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Interaction of talus and calcaneus morphometric values and estimation of carcass weight in cattle

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Abstract

In this study, the calcaneus and talus bones of 20 male and female adult Simmental and Angus cattle were used. The age and sex of these animals were recorded before slaughter, and carcass weights were taken after slaughter. Calcaneus and talus morphometric measurements were used to obtain multipliers that allow the estimation of the carcass weight. These multipliers were found to be mean values of 3.346 and 4.642, respectively. Thus, multipliers were obtained that can be used in the evaluation of chronological differences in archaeological cattle size and consequently carcass weight. LSM (Least Square Means) analysis of calcaneus and talus GL values revealed the effect of sex but not of breed. Proportional factors were obtained for calcaneus and talus pairings and associated bone size (GL) estimates.

KEYWORDS
calcaneus, carcass estimation, cattle, morphometry, talus

1 | INTRODUCTION

The talus and calcaneus are the proximal row bones that form the articulus tarsi, the compound joint (*articulus composita*) in the hind feet of domestic animals (Liebich et al., 2004). Talus is localized on the medial side of the joint and calcaneus on the lateral side (Budras & Habel, 2003).

The talus has always been a bone that has attracted the attention of mankind with its structural features and shape. It is found in archaeological sites not only as an ecofact in the form of butchery waste, but also as an artefact, a different cultural material processed to be used for different functions. (Lowrey, 2014; Renfrew & Bahn, 2012; Russell, 2012). Therefore, worked talus (Knucklebones) are mostly composed of talus of various artiodactyls (Lowrey, 2014; Mazzorin & Minniti, 2013). The choice of animal in processed talus depends on the specific characteristics of animal exploitation at the site. For this purpose, ruminant talus is generally preferred over talus of other species because of their clear cognitive and symbolic meaning (Gál, 2010) and their unique characteristics (Dandoy, 1996; Gilmour, 1997; Russell, 2012).

The talus bone, which was found in the excavation sites as a material for butchery and consumption as well as for cultural purposes, and the calcaneus, which is associated with the tarsal joint, are less damaged than the other bones due to their compact structure in terms of strength. Despite their undamaged condition, these skeletal elements were used relatively less frequently in the estimation of visual morphological characters such as shoulder height. Instead, more numerous long bone measurements have been used to estimate carcass heights (von den Driesch & Boessneck, 1974) or body weight (Anyonge, 1993). However, the estimation of carcass weight in ruminants such as cattle, which are at the forefront of nutrition, has not been emphasized so far.

Carcass and carcass quality in cattle are among the most important factors determining meat yield and are important for breeders and consumers (Ateş & Akbaş, 2022). This positive relationship between meat yield and carcass quality allows obtaining quality meat and meat products from quality carcasses (Şeker et al., 2017). Today, although beef consumption varies according to geographical regions (Santich, 2014), these animals constitute one of the important sources of meat consumption (Ateş & Akbaş, 2022). In the ancient and early medieval world, meat consumption was socially attributed to the upper class or to special occasions related to religious practices such as sacrifices or even communal feasts (Santich, 2014). However, over the years, beef started to have an important place in the diet of everyday society along with other animal species. For example, by the 5th century AD, meat had ceased to be a sacrificial product and became a product ready for human use and was included in the traditional diet (Santich, 2014). For this purpose, the breeding of prime meat-producing animals has gained importance (Herring, 2014).

The zooarchaeological data obtained from excavations in Anatolia show that the consumption of beef and its products was actively practised in every period. Cattle have become an economically important animal for agricultural societies, not only for their meat but also for their skin, milk, dairy products and especially for their combined labour force such as being used for ploughing and carrying loads (Baykara-Silibolatlaz, 2019).

Since the cattle trade is priced based on the value of carcass weight and this method is referred to as 'beef' sales, carcass estimation by visual assessment of live animals has generally been practised (Lonergan et al., 2019). However, estimates based on the bones did not go beyond estimates of body weight or body height (Anyonge, 1993; von den Driesch & Boessneck, 1974). Apart from carcass weight or visual morphological estimates, both the minimum number of animals and the matching of bones for the same animal have always been questions in archaeological studies (Chaplin, 1971). The effect of sexual dimorphism on these bones and the estimation of carcass weight in cattle by using morphometric measurements of calcaneus and talus bones forming the same joint have been discussed in this study. The study tried to obtain factors that will facilitate the estimation calculations by making carcass weight estimates, which are important in terms of meat production, by matching talus and calcaneus for the same individuals in archaeological sites.

