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Estimation of the Length of Tibia Based on the Morphometric Analysis of Its Fragments in South Indian Population - A Descriptive Cross-Sectional Study

Dr. Syed Muqheetuddin Hamad[1], Dr. Geethanjali H. T.[2]

[1]Senior Resident, Department of Anatomy, Maheswara Medical College, Isnapur, Chitkul, Telangana, India

[2]Associate professor, Department of Anatomy, Mandya institute of medical sciences, Mandya, Karnataka, India
Email: *muqheetsyed72[at]gmail.com*
ORCID - https://orcid.org/0009-0004-0182-3591.

Abstract: ***Introduction**: Stature assessment from available skeletal remains is a challenging job in some medico-legal settings, such as terrorist bombs, war zones, airplane accidents, finding fragments of dead individuals in homicide cases, etc.[1] Skeletal remains are analyzed in the discipline of forensic anthropology to identify a deceased person by determining their race, sex, age, and stature. Stature reconstruction from skeletal remains is one method used in forensic anthropological investigations to identify a person. In the event that a bone fragment is discovered, our research attempts to create regression equations that would estimate the length of the tibia. **Methods**: The recorded measurements were then entered in Microsoft Excel Worksheet and statistically analyzed using SPSS software, version 22. Descriptive statistics, correlation coefficients, regression equations and other suitable tests to give correlation between tibial length and the lengths of its fragments were documented and analyzed. **Results**: A total of 364(N) dry adult tibiae were used for this study. 13 measurements were taken from each bone. Descriptive statistics of the tibiae were derived. The maximum length of tibia (MLT) was found ranging from 29cms to 45cms. The mean of MLT was 36.98cms with a standard deviation of 2.66cms and a Standard error of 0.141. **Conclusion**: The current study's objective was to reconstruct the length of the tibia from pieces of tibiae in the South Indian population, which will help resolve medico legal issues because lower limb bones yield more accurate results for stature estimation.[2]***

Keywords: Tibia; Maximum Tibial Length; Correlation; Fragments; Regression Equations

1. Introduction

The **tibia** also known as the **shinbone**, is the larger, stronger, and anterior (frontal) of the two bones in the leg below the knee in vertebrates (the other being the fibula, behind and to the outside of the tibia); it connects the knee with the ankle. The tibia is found on the medial side of the leg next to the fibula and closer to the median plane. The tibia is connected to the fibula by the interosseous membrane of leg, forming a type of fibrous joint called a syndesmosis with very little movement. It is the second largest bone in the human body, after the femur. The leg bones are the strongest long bones as they support the rest of the body.

Lower limb long bones have been found to have a stronger and more direct relationship with an individual's stature than upper limb long bones.[2] The morphometric characteristics of long bone fragments that associated well with bone length can be used to consistently estimate stature, particularly if a linear regression equation has already been developed for that specific bone.[3]

Stature is a significant part of the human biological profile, which is required in the identification of an unknown or deceased individual. Estimation of stature from various skeletal parameters has always been of great interest in the fields of forensic science, anthropology, and archaeology.

The fact that fragmentary long bones can be utilized to determine bone length was initially discovered by Muller.[4] Estimating stature from skeletal remains is a crucial factor, particularly in medico-legal situations like mass casualties, natural disasters, airplane accidents, terrorist bomb victims, and forensic cases involving crimes. Additionally, knowing the individual's stature is crucial when it comes to circumstances correlating the available skeletal remains with the profile of missing people. It is possible to use the maximum length of these bones to estimate the stature of unknown persons due to the positive association that exists between stature and the length of the long bones in the human body.[5-7] While many different types of bones have been used to reconstruct stature, the use of long bones, particularly those of the lower limbs, appears to be more common and is said to yield results that are almost exact.[8] Using long bones that are still intact, regression models have been developed to estimate height in different demographic groups. Since the features of the human skeleton are vulnerable to evolutionary differentiations, formulas relevant to individual populations will need to be calculated.[9]

2. Materials and Methods

A total of 364 ossified dry tibia bones were used in this study. These tibiae of unknown sex and were grouped into right and left.[13] Dry tibiae (both right side and left side) were included in the study. Broken, diseased, malformed, damaged bones and defective bones were excluded from the study.

