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Bone Length Estimation and Population-Specific Features of Calcaneus and Talus Bones of the Late Byzantine Era

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A B S T R A C T

Certain markers in bone structure allow researchers to estimate the length of an entire bone based only on a fragmented piece. Forensic anthropologists and bio-archeologists have recently devoted greater attention to the estimation of bone length from fragmented bones. This study aims to evaluate osteometric data in order to distinguish the population affinity of Byzantine individuals, as well as to estimate the length of the calcaneus and talus bones based on incomplete specimens. This is vital because of the importance of talar bones in the assessments of the population-specific features and because calcaneus and talus bones tend to preserve better archaeologically. The study includes 160 adult, male, complete and non-damaged calcanei (72 left and 88 right) and 84 adult, male, complete and non-damaged talus bones (38 left and 46 right) from the dry, late Byzantine era (13th Century AD) contexts. A total of 10 bony markers were selected for measurements of calcanei and 14 were selected for tali. Data were subjected to statistical analysis in order to assess bilateral differences in the bony markers. Correlation coefficients were also determined between maximum lengths of calcanei and tali against other markers. Dorsal articular facet length and dorsal articular facet breadth parameters of calcanei showed significant side differences ($p<0.01$). Length of the sulcus tali and width of the sulcus tali parameters for talus bones also showed statistically significant differences ($p<0.01$). More than one of the bony markers correlated in a statistically significant way with maximum length of calcanei and tali.

Key words: *bone length estimation, calcaneus, talus, Byzantine Era, osteometry*

Introduction

Research in skeletal biology and methodological approaches to the identification of human skeletal remains have advanced significantly in the recent years. As a result of the increase in population-specific studies and the publication of reviews in the fields of forensic and physical anthropology, knowledge about the affinities of populations and determinations of sex, race, age and stature has increased significantly.[1] It is commonly accepted that standards for skeletal identification vary between populations and that the standards for one population may not be used for another. Accurate methods of identifying human skeletal remains or revealing population affinities also have become more developed in recent years.[2] Standardized measurements can be obtained from remains for further evaluations, which can produce estimations of population and descriptions of racial characteristics. Classifying the individual into demographic categories allows anthropologists to create a profile of a population based only on skeletal remains.

Forensic anthropologists and bioarcheologists have also increased attention on the estimation of bone length from fragmented bones based on markers. The estimation of bone length from incomplete long bones was pioneered by Muller[3] who, in 1935, generated equations for estimating the length of the humerus, radius, and tibia by using measurements of skeletal collections. Fragmented remains of long bones more often retain the relevant bony markers due to their large size, but relatively small bones can also preserve these markers despite the physical conditions of their deposition.

Measurements from skull, pelvis and long bones have been used in the determination of population affinity, and in sex and age assessments. However, it has become

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necessary to assess the usefulness of other bones in the determination of such features since these bones are often recovered fragmentarily instead of whole. Preservation of bones is a very important factor for anthropological and forensic investigation. Accurate estimations and derivations of metric features can be obtained straightforwardly from the calcaneus and talus bones, and since these compact bones are relatively more durable[1,4,5] than other bones, such estimates would be very useful in cases of poor preservation**.**

The tarsus bones of the foot are homologous to the carpus of the hand, but tarsal elements are larger in order to support and distribute body weight. The calcaneus and talus bones are the largest tarsal bones. The calcaneus is the irregularly cube-shaped bone making up the heel of the foot and projects posterior to the tibia and fibula as a short lever for the muscles of the calf, which are attached to its posterior surface. It articulates with two other tarsal bones, the talus and cuboid. The talus is the link between the foot and the leg through the ankle joint and is the second largest of the tarsal bones. The structures entering into ankle joint are the lower end of the tibia, its malleolus, the malleolus of the fibula, and the transverse ligament, which together form a mortise that receives the upper convex surface of the talus and its medial and lateral facets. The talus articulates with four bones: tibia, fibula, calcaneus, and navicular.[6]

Because of the importance of talar bones in assessments of population's specific features (a result of the preservationally favored properties of calcaneus and talus[7]) we aimed to evaluate osteometric data from these two bones to distinguish the population affinity of individuals in the study population as well as to enable the estimation of the full lengths of fragmented calcaneus and talus bones based on their bony markers.

