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Estimating the entire length of the fragmentary tibia with proximal and distal dimensions

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Abstract

Forensic anthropology is an important scientific discipline that determines the ethnicity, sex, height and body type characteristics from human skeletal remains for the benefit of forensic medicine. One of the important tasks of forensic anthropology is to determine the stature of individual from their skeletal remains. Lower extremities are mostly preferred in estimating stature. The current study aims to develop regression formulae to estimate the entire length of the tibia in case a fragmentary tibia is found. The study was conducted on 148 tibiae excavated from the ancient city of Nicaea and are housed in the Department Anatomy, Faculty of Medicine, Bursa Uludağ University. In total, eighteen parameters were examined on the tibiae. SPSS 22.0 was used for the statistical analyses. The descriptive statistics of the tibiae were evaluated. Taking the correlations between proximal and distal morphometric traits of the tibia and the entire tibial length into consideration, regression formulae were developed to determine the entire length of the tibia. In this study, we evaluated that the morphometric characteristics of ethnic groups are different from each other and therefore the use of formulae determined for one group can increase the margin of error for other groups. In addition, we developed formulae that estimate the length of the entire tibia. We believe that the results of this study will be of great importance for both anthropology and forensic medicine.

Key Words: Stature estimation, tibial length, forensic anthropology

Parçalı tibia uzunluğunun proksimal ve distal ölçümlerle hesaplanması

Öz

Adlî antropoloji, adlî tıp yararına insan iskelet kalıntılarından etnik grup, cinsiyet, boy ve vücut tipi özelliklerini belirleyen önemli bir bilim dalıdır. Adlî antropolojinin önemli görevlerinden biri de iskelet kalıntılarından bireyin boyunu belirlemektir. Boy tahmini kullanımında çoğunlukla alt ekstremite kemikleri tercih edilmektedir. Bu çalışma, kırık bir tibia parçası bulunması durumunda tibianın tüm uzunluğunu tahmin etmek için regresyon formülleri geliştirmeyi amaçlamaktadır. Çalışma, Bursa Uludağ Üniversitesi Tıp Fakültesi Anatomi Anabilim Dalı'nda bulunan ve Nicaea antik kentinde çıkarılmış olan 148 tibia üzerinde yürütüldü. Kemiklerinde toplam on sekiz parametre incelendi. İstatistiksel analizler için SPSS 22.0 kullanıldı. Kemiklere ait tanımlayıcı istatistik değerleri incelendi. Tibianın proksimal ve distal morfometrik özellikleri ile tüm tibia uzunluğu arasındaki korelasyonlar dikkate alınarak tibianın tüm uzunluğunu belirlemek için regresyon formülleri geliştirildi. Bu çalışmada, etnik grupların morfometrik özelliklerinin birbirinden farklı olduğunu ve bu nedenle bir etnik grup için belirlenen formüllerin kullanımının diğer etnik gruplar için hata payını artırabileceğini değerlendirdik. Ek olarak, tüm tibianın uzunluğunu tahmin eden formüller geliştirdik ve çalışmanın sonuçlarının hem antropoloji hem de adlî tıp için büyük önem taşıyacağı kanaatindeyiz.

Anahtar Sözcükler: *Boy tahmini, tibia boyu, adlî antropoloji*

Introduction

Forensic anthropology has represented the application of knowledge and techniques of anthropology with the basis of analyzing human skeletal remains within medico-legal significance and it has tried to determine the identity, ancestry, age, stature, sex and also the cause of death from the skeletal remains (Schmitt *et al.*, 2006; Tersigni *et al.*, 2013). One of the fields of the forensic anthropology has been the estimation of stature from skeletal remains. It has played an important role in identifying unknown identities. The parts of bodies or skeletal remains could also inform us about the well-being period of the unknown person as well as highlight trends in growth and development at the population level (Udhaya *et al.*, 2011; Gocha *et al.*, 2013). Pearson (1899) was the first researcher who developed the formula for stature estimation from bones and the results were relevant, particularly on lower extremities. They have provided the stature estimations with smaller associated errors and that is why those equations should be preferred when many long bones are present (Brickley *et al.*, 2004). The stature estimation from the length of the well-preserved tibia has mostly been a common technique (Duyar, 2003).