Ethical consideration: Study was initiated after obtaining approval from the Institutional Ethics committee of MIMS, Mandya.

The bones were measured and the results are listed below. Every fragment was measured three times, and the average of these measurements served as the final measurement as per the recommendations of Singh & Bhasin.[10]

In this study, as per the mandate & to avoid inter individual variability I was the only person who took each measurement.[10] The Osteometric board was used to measure the maximum lengths of the tibiae; Vernier calipers and a measuring tape were used to measure the remaining parameters. The standards suggested by Martin and Saller (Singh and Bhasin) 2004.[10] were followed for all measurements.

Data Collection:
Following measurements will be taken by the Osteometric board: [10]

1) **Maximum Length of Tibia (MLT):** It measures the distance from most projecting point of the inter-condylar eminence to the tip of the medial malleolus.
2) **Bicondylar Breadth (BB)**: It measures the distance between the most laterally placed points on the tibial and fibular condyles.
3) Following measurements will be taken by the Sliding Vernier calipers: [10]
4) **Thickness of the Upper Medial Articular Surface (TUMAS):** It measures the maximum sagittal distance between the anterior and posterior margin of upper medial articular surface.
5) **Breadth of the Upper Medial Articular Surface (BUMAS):** It is the horizontal distance from the medial intercondylar eminence to the middle of the side margin of the articular surface.
6) **Thickness of the Upper Lateral Articular Surface (TULAS):** It measures the maximum sagittal distance between the anterior and posterior surface of upper lateral articular surface.
7) **Breadth of Upper Lateral Articular Surface (BULAS):** It measures the horizontal distance from lateral intercondylar eminence to the middle of the side margin of the lateral articular surface.
8) **Maximum Sagittal Diameter of Tibia at the level of Tuberosity (MSDTT):** It measures the straight distance between the most projecting point on the tibial tuberosity and the mid-point on the posterior surface of the bone lying in the horizontal plane.
9) **Maximum Distal Epiphyseal Breadth of Tibia (MDEBT):** It measures the distance between the most laterally placed points on the tibial malleolus and the lateral surface of the lower epiphysis.
10) **Sagittal Diameter of Distal Epiphysis (SDDE):** It measures the distance between the anterior and posterior surface of the lower epiphysis in the mid-sagittal plane, projected on a plane perpendicular to longitudinal axis of bone.
11) **Anterior-Posterior Diameter at Nutrient Foramen (APDNF):** It measures the straight distance of anterior crest from the posterior surface at the level of nutrient foramen.
12) **Medio-Lateral Diameter at Nutrient Foramen (MLDNF):** It measures the straight distance from the medial border to the interosseous crest at the level of the nutrient foramen.

Following measurements will be taken by the measuring tape: [10]

13) **Girth of Shaft (GS):** It measures the circumference in the middle of the shaft of bone.
14) **Circumference of Shaft at Nutrient Foramen (CSNF):** It measures the circumference of the bone at the level of nutrient foramen.

Statistic analysis
The recorded measurements were then entered in Microsoft Excel Worksheet and statistically analyzed using SPSS software, version 22. Descriptive statistics, correlation coefficients, regression equations and other suitable tests to give correlation between tibial length and the lengths of its fragments were documented and analyzed.

Data obtained from anthropometric measurements were analyzed by descriptive statistics and expressed as mean ± standard deviation (SD). A comparison of differences between right and left tibia was performed using Student's *t*-test.

Pearson's correlation coefficient (r) was used to express the relationship between maximum length of the tibia and other parameters. Furthermore, linear regression analysis was performed and regression equations formulated for the prediction of the maximum length of the bone from the parameters. Statistical significances in all cases were noted at $p<0.01$.