Materials and Methods

The skeletal remains used this study came from a collection at the Department of Anatomy of the School of Medicine of the Uludag University. The study includes 160 adult, male, complete and non-damaged calcanei (72 left and 88 right) and 84 talus bones (38 left and 46 right) from dry, late Byzantine era (early 13th Century AD) contexts. These bones excavated in 1984 from the archeological site of Nicea in Iznik, Turkey. Nicea was the third-largest city in the Byzantine Empire, and flourished under the Romans as well as being the scene of the well-known ecumenical councils. Digital photographs were taken of the specimens with a high-resolution digital camera (a Sony DSC-F717) connected to a computer system running Scion Image for Windows (ver. 4.0.3). All bones were marked with an erasable pen for calibration before taking digital photographs. Measurements were made from the photographs of different planes of the bones using Scion Image for Windows program's freehand and line selection tools, calibrated with metric marks, and then transferred to an Excel spreadsheet for statistical analysis.

A total of 10 bony markers were selected for measurements of calcanei and 14 were selected for tali. Linear measurements were taken in millimeters and the bony markers of calcaneus were as follows[8–12] (Figure 1):

1. Maximum anteroposterior length (MAXL): linear distance between the most anterior point of the calcaneus and the most posterior point on the calcaneal tuberosity.
2. Maximum height (MAXH): linear distance between most superior and the most inferior points on the posterior calcaneal tuberosity.
3. Cuboidal facet height (CFH): linear distance between the most superior and the most inferior points on the cuboidal articular facets.
4. Body height (BH): linear distance between the superior and the inferior surfaces of the body of the calcaneus taken in the coronal plane, at the midpoint between the most posterior point of the posterior articular facet and the most anterior point of the calcaneal tuberosity.

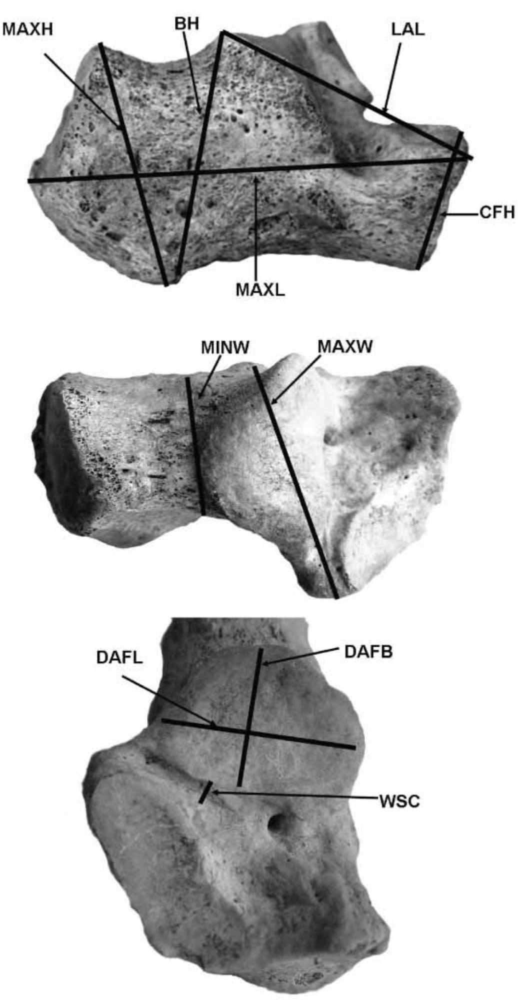

Fig. 1. Parameters of calcanei; lateral, top and front views, respectively.