Although there have been many formulae, using the same formulae for different populations and nationalities, and their practical application could lead to serious inaccuracies in forensic sciences (Radoinova

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et al., 2002). That is mainly because the features and variations of the human skeleton determine the ethnical characteristics of the populations, which is and have been subject to evolutionary differentiations. Stature has also been an inherent characteristic of both genetic predisposition and childhood periods in different environmental and social stresses (Brickley *et al.*, 2004 ; Ari *et al.*, 2009).

The preservation state of the bones is important for stature estimation. In some cases, the bones could be recovered fragmentarily instead as a whole. In that case, it has become a problematic issue because of the deterioration of the long bones during burial (Wright *et al.*, 2003; Ari *et al.*, 2009). When the fragmented bones have been considered, estimation of stature from a common formula could not be valid not only for all populations and nations, also for different periods in the same populations. On the other hand, the formular for stature estimation from tibial length might have become useless when only a part of the tibia could be removed from the excavated area.

Although the population-specific body stature estimation from tibial length was numerously mentioned in previous studies, studies to estimate the entire tibial bone length from the fractured tibial bone were not sufficient. The aim of this study was to develop formulae for estimating the entire tibial length based on the proximal and distal tibial measurements in case the whole tibia could not be found.

Materials and methods

The sample of the current study consisted 148 male tibiae. The bones were obtained from the collection at the Department of Anatomy of the School of Medicine, Bursa Uludağ University, Turkey. The tibiae were excavated in 1984 from the archeological site of Nicaea in Bursa (Özbek, 1984). Deformed and/or fractured parts of bones were excluded from the study.

Three mesaurements of tibial length (Figure 1) were taken using the osteometric board. The measurements from the proximal part of the tibia (Figure 2) were measured from digital photographs using the ImageJ software (Schneider *et al.*, 2012). The measurements from the distal part of the tibia (Figure 3) were measured by using a sliding caliper. The measurements are as follows:

- Tibial length (TL): The distance between the superomedial edge of the tibia and the inferior edge of the medial malleolus.
- Ordinary length of tibia (OLT): The distance between the center of the articular surface of the lateral condyle and the center of the inferior articular surface (Mandela *et al.,* 2013).

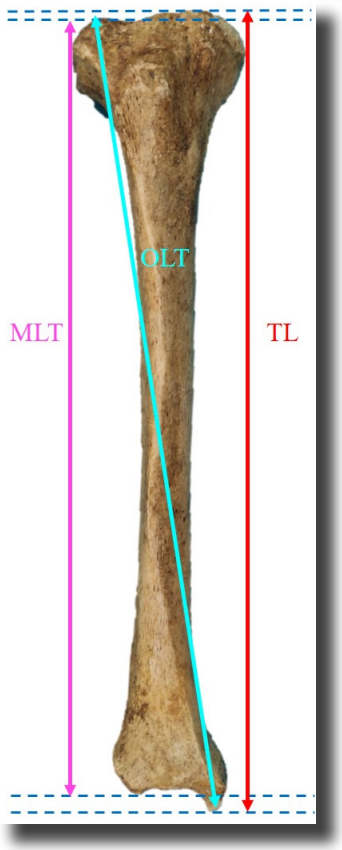

Figure 1. Length of the tibia. TL: Tibial length, OLT: Ordinary length of tibia, MLT: Maximum length of the tibia (references in text).