3. Results

Results are presented as descriptive statistics (mean±SD), with their respective Standard Errors of Estimate (SEE) for both right and left tibia (Table 1)

Table 1: Descriptive Statistics for the measurements of fragments including right & left tibiae

	N	Minimum (cm)	Maximum(cm)	Mean (cm)	Std. Error	Std. Deviation
MLT	364	29	45	36.98	0.141	2.661
BB	364	5.4	8.4	6.823	0.0275	0.5166
TUMAS	364	3.2	5.2	4.167	0.0196	0 369.5
BUMAS	364	2.2	4	3.142	0.0154	0.2889
TULAS	364	3	5	3.63	0.018	0.346
BULAS	364	2.1	3.8	3.091	0.0152	0.2853
MSDTT	364	2.6	5.5	4.146	0.0232	0.4359
MDEBT	364	3.3	5.4	4.052	0.0194	0.3657
MLDNF	364	1.4	3.4	2.123	0.015	0.2813
APDNF	364	2	4.3	3.125	0.02	0.376
SDDE	364	2.7	4.5	3.422	0.0169	0.3185
GS	364	4.8	8.8	6.6479	0.03668	0.69017
CSNF	364	5.5	11.4	8.358	0.0487	0.9166
Valid N (listwise)	364					

Table 2: Descriptive Statistics for the measurements of fragments of right tibiae

Measurement	N	Minimum (cm)	Maximum (cm)	Mean(cm)	Std. Error	Std. Deviation
MLT	187	30.4	43.7	36.867	0.196	2.6804
BB	187	4	7.9	6.84	0.0363	0.4966
TUMAS	187	3	5	4.21	0.026	0.355
BUMAS	187	2	4	3.1	0.02	0.277
TULAS	187	2.9	4.5	3.692	0.0259	0.3542
BULAS	187	2	4	3.11	0.021	0.282
MSDTT	187	3	5.5	4.118	0.032	0.4378
MDEBT	187	3	5	4.09	0.026	0.355
MLDNF	187	2	3	2.12	0.02	0.27
APDNF	187	2.1	4.3	3.093	0.0262	0.3588
SDDE	187	3	4	3.42	0.021	0.294
GS	187	5	7.8	6.587	0.0481	0.6581
CSNF	187	6	11	8.346	0.0654	0.8938
Valid N (list wise)	187					

The maximum length of tibia (MLT) was found ranging from 30.4cms to 43.7cms. The mean of MLT was 36.867cms with a standard deviation of 2.6804cms and a Standard error of 0.196.

Table 3: Descriptive Statistics for the measurements of fragments of left tibiae

Measurement	N	Minimum (cm) statistic	Maximum (cm) Statistic	Std. Error	Mean(cm)	Std .deviation
MLT	177	29	45	37.1	0.196	2.603
BB	177	5.4	8.4	6.82	0.0403	0.5357
TUMAS	177	3.2	5.2	4.133	0.0287	0.3815
BUMAS	177	2.2	4	3.197	0.0218	0.2898
TULAS	177	3	5	3.57	0.025	0.329
BULAS	177	2.1	3.8	3.076	0.0212	0.2823
MSDTT	177	2.6	5.4	4.177	0.0326	0.4343
MDEBT	177	3.3	5.4	4.032	0.0287	0.3816
MLDNF	177	1.4	3.4	2.129	0.0219	0.292
APDNF	177	2	4.3	3.152	0.0292	0.388
SDDE	177	2.7	4.5	3.423	0.0256	0.349
GS	177	4.8	8.8	6.7054	0.0536	0.71304
CSNF	177	5.5	11.4	8.369	0.0711	0.9455
Valid N (list wise)	177					

The maximum length of tibia (MLT) was found ranging from 30.4cms to 43.7cms. The mean of MLT was 37.1cms with a standard deviation of 2.603cms and a Standard error of 0.196.

Table 4: Correlations of measurements of tibial fragments with MLT

Fragments	MLT (rt)	MLT (lt)	MLT (both)
BB	.614**	.679**	.647**
TUMAS	.614**	.624**	.619**
BUMAS	.538**	.594**	.568**
TULAS	.738**	.637**	.678**
BULAS	.555**	.591**	.571**
MSDTT	.626**	.657**	.649**
MDEBT	.534**	.601**	.578**
MLDNF	.578**	.634**	.608**
APDNF	.654**	.675**	.667**
SDDE	.618**	.691**	.659**
GS	.686**	.706**	.697**
CSNF	.656**	.676**	.670**

Girth of Shaft (GS) showed highest correlation with a value of 0.706 on Table 4 shows the correlation between maximum length of tibia (MLT) & other tibial fragments in right & left tibiae. It can be noted from the above table that Thickness of the Upper Lateral Articular Surface (TULAS) had highest correlation with length of tibia in the right side with a correlation value of 0.738. Whereas Girth of Shaft (GS) showed highest correlation with a value of 0.706 on the left side. The fragment which showed least correlation with MLT was Maximum Distal Epiphyseal Breadth of Tibia (MDEBT) with a value of 0.534 on right side. Whereas 40 Breadth of Upper Lateral Articular Surface (BULAS) showed least correlation with MLT with a value of 0.591 on the left. While considering both sides Girth of Shaft (GS) showed highest correlation with MLT having a value of 0.697 & Breadth of the Upper Medial Articular Surface (BUMAS) showed least correlation with MLT with a value of 0.568.