5. Load arm length (LAL): linear distance between the most anterior point of the calcaneus and the most posterior point on the posterior articular facet.
6. Minimum transverse width (MINW): minimum linear distance between the medial and lateral surfaces of the body of the calcaneus.
7. Maximum transverse width (MAXW): maximum linear distance between the medial and lateral surfaces of the body of the calcaneus.
8. Dorsal articular facet length (DAFL): linear distance between the most posterior and the most anterior points on the posterior articular facet on the calcaneus.
9. Dorsal articular facet breadth (DAFB): linear distance between the most medial and the most lateral points on the posterior articular facet on the calcaneus.
10. Width of the sulcus calcanei (WSC): width of the sulcus calcanei, taken between the posterior articular facet and medial articular facet on the calcaneus.

The bony markers selected for the talus were[8] (Figure 2):

1. Maximum anteroposterior length (MAPL): Linear distance between most anterior point on the head and most posterior point on the body.
2. Maximum transverse width (MTW): Linear distance between most medial and most lateral points on the body.
3. Trochlear length (TL).
4. Circumference of the facies articularis navicularis (CFAN).
5. Facies articularis navicularis maximum width (FANM).
6. Facies articularis navicularis minimum width (FANm).
7. Circumference of the facies articularis calcanea posterior (FACP).
8. Facies articularis calcanea posterior maximum width (FCAPM).
9. Facies articularis calcanea posterior minimum width (FCAPm).
10. Length of the sulcus tali (LST).
11. Width of the sulcus tali (WST).
12. Circumference of the facies malleolaris medialis (CFMM).
13. Facies malleolaris medialis maximum width (MaxFMM)
14. Facies malleolaris medialis minimum width (MinFMM).

The parameters FANM, FANm, FCAPM, FCAPm, MaxFMM and MinFMM were automatically acquired with Scion Image software. Data were then subjected to statistical analysis in order to assess bilateral differences in the bony markers of all calcanei and tali. Means, standard deviations and standard error of means were determined for the right and left calcanei and tali and Student's unpaired t-test was used to compare means for side differences. Correlation coefficients were determined between maximum lengths of calcanei and tali against other markers. Maximum length parameters of calcanei and tali also were regressed against the significantly correlated markers. SPPS (ver. 14) and MS Excel were used for the statistical analyses.

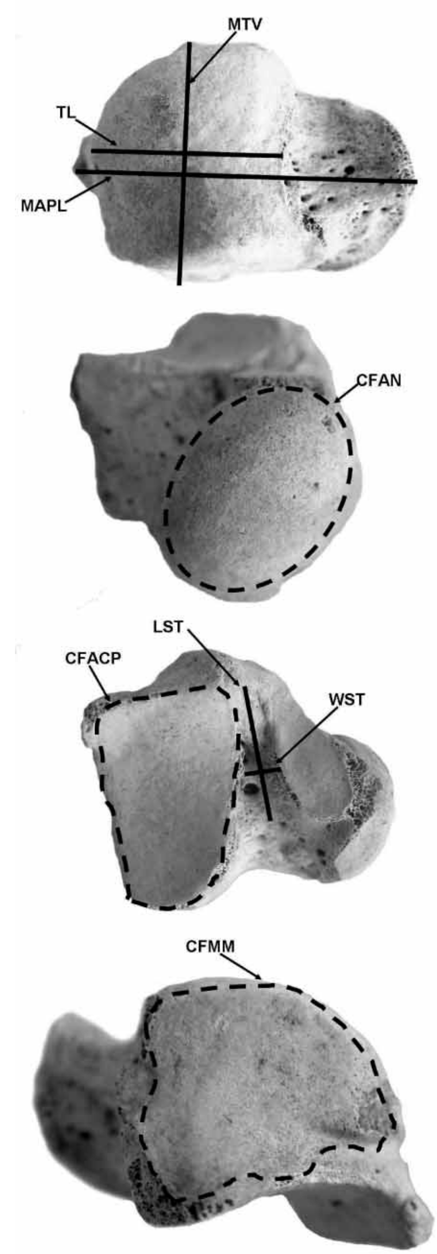

Fig. 2. Parameters of tali; top, front inferior and medial views, respectively.

