horses [11, 38]. As this study has evaluated the presence of such an asymmetry condition in modern horses in both general horses as well as racial levels, it has been found that both at general and racial levels, the difference between the osteometric values of right and left McIII were not statistically significant. The averages of osteometric values of right and left McIII have been used because of the withers height were measured and radiographic images were taken according to normal position of horses as well as there was no statistical observation of homotypic variation.

No statistically significant difference was found between the withers height when general horses were evaluated regardless of racial observation in our study. Statistically, no sexually significant differences have been found in both general and racial horses in the calculation of this study or most commonly used literatures [14, 26, 27, 46] on the withers height / GL (factor 1) or withers height / L1 (factor 2) values. This was also due to the lack of sexual dimorphism between the withers height in both female and male horses.

Considering the measurement points, we found that the values of withers height / GL (factor 1) and withers height / L1 (factor 2) in our study were lower than those given in the literature (Table VII).

It is known that the measurement points of the multipliers (such as L1) are specified by Eisenmann [14], however, no information is available whether the withers height was taken from live or mounted skeletons. However, the established multiplier for Arabian horses as 5.81 is quite close to the value we find in Arabian horses (5.71). At the same time, regardless of racial distinction, the multiplier of the general horses (5.84) was almost close to each other.

Alongside of Eisenmann’s [14] multipliers on the Arabian and Przewalski horses, there is a clear difference between the obtained metacarpal based estimation of multipliers from this study and two systems [26, 43] of metacarpal based multipliers estimation still commonly used by zooarchaeologists. This difference is about 12 cm with Vitt [43] multiplier based on GL measurement, and about 15 cm with Kiesewalter [26] multiplier in respect to L1 measurement. The multipliers obtained in our study reject this exaggerated estimation.

While estimating the withers height, the stepwise regression analysis obtained in our study showed that GL and L1 length measurements were more predictive than other length measurements (GL1 and ML). However, it was observed that the coefficient of determination (R²), which indicates how strong the estimation of the obtained regression is, has a low or moderate determinant based on a single measurement (Table III). It was therefore determined that these measurements were high when the other osteometric measurements (transverse measurements of the bone, e.g. SD) were incorporated. In the generated stepwise regression formulas, SD measurement was found to be more efficient than other transversal measurements. The determination value of formulations containing SD or together with GL or L1 measurement was 80 %. This would have been increased if the number of animals had been even more.

The average 0.06 cm difference between the estimated withers height using the multipliers and formulas obtained.
in the study and the withers height of the living animal is actually quite low. This is also important in the way that obtained multiplications and formulations by considering other anatomical factors of the horse (such as articular cartilage, articular cavity, hoofs, muscle and skin of the wither region) show more accurate results.

Conclusions

In conclusion, it is necessary to include all the anatomical parts in the estimation of wither height formulas and multipliers which are obtained by using horse metacarpal measurements. Although the result of the regression analysis (of withers height/GL; withers height/L1) factor in this study as well as the coefficients of determination are unknown, the other metacarpal factors are more reliable in terms of inclusion of all anatomical structures [26, 27, 43]. As a result of the regression analysis, in particular the GL and L1 length measurements are more effective. However, the coefficient of occurrence is increased by adding SD from the transversal measurements in the formulations. Therefore, we believe that the SD should always be taken into account in the intended estimation. However, one thing should not be forgotten is that, it is necessary to osteometrically elaborate the leg ratios (lower and upper extremity bones) when evaluating the body conformation of the horses. In this way, it is necessary to know the withers height as well as which bone parts are and how much active are the distinct bones bone parts in visible morphology. Therefore, we think that it would be useful to put forward the structural ratios of the different bones of modern horses and the leg ratio of the past horses in the evaluation and expansion of these formulations.

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Conflict of interests

The authors declare that there is no conflict of interest regarding the publication of this paper.

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NEW METHOD TO ESTIMATE THE WITHERS HEIGHT IN HORSE

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