Table 5: Showing equations for estimating MLT, Correlation & SEE from measurements of tibial fragments

S. No.	Equations	Correlation	SEE
1	13.047+0.065(BB) +0.369(TUMAS)+ 0.328 (BUMAS) + 2.107 (TULAS) +0.123 (BULAS) +0.329 (MSDTT) - 0.183(MDEBT) +0.264 (MLDNF) +0.999 (APDNF) +0.962(SDDE) +1.156 (GS) -0.287(CSNF)	0.777	1.696
2	13.282+3.301(BB) +0.778(TUMAS) +1.311 (BUMAS) + 2.385 (TULAS)+ 0.683(BULAS) +1.338 (MSDTT)	0.735	1.804
3	21.068+1.933(MLDNF)+2.816(APDNF)+0.361(CSNF)	0.687	1.9265
4	15.121+0.708(MDEBT)+2.294(SDDE)+1.675(GS)	0.733	1.8033
5	14.434+3.301(BB)	0.644	2.0239
6	18.801+4.355(TUMAS)	0.61	2.0969
7	20.710+5.174(BUMAS)	0.563	2.1862
8	18.383+5.119(TULAS)	0.672	1.9578
9	20.552+5.311(BULAS)	0.568	2.1772
10	20.869+3.885(MSDTT)	0.642	2.0283
11	20.664+4.015(MDEBT)	0.561	2.1903
12	24.885+5.696(MLDNF)	0.605	2.1065
13	22.328+4.694(APDNF)	0.665	1.9768
14	18.370+5.436(SDDE)	0.652	2.0051
15	19.210+2.674(GS)	0.695	1.9008
16	20.983+1.914(CSN	0.665	1.9752

Table 5 shows 16 sets of regression equations calculating the maximum tibial length from various tibial fragments along with their correlation and the standard error of estimate (SEE). Equation 1 estimates the tibial length from all the fragments of tibia used in this study. Equation 2 and Equation 4 estimates the maximum tibial length in the event of obtaining only the upper end or only lower end respectively. Equation 3 estimates the tibial length in case of the fragment of tibia at the level of nutrient foramen is only available. Equations 5 to 16 estimates the tibial length using individual mentioned fragment. Regression equations were not separated for right & left sides to predict MLT from the fragments because the relation between them moved in the same direction during statistical analysis & in line with other studies were not statistically significant also.

4. Discussion

Anatomists, forensic specialists, and physical anthropologists have long been interested in estimating an individual's stature from the skeletal remains.[11]

Karl Pearson was the first person to develop regression formulas in the 1800s.[12] Four measurements of the body were published in 1755 by the French anatomist Sue JJ: stature, trunk length, upper extremity length, and lower extremity length. He mentioned the following two crucial elements of body proportions throughout growth: 1. The trunk is longer than the lower extremity until the age of 14, at which point they are equal. 2. Up until roughly birth, the upper extremities are longer than the lower extremities; after that, the lower extremities are longer.[13]

In 1958, Trotter and Glesser reexamined the entire issue of reconstructing skeleton using long bones. Skeletal remains from Korean War victims were used. In addition to the limited series of Mongoloids, Mexicans, and Puerto Ricans, far larger series of Whites and Blacks were available for this study. The regression equation was provided for estimating the stature of Mexicans, Black Americans, White Americans and Mongoloids. The three races (Caucasoid, Negroid, and Mongoloid) have sufficiently diverse associations between stature and length of long bones to necessitate using distinct regression equations to determine the most accurate estimations of stature for members of each race.[14]