Results

Table 1 gives descriptive statistics for each side of the bony markers of calcaneus and talus bones. DAFL and

TABLE 1
OSTEOMETRIC DATA AND DESCRIPTIVE STATISTICS

Parameter	Side	N	Mean	SD	SEM	Parameter	Side	N	Mean	SD	SEM
Calcaneum						Talus					
MAXL	L	72	7.43	0.84	0.10	MAPL	L	38	5,64	0,37	0,05
	R	88	7.50	0.71	0.08		R	46	5,72	0,40	0,06
MAXH	L	72	4.24	0.53	0.06	MTW	L	38	4,69	0,79	0,12
	R	88	4.21	0.45	0.05		R	46	4,91	0,33	0,05
CFH	L	72	2.42	0.33	0.04	TL	L	38	3,08	0,58	0,09
	R	88	2.42	0.32	0.03		R	46	3,15	0,32	0,05
BH	L	72	4.39	0.54	0.06	CFAN	L	36	8,73	1,25	0,19
	R	88	4.37	0.51	0.05		R	44	8,88	0,66	0,11
LAL	L	72	4.50	0.59	0.07	FANM	L	36	3,13	0,34	0,05
	R	88	4.55	0.51	0.05		R	44	3,14	0,25	0,04
MINW	L	72	2.68	0.47	0.06	FANm	L	36	2,23	0,23	0,03
	R	88	2.77	0.33	0.03		R	44	2,21	0,21	0,03
MAXW	L	72	4.35	0.43	0.05	CFACP	L	36	9,85	0,78	0,12
	R	88	4.40	0.53	0.06		R	45	10,13	2,44	0,41
DAFL*	L	72	2.14	1.45	0.17	FACPM	L	36	3,55	0,30	0,04
	R	88	2.69	0.76	0.08		R	45	3,64	0,77	0,13
DAFB*	L	72	1.56	1.06	0.12	FACPm	L	36	2,29	0,19	0,03
	R	88	1.91	0.57	0.06		R	45	2,35	0,56	0,09
WS	L	72	0.38	0.36	0.04	LST*	L	36	2,10	0,32	0,05
	R	88	0.45	0.24	0.03		R	45	1,76	0,45	0,07
						WST*	L	36	0.48	0.14	0.02
							R	45	0.38	0.17	0.03
						CFMM	L	36	9.46	0.82	0.12
							R	44	9.10	1.15	0.19
						MaxFMM	L	36	3.03	0.27	0.04
							R	44	2.89	0.37	0.06
						MinFMM	L	36	2.49	0.33	0.05
							R	44	2.51	0.27	0.04

Unpaired T-Test for differencies between right and left calcanei and talus, $p<0.01$. MAXL – Maximum anteroposterior length, MAXH – Maximum height (MAXH), CFH – Cuboidal facet height, BH – Body height (BH), LAL – Load arm length, MINW – Minimum transverse width, MAXW – Maximum transverse width, DAFL – Dorsal articular facet length, DAFB – Dorsal articular facet breadth and WS – Width of the sulcus calcanei. Parameters for talus MAPL – Maximum anteroposterior length, MTW – Maximum transverse width, TL – Troclear length, CFAN – Circumference of the facies articularis navicularis, FANM – Facies articularis navicularis maximum width, FANm – facies articularis navicularis minimum width, CFACP – Circumference of the facies articularis calcanea posterior, FACPM – Facies articularis calcanea posterior maximum width, FACPm – Facies articularis calcanea posterior minimum width, LST – Lenght of the sulcus tali, WST – Wight of the sulcus tali, CFMM – Circumference of the facies malleolaris medialis, MaxFMM – facies malleolaris medialis maximum width and MinFMM – Facies malleolaris medialis minimum width.

DAFB parameters of the calcaneus showed significant side differences ($p<0.01$). The LST and WST parameters for the talus also showed significance for side differences ($p<0.01$).