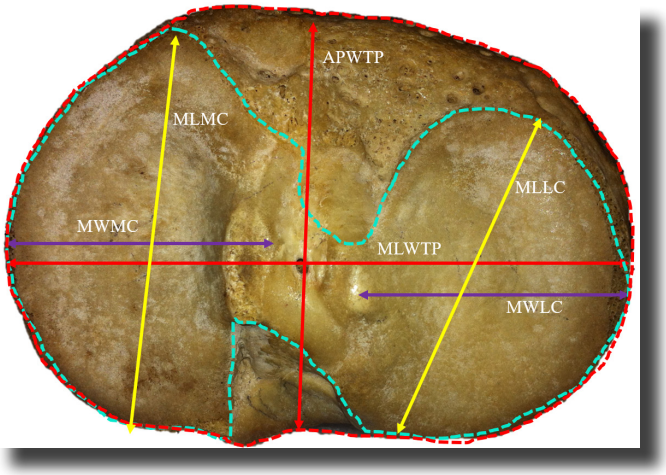

Figure 2. Proximal tibia. MLWTP: Medio-lateral width of the tibial plateau, APWTP: Antero-posterior width of the tibial plateau, CTP: Circumference of the tibial plateau, ASAS: Area of the superior articular surface, MLMC: The maximum length of medial condyle, MWMC: Maximum width of medial condyle, MLLC: Maximum length of lateral condyle, MWLC: Maximum width of lateral condyle (references in text).

- Maximum length of the tibia (MLT): End of malleolus against the vertical wall of the osteometric board, bone resting on its dorsal surface with its long axis parallel with the long axis of the board, block applied to the most prominent part of the lateral half of lateral condyle (Trotter and Gleser, 1952).

- Medio-lateral width of the tibial plateau (MLWTP): Maximum width of the tibial plateau in the mediolateral direction (Gandhi *et al.,* 2014).
- Antero-posterior width of the tibial plateau (APWTP): Maximum width of the tibial plateau in the anteroposterior direction (Gandhi *et al.,* 2014).
- Circumference of the tibial plateau (CTP): Circumference of the superior articular surface of the tibial plateau (Gandhi *et al.,* 2014).
- Area of the superior articular surface (ASAS): Area of the superior articular surface of the tibial plateau (Gandhi *et al.,* 2014).
- Maximum length of medial condyle (MLMC): Maximum length of the medial tibial plateau in the anteroposterior direction (Gandhi *et al.,* 2014).
- Maximum width of medial condyle (MWMC): Length of the medial plateau in the mediolateral direction measured from the eminence midpoint to the most medially projecting point of the tibial plateau (Gandhi *et al.,* 2014).
- Maximum length of lateral condyle (MLLC): Maximum length of the lateral tibial plateau in the anteroposterior direction (Gandhi *et al.,* 2014).
- Maximum width of lateral condyle (MWLC): Length of the lateral plateau in the mediolateral direction measured from the eminence midpoint to the most laterally projecting point of the tibial plateau (Gandhi *et al.,* 2014).

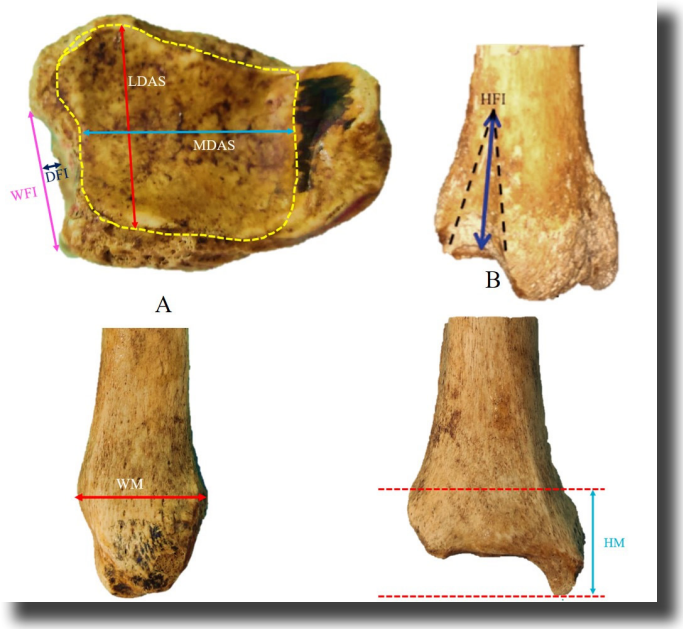

Figure 3. Distal tibia. DFI: Depth of the fibular notch, HFI: Height of the fibular incisura, WFI: Width of the fibular incisura, LDAS: Length of the distal articular surface, WDAS: Width of the distal articular surface, HM: Height of the malleolus, WM: Width of the malleolus (references in text).