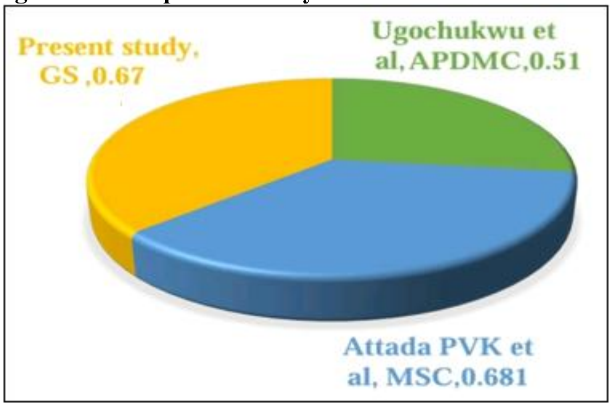
In addition to deriving regression equations to estimate tibia length, Ugochukwu et al (2016) conducted a study on 68 intact adult tibiae (35 right, 33 left), and they concluded that in their population, proximal shaft diameter showed the least correlation with maximum tibial length and bicondylar tibial width showed the maximum.[3]

36 intact adult human tibia (18 left and 18 right) from the bone bank of the anatomy department of the NRI Institute of Medical Sciences, Visakhapatnam, were used in the work by Attada PVK, et al.[15]

In the present study, 51% of bones were of right side while 49% belonged to left. Marginally right sided bones procured were more. The right sided bones showed a mean length of 36.867cms while those of left showed 37.1cms. It is consistent with other studies done on tibia bones. standard deviation (SD) of maximum tibial length (MLT) was slightly more on the right side with a value of 2.680. SD of both sides measured to 2.661 followed by SD of left side which was valued at 2.603. BUMAS & MSDTT mean lengths were slightly more on left side. TUMAS & BULAS had slightly more values on the right side. None showed statistically significant differences between right & left sides.

In the present study among 12 measurements TULAS (right) with a value of 0.738 while GS with a value of 0.706(left) showed highest correlation respectively. MDEBT (right) with a value of 0.534 & BULAS (left) with a value of 0.591 showed least correlation. When both sides were considered GS (0.697) showed highest & BUMAS (0.568) showed least correlation. This is shown in Table 6 & the P- value of all fragments were significant at <0.01.

Comparison of the maximally MLT – correlating tibial fragment of the present study with similar studies.



5. Conclusion

In the present descriptive cross – sectional study, we used measurements of 12 various tibial fragments from proximal end (5), Distal end (2), shaft (5).We evaluated and correlated parameters of these fragments to entire Tibial length. After multivariate analysis considering the correlations, we developed Regression formulae which can be used to estimate the length of tibia even when only fragmented proximal or distal or shaft parts are found. Since using the same formula for estimating Tibial length and in turn stature in different populations might cause major mistakes we analyzed locally available bones.[9]

The necessity of estimating population specific formulae for the benefit of Forensic Anthropology led us towards conduct of this study. In this study we gave formulae specific to South Indian population for benefit of the field of Anatomy, Forensic Medico legal cases and even archeological excavations. The measurements taken here can also be considered for designing knee prostheses best suitable for South Indian population for use in Orthopaedics surgeries also.[16] However even within the same adult populations the bones may show slight variations owing to sex, nutritional status, dry/living (dry bones are 2 to 3 mm shorter) habitual activities, different occupations etc. These became unavoidable limitations of this study as we have begun using dry bones. However, this was partially compensated with a specimen number of more than 350, better results were derived & we got either moderate or high correlation. (0.00-0.30 weak, 0.30-0.700 moderate and >0.700 high correlation). This study has given an initiation for deriving race specific formulae. The study may be improvised by studying various fragment measurements in intact skeletons where stature and sex is already known which will help in increased accuracy, aiding in 'Identification' of the deceased even when a small piece of bone is recovered.

In our study data obtained from morphometry of tibia were sex pooled. But it has been told by anthropologists that sex of the individual must be considered to obtain higher accuracy in stature estimation.[3] This became the limitation of our study. But on the contrary, based on Petersen's study the differences in lengths were not dependant on sex & gender may not always be known, the present study was carried out on bones of unknown gender, statistically significant Regression Equations were derived.

Ethical Considerations

Compliance with ethical guidelines

The research is on dry tibia and did not involve any animal and patients. The ethical approval is obtained from the our institutional ethical committee.

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Conflict of interest: The authors declared no conflict of interest.

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