This study aimed to estimate carcass weight and thus meat weight by using morphometric measurements of calcaneus and talus bones of contemporary Simmental and Angus breed male and female adult cattle. It can contribute to our understanding of the meat production and consumption of past societies based on the talus and calcaneus bones of cattle recovered from archaeological sites.

2 | MATERIALS AND METHODS

In this study, 20 female and 20 male cattle of Simmental and Angus breeds, which are suitable for the meat production in Türkiye (Herring, 2014; Kayar & İnal, 2019), were used. All animals used were adults (4–7 years old). The age and sex of these animals were recorded before slaughter and carcass weights were taken after slaughter. Right and left talus and calcaneus were subjected to maceration by boiling method (Onar & Kahvecioğlu, 1999).

Morphometric measurements of the talus and calcaneus of each animal were taken. Morphometric measurements were based on (von den Driesch, 1976).

Morphometric measurements (Figure 1):

Talus.
GL: Greatest length of the lateral half.
Bd: Greatest breadth of the distal end.
Calcaneus.
GL: Greatest length.
GB: Greatest breadth.

Using the morphometric measurements, an index was calculated for each bone. These index values were given as talindex for talus and calindex for calcaneus.

$$\text{Index} = \text{GB (Bd)} / \text{GL}$$

All morphometric measurements of the bones were used to check for homotypic variation between right and left bones. When the student *t*-test was applied between right and left bone morphometry, no statistical difference was observed. For this reason, the left bones were evaluated in the evaluation. Regression analysis and factor calculation were performed to reveal the relationship between GL measurements of talus and calcaneus. Also, regression analysis and factor calculation were performed to be used in carcass weight estimations. SPSS 21.0 program (Version 21.0, SPSS Inc., Chicago, IL, USA) was used for statistical analysis.

Apart from regression analysis, talus and calcaneus GL measurements were ratioed to carcass value to obtain multipliers for both talus (talfactor) and calcaneus (calfactor). The obtained factors were calculated with the following formulation:

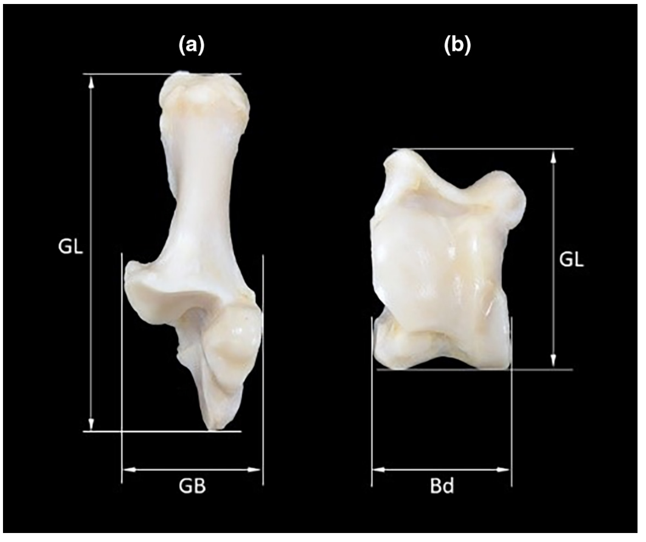

FIGURE 1 Morphometric measurements. (a) Calcaneus; GB, greatest breadth; GL, greatest length; (b) talus. GL: greatest length of the lateral half, Bd: greatest breadth of the distal end.

$$\text{Talfactor} = \text{Carcass weight (kg)} / \text{Talus GL}$$

$$\text{Calfactor} = \text{Carcass weight (kg)} / \text{Calcaneus GL}$$

In order to estimate the calcaneus and talus GL values depending on a value, the ratio of Calcaneus GL and Talus GL was calculated. Thus, a multiplier (Calcaneus GL/Talus GL) was obtained for the other GL estimation depending on a known GL value from the calcaneus or talus.

After the talus and calcaneus mean and standard deviation values were calculated, the Shapiro–Wilk test was used to check whether the measurements were normally distributed (George & Mallery, 2010). Independent-samples *t*-test was used to check the significance of the difference between the mean values of both sexes and between the mean values of the right and left bones. The least square means (LSM) test was applied to see whether there was an effect of sex and breed on the carcass weight and morphometric measurements index and factor values obtained.

The statistical data obtained are presented in tables Nomina Anatomica Veterinaria (2017) was used as a basis for writing the study.