- Depth of the fibular notch (DFI): Depth of the fibular notch measured from the deepest point of the fibular incisura to a line between the tips of the anterior and posterior tubercles (Taşer *et al.,* 2009).
- Height of the fibular incisura (HFI): Height between the tibial plafond and top of the fibular notch (Taşer *et al.,* 2009).
- Width of the fibular incisura (WFI): Width of the fibular notch measured between the anterior and the posterior tubercles (Taşer *et al.,* 2009).
- Length of the distal articular surface (LDAS): Maximum dimension of antero-posterior direction of tibial plafond (DeSilva *et al.,* 2010).
- Width of the distal articular surface (WDAS): Maximum dimension of medio-lateral direction of tibial plafond (DeSilva *et al.,* 2010).
- Height of the malleolus (HM): Distance from base at the tibial plafond to its tip (DeSilva *et al.,* 2010).
- Width of the malleolus (WM): The length of malleolus in the anteroposterior direction (DeSilva *et al.,* 2010).

For the statistical analyses including descriptive statistics, correlations between the tibial lengths and other measurements, and linear regression equations for estimating the entire tibial bone length from the measurements of proximal and distal parts, SPSS 22.0 statistical analysis software was used.

Results

The outputs for the descriptive statistics are given in Table 1. The equations for estimating the Tibial Length (TL), the equations for estimating the Ordinary Length of the Tibia (OLT), and the equations for estimating the Maximum Length (MLT) of the tibia were given in Table 2, Table 3 and Table 4, respectively.

Discussion and conclusion

One of the targets of forensic anthropology has been to analyze skeletal remains and estimate the stature of an individual using the dimensions of body parts. Particularly, lower extremity mesaurements such as tibial length, both including and excluding the medial malleous, have been preferred to the measurements of upper extremities in order to estimate the body height due to their strong correlations with stature (Brickley *et al.*, 2004; Agnihotri *et al.*, 2009, Udayha *et al.*, 2011). But it should be considered that growth has been determined by a complex combination of genetic and environmental factors and the stature has been affected by habitual activities and occupation as well (Ross *et al.*, 2002, Brickley *et al.*, 2004). Thus, forensic anthropology has become not only concerned with

human identification but also the assessment of human variations (İşcan, 2005).

All because of those reasons, numerous formulae have been designed to estimate the stature from body parts for different populations (*e.g.* Pearson, 1899; Trotter and Gleser, 1952; Boldsen, 1984; Radoinova *et al.*, 2002; Özaslan *et al.*, 2003; Celbis *et al.*, 2006; Agnihotri *et al.*, 2009). In addition, Pelin and colleagues (2003) have also developed a formula for estimating the stature for the Turkish population and compared it with other studies. However we have developed the formulae by considering ethnic diversities, habitual activities, changing environmental conditions, and other periodic differentiations in the same population in case fractured

