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Stature Estimation from Femur and Tibia Bone Using Regression Equation Method: A Pilot Study

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Authors' contributions

This work was carried out in collaboration among all authors. Author Achal Mundane designed the study, wrote the protocol, and wrote the first draft of the manuscript. Author SA performed the statistical analysis. Author LB managed the literature searches and draft writing. Author Archana Mahakalkar managed the analyses of the study. All authors read and approved the final manuscript.

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ABSTRACT

Anthropometry plays a crucial role in the field of forensic anthropology, particularly in the identification of human remains. Among the various parameters used for personal identification, stature holds significant importance. It is a key factor in medico-legal investigations, especially when dealing with unknown fragmentary and mutilated remains. The objective of present pilot study was to develop a mathematical formula for estimating human stature based on the measurement of long bones, specifically the femur and tibia. A sample of 150 randomly selected girls, aged between 18 and 24 years, was chosen from Nagpur's Institute of Forensic Science, Maharashtra. The length

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of the right tibia and femur bones was measured, calculated and regression formulae was derived to estimate stature for the female population of Maharashtra. To assess the relationship between bone length and stature, Pearson's correlation coefficient was employed and revealed regression coefficient (r) of 0.92 for the femur and 0.77 for the tibia, indicating a significant positive correlation between bone length and stature. Consequently, the findings of this study demonstrate that the length of the femur and tibia bones can serve as reliable predictors for estimating the stature of an individual. In conclusion, anthropometric measurements, particularly those involving long bones such as the femur and tibia, hold immense value in the identification of human remains in the field of forensic anthropology.

Keywords: Anthropometry; stature estimation; femur bone; tibia bone; regression equation.

1. INTRODUCTION

"Forensic anthropometry is a scientific specialization emerged from the discipline of forensic anthropology dealing with identification of human remains with the help of metric techniques". This advanced technique relies on a range of parameters to reconstruct and analyse human remains, thereby assisting in the identification and comprehension of individuals involved in criminal investigations or historical research [1].

One aspect of anthropometry is osteometry, encompassing the measurement of the skeleton and its various parts, including the skull. It is described as a method employed to obtain measurements from skeletal remains. By utilizing this technique, forensic scientists can examine the variations in skeletal structures among different populations worldwide. Osteometry has proven to be highly effective in estimating stature, age, and race in the fields of forensic and legal sciences. These four parameters, namely age, race, stature, and sex are widely recognized as the "Big Four" of forensic anthropology [1].

Estimating stature is one of these variables that is very important. Stature is a distinct biological characteristic that may be assessed from individual's skeleton years after they have passed away also from those who are still alive [2]. In order to establish the individuality of an unidentified deceased person or any mutilated part of such body, estimation of stature is a crucial step in the identification process of human skeletal remains or body parts [3]. Additionally, stature reconstruction is imperative in determining the relationship between stature and the measurements of different body parts [4].

Long bones, such as the femur and tibia, play a significant role in determining an individual's stature. These particular bones are more reliable indicators compared to the humerus and ulna [5]. Estimating a person's height can be achieved by examining long bones, particularly the tibia and femur, as they exhibit a direct correlation to an individual's height [6]. The femur is the longest and strongest bone in the human body and the tibia, which maintains its anatomical shape even after burial, are particularly suitable for this purpose. Additionally, the tibia makes up 22% of the total body length [7-9].

The estimation of stature is population-specific and depends on the deceased's ancestry, sex, and age of death. For the estimation of stature in different populations, mathematical formulae have been established. The anatomical method and the mathematical method are the two main methods for estimating stature. When a full skeleton is available for the forensic investigation, the anatomical technique may be used. This is accomplished by utilising some correction factors [10,11]. On the other side, using mathematical methods like regression analysis and the multiplication factor method, fragmentary bones and dismembered deceased bodies can be utilised to estimate stature [12].