3 | RESULTS

Carcass weights of the cattle used in the study according to both breeds and sex are given in Table 1.

No effect of breed or sex was observed in the LSM test on carcass weight. This effect was reflected in the mean values of sex and breed. Differences between mean values were not statistically significant (Table 1).

In the LSM test on calcaneus values, an effect of sex was observed, while an effect of breed (except calfactor) was not found. The effect of sex was observed on GL and calfactor values. The difference between the mean values of GL and calfactor between male and female was significant at $p < 0.05$ level (Table 2).

While a relative effect of breed on calfactor was observed in the LSM test, this effect value was found to be at the exact limit of $p < 0.05$. However, there was no difference between the mean values of calfactor values of calcaneus according to specific breed when Independent-samples *t*-test was applied.

As a result of the LSM test on the GL value of talus, it was observed that sex had an effect while breed had no effect. Independent-samples *t*-test was applied to check the significance of the difference between the mean values of GL values of female, male and breed. As a result of this statistical evaluation, it was observed that the difference between female and male cattle was significant at $p < 0.05$ level, while the difference between the mean values for each cattle breed was not statistically significant (Table 3).

Only the effect of breed on the talus BD value was observed with the LSM test. No effect of sex was found. This means that the difference between the mean values of the breeds was significant at $p < 0.05$ level in the significance control using Independent-samples *t*-test and it was observed that Simmental breeds had a larger value (Table 3).

Only sex had an effect on the talus factor. While this was determined by the LSM test, no effect of breed was found. When Independent-samples *t*-test was performed between the sex mean values, it was seen that the mean value differences were significant at $P < 0.05$ level. The talfactor value, which is considered to be used in carcass weight estimation, was found to be higher (4.795) in males than females (Table 3).

The LSM test on the talus index showed that both sex and breed were effective. Independent-samples *t*-test between mean values showed that these differences were significant at $p < 0.05$ level (Table 3).

When the ratio of calcaneus GL and talus GL was calculated, an average value of 1.940 was obtained (Table 4). These data were useful for estimating the GL of one of the two bones relative to the GL of the other. The LSM test on this value showed that breed and sex had no effect.

No statistically significant correlation was observed between carcass weight and calcaneus and talus mofometric values (Table 5). Although a negative correlation was observed between carcass weight and calcaneus, it was not statistically significant. Since the desired high correlations between carcass weight and calcaneus and talus morphometric values were not detected, regression equations for carcass weight estimation could not be established. Because the level of determination (R2) of the regression equations was obtained at very low levels. For example, in the regression equation formed by using calcaneus GL and BD value, the level of determination (R2) was obtained as 0.049, which is quite low.

TABLE 1 Carcass weights by sex and breed (kg).

	Mean	N	SD	Minimum	Maximum
Sex					
Female	384.7^{NS}	20	16.8	352.0	418.0
Male	393.1^{NS}	20	20.8	360.0	425.0
Breeds					
Angus	392.9^{NS}	20	15.1	367.0	423.0
Simmental	384.9^{NS}	20	22.1	352.0	425.0
Total	388.9	40	19.1	352.0	425.0

Abbreviation: NS, Not significant.

TABLE 2 Calcaneus morphometric data (mm) and factor and index values.

Sex/breeds	Statistical	GL	GB	Calfactor	Calindex
Sex					
Female	Mean	166.1*	54.9NS	2.322*	33.08NS
	N	20	20	20	20
	SD	8.5	3.5	0.163	2.07
	Minimum	142.9	49.6	1.999	28.87
	Maximum	177.9	63.5	2.573	36.90
Male	Mean	159.4*	53.4NS	2.470*	33.57NS
	N	20	20	20	20
	SD	6.8	2.8	0.158	1.90
	Minimum	147.4	49.3	2.158	29.38
	Maximum	171.5	58.9	2.752	37.04
Breeds					
Angus	Mean	161.1NS	54.1NS	2.446NS	33.62NS
	N	20	20	20	20
	SD	8.3	3.5	0.170	2.19
	Minimum	147.4	49.3	2.113	28.87
	Maximum	177.9	63.5	2.752	37.04
Simmental	Mean	164.4NS	54.2NS	2.346NS	33.03NS
	N	20	20	20	20
	SD	8.2	3.1	0.170	1.7
	Minimum	142.9	49.5	1.999	29.38
	Maximum	177.2	59.3	2.600	35.69
Total	Mean	162.8	54.2	2.396	33.33
	N	40	40	40	40
	SD	8.3	3.2	0.175	1.98
	Minimum	142.9	49.3	1.999	28.87
	Maximum	177.9	63.5	2.752	37.04

Abbreviation: NS, Not significant.
*$p < 0.05$.