Table 1. Descriptive statistics. SE: Standard error, SD: Standard deviation

Measurements	Min.	Max.	Mean	SE	SD
Tibial length (TL)	31,10	41,40	35,39	0,195	2,095
Ordinary length of tibia (OLT)	30,20	41,20	34,71	0,195	2,149
Maximum length of tibia (MLT)	31,40	42,60	35,93	0,199	2,137
Medio-lateral width of tibial plateau (MLWTP)	63,95	82,38	73,12	0,355	3,739
Antero-posterior width of tibial plateau (APWTP)	41,73	55,65	48,44	0,278	2,916
Circumference of tibial plateau (CTP)	184,59	240,96	208,95	1,063	11,146
Area of the superior articular surface (ASAS)	1731,29	2958,47	2349,41	24,688	260,108
Maximum length of medial condyle (MLMC)	37,12	54,82	46,03	0,352	3,708
Maximum width of medial condyle (MWMC)	22,35	39,76	30,74	0,389	4,102
Maximum length of lateral condyle (MLLC)	32,74	48,33	41,11	0,307	3,236
Maximum width of lateral condyle (MWLC)	20,62	41,74	32,91	0,408	4,295
Depth of fibular incisura (DFI)	2,60	8,30	5,33	0,145	1,331
Height of fibular incisura (HFI)	20,40	43,10	32,15	0,344	3,921
Width of fibular incisura (WFI)	16,60	29,60	22,43	0,281	2,576
Length of the distal articular surface (LDAS)	20,70	35,80	28,02	0,254	2,894
Width of the distal articular surface (WDAS)	16,40	38,90	31,38	0,286	3,193
Hight of malleolus (HM)	9,90	19,40	14,20	0,176	1,989
Width of malleolus (WM)	16,20	32,20	24,69	0,230	2,588

Table 2. Equations for estimating tibial length (TL) using measurements

Measurements	Equations for TL estimation	R	R^2	SE of the estimation
MLWTP	TL= 16,493 + 0,480 x MLWTP	0,480	0,230	1,80929
APWTP	TL =23,755 + 0,435 x APWTP	0,345	0,119	1,91332
CTP	TL = 19,544 + 0,432 x CTP	0,432	0,186	1,83922
ASAS	TL = 26,265 + 0,499 x ASAS	0,499	0,249	1,78719
MLMC	TL = 27,449 + 0,327 x MLMC	0,327	0,107	1,94900
MWMC	TL = 32,096 + 0,210 x MWMC	0,210	0,044	2,01601
MLLC	TL = 20,701 + 0,559 x MLLC	0,559	0,313	1,70922
MWLC	TL = 31,540 + 0,241 x MWLC	0,241	0,058	2,00111
HFI	TL = 25,938 + 0,547 x HFI	0,547	0,300	1,77246
WFI	TL = 29,055 + 0,343 x WFI	0,343	0,118	2,04533
LDAS	TL = 26,974 + 0,409 x LDAS	0,409	0,167	1,92710
WDAS	TL = 27,959 + 0,359 x WDAS	0,359	0,129	1,97402
HM	TL = 31,116 + 0,290 x HM	0,290	0,084	2,01506
WM	TL =28,583 + 0,347 x WM	0,347	0,120	1,98054

Table 3. Equations for estimating ordinary length of tibia (OLT) using measurements

Measurements	Equations for TL estimation	R	R^2	SE of the estimation
MLWTP	OLT = 14,715 + 0,485 x MLWTP	0,485	0,235	1,88194
APWTP	OLT = 22,814 + 0,336 x APWTP	0,336	0,113	2,00464
CTP	OLT = 17,559 + 0,443 x CTP	0,443	0,196	1,90826
ASAS	OLT = 25,242 + 0,496 x ASAS	0,496	0,246	1,86805
MLMC	OLT = 26,410 + 0,325 x MLMC	0,325	0,105	2,03535
MWMC	OLT = 30,350 + 0,268 x MWMC	0,268	0,072	2,07352
MLLC	OLT = 20,201 + 0,522 x MLLC	0,522	0,273	1,83528
MWLC	OLT = 31,335 + 0,201 x MWLC	0,201	0,040	2,10828
HFI	OLT = 24,995 + 0,548 x HFI	0,548	0,300	1,81381
WFI	OLT = 29,028 + 0,297 x WFI	0,297	0,088	2,12386
LDAS	OLT = 26,792 + 0,388 x LDAS	0,388	0,150	2,00022
WDAS	OLT = 26,710 + 0,376 x WDAS	0,376	0,141	1,99589
HM	OLT = 30,513 + 0,280 x HM	0,281	0,078	2,05441
WM	OLT = 27,911 + 0,338 x WM	0,338	0,114	2,02128