A more suitable method for defining relationships between measurements of long bone fragments and their maximum length and between the length of long bones and living height of individuals is regression analysis [13].

The stature of an individual is affected by numerous factors. Therefore, the correlation factors observed in one region may not be applicable to another. Consequently, it is necessary to conduct research on a regional basis in order to gain a comprehensive understanding [3].

The objective of current pilot study was to utilize the length of long bones in the lower limbs (Right

femur and tibia) and to derive regression formulae for the females of Maharashtra population that would help the forensic investigators and professionals in improving accuracy in stature estimation methods.

2. METHODOLOGY

2.1 Study Sample and Experimental Design

A total of 150 girls within the age group of 18-24 years were randomly selected from 12 different districts of Maharashtra, namely Nagpur, Bhandara, Buldhana, Gondia, Wardha, Amravati, Latur, Parbhani, Yavatmal, Chandrapur, Beed, and Ahmadnagar etc. enrolled at the Government Institute of Forensic Science in Nagpur. The sample size distribution of aforementioned regions given in Fig. 1.

2.2 Inclusion Criteria

1. Healthy and asymptomatic

2.3 Exclusion Criteria

1. Below 18 years old (Age <18) and over the age of 25 (Age $\geq$ 25)
2. With systemic illnesses that affected stature

Prior to commencing the study, the purpose and methodology were thoroughly explained to all participants, and their consent was obtained.

The right femur and tibia bone were chosen as anthropometric parameters for this study. Initially, participants were instructed to sit in a relaxed position on a chair, with their head in a natural position. Using a measuring tape, the length of the femur bone was measured for each participant. This measurement involved determining the distance from the highest point that could be felt by touching the greater trochanter to the lowest point on the lateral femoral condyle (Fig. 2). Similarly, the length of the tibia was measured from the medial condyle to the medial malleolus (Fig. 3). To assess the stature of each participant, their vertical distance was measured from the plane where they stood barefooted to the vertex on their head. This measurement was taken with the participant's back against a fixed scale (Fig. 4). The purpose of this measurement was to compare the actual stature value with the calculated stature value. All measurements were recorded in centimeters (cm).