Although there were positive correlations between calcaneus and talus morphometric values at $p < 0.01$ level, the correlation coefficients indicating the extent of the relationship between them were moderate.

4 | DISCUSSION

Carcass and carcass quality is one of the most important factors affecting meat yield in cattle (Ateş & Akbaş, 2022). Therefore, age, sex and breed of the animal are important factors (Şireli, 2018). A positive correlation was found between carcass muscularity class and the animal's age, and it was concluded that sex and age affect carcass yield and muscularity class (Jukna et al., 2009). In this study, two different cattle breeds that are important in terms of meat yield (Herring, 2014) were used. The Angus and Simmental breeds used were adult cattle with the interaction between post-slaughter carcass weights and the talus and calcaneus from the tarsal bones of these animals evaluated. In addition to carcass estimation, the relationship between two bones complementing the same joint was also evaluated.

As a result of LSM analysis, it was observed that breed and sex had no effect on carcass weights of cattle. This is likely to be due to the fact that both breeds used in the study have almost similar visual morphology. Although the existing literature studies (Jukna et al., 2009; Şireli, 2018) mentioned an interaction between breed and sex, the differences between male and female cattle were not statistically significant in this study.

In order to establish a relationship between carcass weight and morphometric values of calcaneus and talus, the effect of breed and sex on the morphometric values of these bones was determined by LSM test. There was an effect of sex on calcaneus and talus GL values. Although no effect of breed was observed, it is possible that the sexes in different cattle types of influence body conformation (Bene et al., 2007).

The basis of animal production is in the breeding herd. Animal selection is of great importance in determining the desired carcass composition for high productivity (Kutz, 2023). This contributes

TABLE 3 Talus morphometric data (mm) and factor and index values.

Sex/breeds	Statistical	GL	BD	Talfactor	Talind
Sex					
Female	Mean	85.8*	39.7[NS]	4.488*	46.22*
	N	20	20	20	20
	SD	3.8	2.2	0.247	1.50
	Minimum	78.6	35.9	3.957	43.44
	Maximum	95.0	43.8	4.899	48.61
Male	Mean	82.1*	39.2[NS]	4.795*	47.80*
	N	20	20	20	20
	SD	3.1	2.8	0.274	2.59
	Minimum	74.2	36.0	4.408	44.46
	Maximum	88.0	46.8	5.253	54.48
Breeds					
Angus	Mean	83.6[NS]	38.6*	4.715[NS]	46.25*
	N	20	20	20	20
	SD	4.6	2.0	0.329	1.88
	Minimum	74.2	35.9	3.957	43.44
	Maximum	95.0	43.8	5.253	50.20
Simmental	Mean	84.3[NS]	40.3*	4.568[NS]	47.77*
	N	20	20	20	20
	SD	3.2	2.7	0.257	2.35
	Minimum	78.6	36.7	4.011	44.75
	Maximum	88.9	46.8	5.028	54.48
Total	Mean	83.9	39.5	4.642	47.01
	N	40	40	40	40
	SD	4.0	2.5	0.301	2.23
	Minimum	74.2	35.9	3.957	43.44
	Maximum	95.0	46.8	5.253	54.48

Abbreviation: NS, Not significant.
*$p < 0.05$.

TABLE 4 Calcaneus GL and talus GL ratio.

Sex/breeds	Mean	N	SD	Minimum	Maximum
Sex					
Female	1.937[NS]	20	0.092	1.780	2.144
Male	1.944[NS]	20	0.082	1.796	2.105
Breeds					
Angus	1.930[NS]	20	0.092	1.780	2.105
Simmental	1.951[NS]	20	0.081	1.796	2.144
Total	1.940	40	0.086	1.780	2.144

Abbreviation: NS, Not significant.

greatly to the amount of meat obtained. Considering this view, it has been suggested that the linear relationship between meat yield and carcass quality (Şeker et al., 2017) is an indicator of efficiency in breeding for meat production with the ability to convert direct feed into meat in cattle as a ruminant animal (Herring, 2014). In this relationship, visual assessment of body conformation has always been preferred for efficiency (Enevoldsen & Kristensen, 1997; Lonergan et al., 2019; Santich, 2014). However, this method has generally been estimated in relation to body measurements in living animals (Enevoldsen & Kristensen, 1997). The visual morphology of archaeological cattle can only be estimated by morphometric measurements of bone remains. For this purpose, it has been commonly attempted to be determined by regression between the long bone measurements and the height of the caudal vertebrae (von den Driesch & Boessneck, 1974). This is of great importance as it provides possible evidence for

TABLE 5 Correlation analysis of carcass weight and morphometric values.