Table 2 gives the correlation coefficients of the maximum length of the calcaneus and talus against other bony markers. The maximum length of calcaneus correlated to a statistically significant extent with the parameters MAXH, CFH, BH, LAL, MINW and MAXTD. Maximum anteroposterior length of talus significantly correlated with MTW, TL, CFAN, FANM, FANm, CFACP, FACPM and FACPm parameters.

Simple regression suggests that maximum length of calcaneus regressed significantly with load arm length, body height, cuboidal facet height, maximum height, maximum transverse width and minimum transverse width. Maximum anteroposterior length of talus regressed significantly with maximum transverse width, trochlear length, facies articularis navicularis maximum and minimum widths (Table 3).

TABLE 2
CORRELATION COEFFICIENTS OF THE MAXIMUM LENGTH OF THE CALCANEUM AND TALUS AGAINST OTHER BONY MARKERS

Calcaneum		
Parameters		
MAXL	MAXH	0.73*
	CFH	0.78*
	BH	0.81*
	LAL	0.83*
	MINW	0.27*
	MAXTD	0.32*
	DAFL	0.02
	DAFB	0.008
	WS	0.07
Talus		
Parameters		
MAL	MTW	0.45*
	TL	0.39*
	CFAN	0.29*
	FANM	0.36*
	FANm	0.42*
	CFACP	0.32*
	FACPM	0.30*
	FACPm	0.35*
	LST	0.07
	WST	0.03
	CFMM	0.18
	MaxFMM	0.11
	MinFMM	0.18

*$p<0.01$

Discussion

Oygucu et al.[13–14] found that the Late Byzantine Era calcaneus and talus have no significant side differences in talar articular facets in a study of 174 calcanei and calcaneal articular facets and 179 talus. Of these, 64.4% of the calcaneal facets were classified as type B (the calcaneus bearing two facets for the talus), and 55.3% of the talar facets were classified as type B (the talus bearing two facets for the calcaneus); the remaining bones were classified as the other two major types of calcaneal and talar facets. Morphological variations in the calcaneal and talar facets within the different type distributions could result from differences in gait or be otherwise influenced by habit post-natally, or they could be indicative of genetically determined variations.[15] These considerations could be valid for the variation noted in other bony markers in the calcaneus and talus bones.

However, this study has shown that significant side differences do exist in at least two parameters for both the calcaneus and talus, and that the right sides of these bones are larger than the left sides for several parameters (dorsal articular facet length and dorsal articular facet breadth for calcanei, and the length of the sulcus tali and width of the sulcus tali parameters for tali).

A number of authors have discussed estimating bone length or other characteristic measurements (such as angles of specific portions of bones) from fragments. For instance, it has been determined that the length of the humerus is correlated with the width and depth of the intertubercular sulcus[16], that femoral neck-shaft angle significantly correlates with the length of the neck of the femur,[17] and that bony markers such as the head and neck of the femur can be of use in determining the femoral length when only a fragment of the proximal femur is

TABLE 3
SIMPLE REGRESSION OF MAXIMUM ANTEROPOSTERIOR LENGTH OF CALCANEUM (MAXL) AND MAXIMUM ANTEROPOSTERIOR LENGTH (MAL) OF TALUS AGAINST OTHER PARAMETERS THAT CORRELATED SIGNIFICANTLY