Table 4. Equations for estimating maximum length of tibia (MLT) using measurements

Measurements	Equations for TL estimation	R	R^2	SE of the estimation
MLWTP	MLT = 16,771 + 0,477 x MLWTP	0,477	0,227	1,85050
APWTP	MLT = 24,335 + 0,337 x APWTP	0,337	0,113	1,96549
CTP	MLT = 19,236 + 0,444 x CTP	0,444	0,197	1,87002
ASAS	MLT = 26,647 + 0,497 x ASAS	0,497	0,247	1,82605
MLMC	MLT = 28,195 + 0,312 x MLMC	0,312	0,097	1,99985
MLLC	MLT = 20,870 + 0,562 x MLLC	0,562	0,316	1,74105
MWLC	MLT = 31,508 + 0,271 x MWLC	0,271	0,073	2,02632
DFI	MLT = 33,917 + 0,243 x DFI	0,243	0,059	2,19215
HFI	MLT = 26,027 + 0,562 x HFI	0,562	0,315	1,78877
WFI	MLT = 29,765 + 0,325 x WFI	0,325	0,105	2,13724
LDAS	MLT = 27,728 + 0,390 x LDAS	0,391	0,152	1,98462
WDAS	MLT = 28,535 + 0,349 x WDAS	0,349	0,122	2,02891
HM	MLT = 31,225 + 0,312 x HM	0,312	0,098	2,03978
WM	MLT = 28,453 + 0,373 x WM	0,373	0,139	1,99991

bones might be removed from mass graves or found not only for investigations but also for incidental reasons.

Mandela *et al.* (2013) gave the formulae for estimating of the length of the tibia on the basis of mesaurements of the distal articular surface in Kenyan population. They found that the tibial length strongly correlated with the length of tibial plafond (the distal articular surface), the width of the tibial plafond, height of the fibular incisura, width of the fibular incisura and width of the medial malleolus. They designed the regression models including combinations of those correlated parameters.

Chibba *et al.* (2007) formulated the estimation of the maximum tibial length and stature using five measurements from the proximal tibia and only one measurement from the distal tibia in South African populations.

Table 5. Comparison of tibial legth measurements from different populations

Reference	Population	Mean	SD
Current study	Anatolian (Nicaea)	35,39	2,09
Gocha *et al.*, 2013	Southeast Asian	36,14	1,39
Mandela *et al.*, 2013	Kenyan	38,2	2,75
Akhlaghi *et al.*, 2011	Iranian	38,34	2,31
Blessing *et al.*, 2009	Nigerian	46,66	4,5
Radoinova *et al.*, 2002	Bulgarian	36,48	2,48
Boldsen, 1984	European	37,85	-

Lynch *et al.* (2019) took the tibia length measurements on an osteometric board. They used three techniques for the tibia length. In technique A, they measured the tibia length from the intercondylar eminence to the tip of the malleolus; in technique B, they measured the tibia length vertically from the tip of the malleolus to the lateral proximal condyle line; and in technique C, they measured the tibia length diagonally from the tip of the malleolus to the lateral proximal condyle. They concluded that the technique B gave similar results to technique A and argued that the measurement from the tip of the malleolus to the lateral condyle with longitudinal axis is less preferable than diagonal axis.

In the current study, we used three forms of tibial length, (*i.e.*, TL, OLT and MLT). We evaluated the correlated parameters of proximal and distal tibial parts with the entire tibial length. Considering the correlations, we developed the regression formulae in order to estimate the entire length of tibia in the event that only fragmented proximal or distal tibial parts are found.

As it was shown in Table 5, the proportions of each population have distinctive characteristics. Thus, using the same formula for estimating not only the stature but also the length of fractured bones might cause major mistakes. Consequently, new estimation formulae should be designed considering all populations for the benefit of the forensic sciences and anthropology. In this study, we gave the formulae specific to the Anatolian population for forensic sciences and anthropology.

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