	Carcass weight	Calcaneus GL	Calcaneus GB	Talus GL	Talus BD
Carcass weight	1	−0.092^{NS}	0.144^{NS}	0.083^{NS}	0.114^{NS}
Calcaneus GL	−0.092^{NS}	1	0.422**	0.602**	0.457**
Calcaneus GB	0.144^{NS}	0.422**	1	0.500**	0.585**
Talus GL	0.083^{NS}	0.602**	0.500**	1	0.661**
Talus BD	0.114^{NS}	0.457**	0.585**	0.661**	1

Abbreviation: NS, Not significant.

**$p<0.01$

chronological differences in cattle size in archaeological samples (de Wet-Bronner, 1997).

In this study, calcaneus and talus morphometries of Simmental and Angus breeds of beef cattle (Herring, 2014; Kayar & İnal, 2019) were presented, and multipliers useful in carcass weight estimation were obtained using this data. In this estimation method, since the level of determinism (R2) of the regression equations formed as a result of regression analyses is generally low, it was preferred to obtain factors (von den Driesch & Boessneck, 1974) that are suitable for existing resources and easy to use. Thus, it was aimed to obtain a coefficient (Factor) based only on the ratio (carcass weight/GL) and to make carcass weight estimation based on it. Because such coefficient calculations and their use have been widely used in many zooarchaeological studies (Harcourt, 1974; Kiesewalter, 1888; Koudelka, 1885; Matolcsi, 1970; Teichert, 1975; von den Driesch & Boessneck, 1974).

Correlation analysis was first performed to predict (match) the bones that make up the same joint of an individual and to see the relationship between them. The moderate positive correlations between the calcaneus and talus were reflected in the regression analysis. When regression analysis was performed, which was supposed to allow estimation of the size between the two bones, the level of determinism (R2) of the regression equations was very low. For example, in the regression analysis using calcaneus GL value for talus GL estimation, the level of determinism (R2) was 0.36. This indicated a low level of determinism. The obtained value of 1.940, through the ratio calculation of calcaneus GL and talus GL similar to the estimation of carcass weight, is believed to contribute to size-based matching of calcaneus and talus in archaeological excavations, particularly in multiple burials or multiple waste deposits. The talus GL value could be estimated by dividing the calcaneus GL value by 1.940, and the talus GL value could be estimated by dividing the calcaneus GL value by 1.940. The LSM test on this value showed that breed and sex had no effect.

Talus and calcaneus index values are likely to be taken into account in the overall evaluation of the leg skeleton of these breeds. Because generally the metapodial slenderness indices created for horses are used to interpret the thinness, very thin, moderate or thick (massive) of the legs (De Grossi Mazzorin et al., 1998), it is aimed that talus and calcaneus index values contribute to similar slenderness index evaluations that are likely to be made for cattle. In our study, Talind and Calind were calculated in the same direction as the thinness index calculation. While there was a statistical difference between the calculated talus index (Talind) values depending on the breed, the difference in the calcaneus index value (Calind) was not statistically significant. Thus, it was concluded that Angus breeds have a lower and therefore thinner talus than Simmental breeds.

In conclusion, although the formulations obtained from the results of the regression analysis in this study have low coefficient of determination (R^2), obtaining factors commonly used in zooarchaeological studies contributes to the determination of visual morphology. It was possible to estimate carcass weight in cattle with calcaneus and talus multipliers obtained considering their ease and usability. It is believed that the estimates obtained will pave the way for the use of calcaneus and talus, which are commonly found in archaeological sites, in the evaluation of chronological differences in cattle size and consequently carcass weight. The value of 1.940 is believed to be beneficial in determining talus and calcaneus bones belonging to the same individual in mass burials or minimum number of individuals (MNI) calculations. Additionally, it is thought that this factor will contribute to identifying matching calcaneus and talus bones that form the same joint. Given that carcass weight in cattle is one of the most important factors determining meat yield, and changes in animal size are directly associated with skeletal bones, it is believed that talus and calcaneus morphometrics, along with the obtained factors, will be useful in visual morphological predictions.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Research data are not shared.

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