Calcaneum		Constant ± SEM	B ± SEM	r2	Std. Error of the Estimate	p
MAXL	MAXH	2.60 ± 0.36	1.15 ± 0.09	0.54	0.52	<0.0001
	CFH	2.98 ± 0.29	1.85 ± 0.12	0.61	0.48	<0.0001
	BH	2.27 ± 0.30	1.19 ± 0.07	0.66	0.45	<0.0001
	LAL	2.23 ± 0.28	1.16 ± 0.06	0.69	0.43	<0.0001
	MINW	6.03 ± 0.41	0.53 ± 0.15	0.08	0.74	0.000453
	MAXTD	5.28 ± 0.52	0.50 ± 0.12	0.10	0.73	<0.0001
Talus		Constant ± SEM	B ± SEM	r2	Std. Error of the Estimate	p
MAL	MTW	3.23 ± 0.54	0.50 ± 0.11	0.21	0.35	<0.0001
	TL	4.19 ± 0.39	0.47 ± 0.12	0.16	0.36	0.000218
	CFAN	4.72 ± 0.37	0.11 ± 0.04	0.08	0.38	0.010204
	FANM	4.23 ± 0.44	0.46 ± 0.14	0.13	0.37	0.001384
	FANm	4.04 ± 0.42	0.74 ± 0.19	0.17	0.36	0.000156
	CFACP	4.96 ± 0.25	0.07 ± 0.02	0.10	0.37	0.003956
	FACPM	4.94 ± 0.27	0.21 ± 0.08	0.09	0.37	0.007086
	FACPm	4.88 ± 0.25	0.35 ± 0.10	0.12	0.37	0.001407

available.[18] In addition, bony markers of the radius have also been studied in order to estimate the radial length of the complete bone,[19] and Koshy et al. found that maximum length of the calcaneus regressed significantly with the maximum transverse width, length, width and depth of the groove on the sustentaculum tali, and the length, width, and depth of the sulcus calcanei, while the maximum length of the talus regressed significantly with maximum transverse width, length and width of the lateral articular surface, the length of the medial articular surface, the vertical and transverse diameters of the head, and the depth of the sulcus tali which were derived from skeletons of a modern population from South India. Correlations of maximum transverse widths with maximum lengths of both the calcaneus and talus are similar to our results but several other parameters diverge between these Indian and our late Byzantine period populations. After the excavations that took place between 1981 and 1982, Ozbek[20] reported that these late Byzantine era skeletons' mean stature was approximately 167.4 cm, based on estimates from femur, tibia and humerus on 16 skeletons. Yalman[21] reported that the mean stature of this population was 169 cm, based on 34 skeletons recovered during the 1985 excavations.

Byzantine-era skeletal remains are frequently being recovered in Anatolia and presented data are useful for determining population-specific affinities of late Byzantine-period populations, and also contribute to the determination of the racial origins of skeletal remains from archeological sites, as well as having potential applications for physical anthropology.

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ODREĐIVANJE DUŽINE I SPECIFIČNOSTI PETNE I GLEŽANJSKE KOSTI IZ KASNE BIZANTINSKE ERE

S A Ž E T A K

Određeni markeri u koštanoj strukturi omogućili su istraživačima određivanje dužine i širine kostiju bazirane samo na fragmentiranim ostacima. Forenzičari i bioarheolozi posvetili su veliku pozornost proučavanju dužine kostiju iz fragmentiranih ostataka. Ova studija je za cilj imala procijeniti osteometrijske karakteristike binzantinskih pojedinaca. Ove dvije kosti izabrane su iz razloga što su arheološki uvijek bolje sačuvane. Studija je uključivala 160 odrasle, muške, kompletne – ne oštećene gležanjske kosti (72 lijeve i 88 desne) i 84 odrasle, muške ne oštećene petne kosti (38 lijeve i 46 desne) iz kasne Bizantinske ere (13. stoljeće). U ispitivanjima je korišteno 10 koštanih markera za analizu petne kosti i 14 koštanih markera za analizu gležanjske kosti. Podaci su statistički obrađeni kako bi pratili bilateralnu razliku između koštanih markera. Korelacijski koeficijenti bili su određivani između maksimuma dužine petne i gležanjske kosti nasuprot ostalim markerima. Dužina i širina dorzalne površine zglobne ploštine pokazale su statistički značajne razlike ($p<0,01$). Dužina i širina žlijeba petne kosti također su pokazale statistički značajne razlike ($p<0,01$). Više od jednog koštanog markera statistički značajno je korelirao sa maksimumom dužine gležanjke i petne kosti.