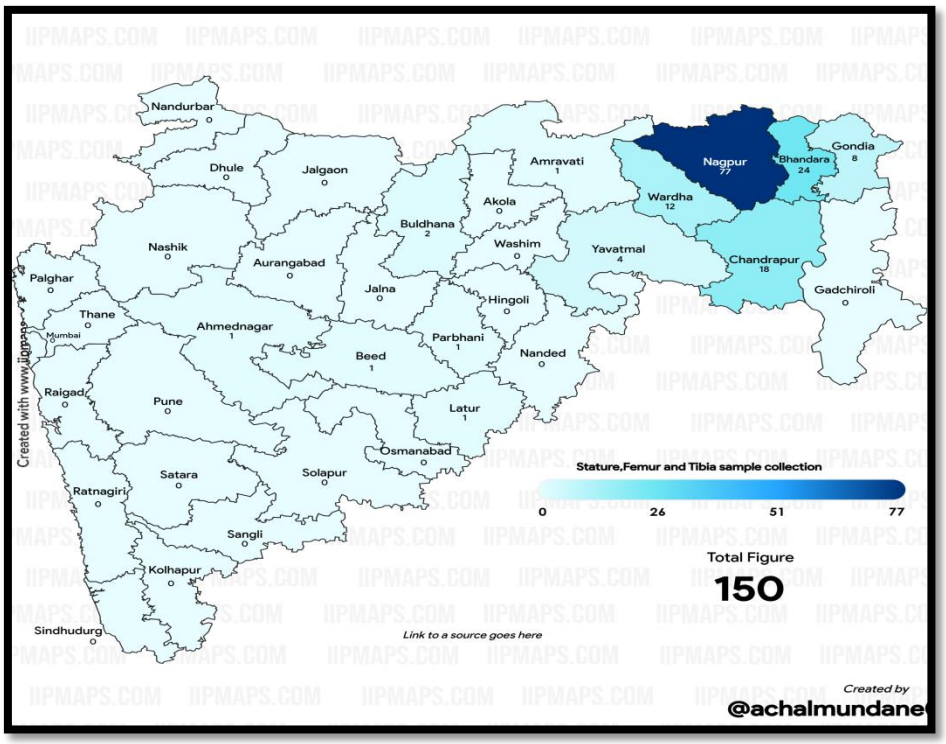

Fig. 1. Illustrates the sample size distribution across 12 districts of Maharashtra. This image has been sourced from (Iipmaps n.d.)

Fig. 2. Measurement of femoral bone length from greater trochanter to lateral condyle

Fig. 3. Measurement of tibia bone length from medial condyle to medial malleolus

Fig. 4. Stature determination by drawing a fixed scale on the wall

To ensure accuracy and minimize measurement errors, each measurement was performed thrice by the same individual. The mean of the three measurements was then calculated for each variable i.e., Femur bone, Tibia bone and Stature.

2.4 Statistical Analysis

All the data was entered and analyzed using Microsoft Excel 2010. Calculations were performed and the results were visually presented through graphs. The metric data, including femur length, tibia length, and stature, were reported as the mean values. P values lower than 0.05 were considered as significant. To examine the correlation between an individual's stature and anthropometric parameters (femur and tibia), the Pearson correlation coefficient (r) was utilized.

A regression equation has been derived to estimate stature based on femur and tibia bone measurements is given in the following form,

$$y = \beta 0 + \beta 1x$$

Where,

y =Stature
x = Femur Length or Tibia length
β0= Regression constant
β1= Regression coefficient

3. RESULTS

The mean values of variables, including femur length, tibia length, and stature, were calculated for a total of 150 samples. A correlation analysis was conducted to examine the relationship between stature and anthropometric parameters, specifically femur and tibial length. The regression equations derived from this analysis were y = 2.1515x + 75.798 for femoral bone length and y = 2.2967x + 80.146 for tibial bone length given in Table 1. Here, "x" represents the length of the femur or tibia, and "y" represents the stature of the individual, as shown in Fig. 5 and Fig. 6. The Pearson's correlation coefficient was found to be 0.92 for femur length and 0.77 for tibia length indicates a significant positive correlation between the length of the right femoral bone and stature, as well as between the length of the right tibial bone and stature.

The predicted height (y) obtained by randomly selecting femur length and tibial length values from the collected data, and calculating the stature using a regression equation, was found to be acceptable within a certain range of error. Moreover, it closely approximated the observed height. This suggests that the derived predicted stature is reliable and accurate.

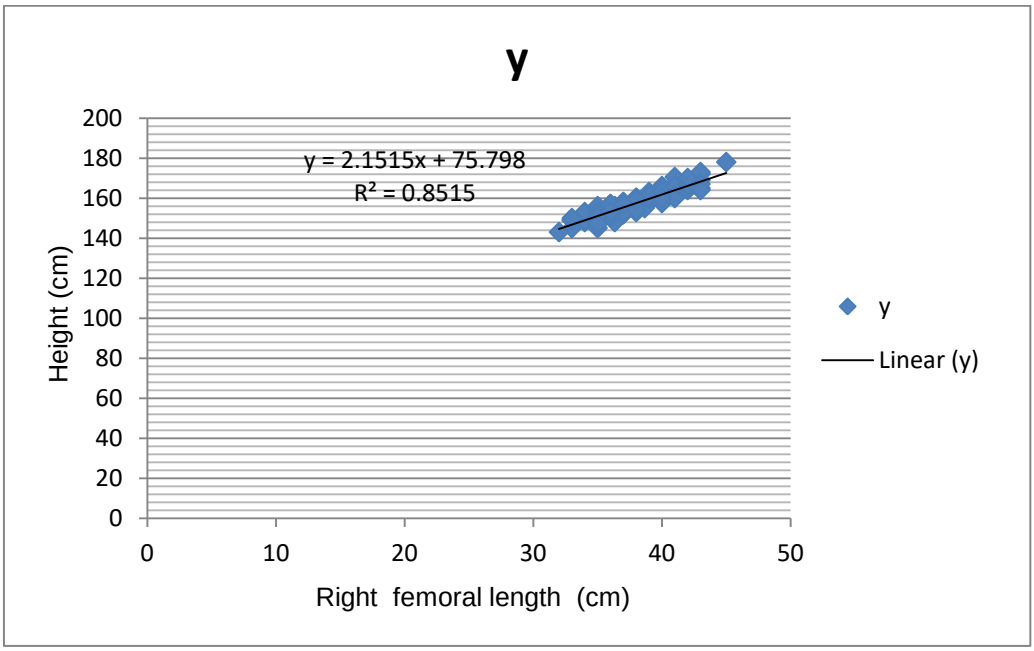

Fig. 5. Graph illustrates a correlation between the right femoral length and stature of participants

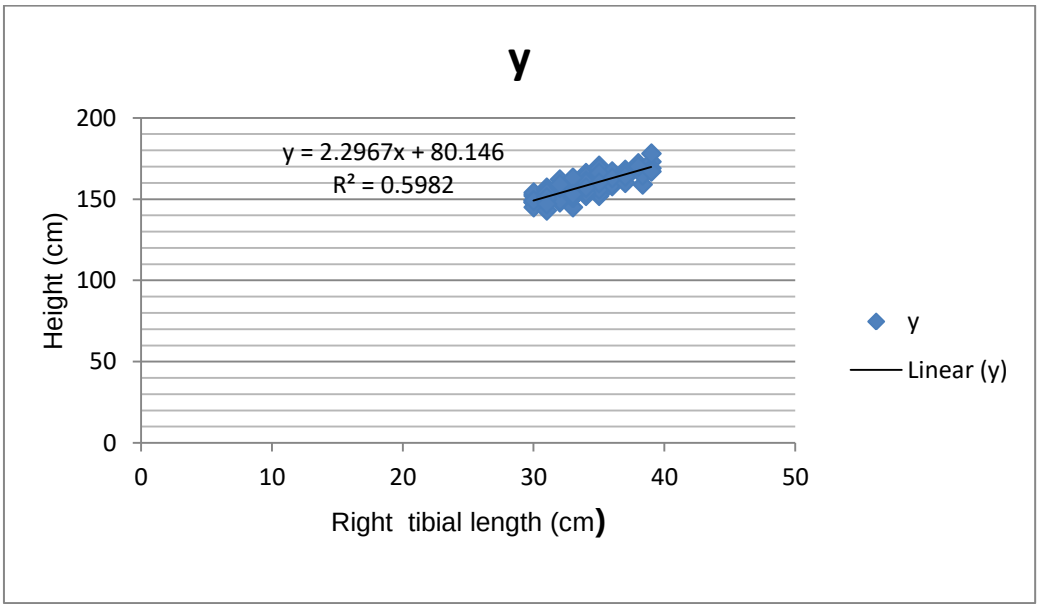

Fig. 6. Graph illustrates a correlation between the right tibial length and stature of participants

Table 1. Derivation of regression formula for right femoral bone and tibial bone

Variables ->	Right Femoral bone	Right Tibial bone
Regression equation	y = 2.1515x + 75.798	y = 2.2967x + 80.146
Regression constant (β0)	75.798	80.146
Regression coefficient (β1)	2.1515	2.2967
Correlation coefficient (r)	0.92	0.77
R^2	0.8515	0.5982

4. DISCUSSION

Identification is vital in both civil and criminal cases and is required for the living, recently deceased, decomposing, mutilated, and skeletal remains [7]. For physical anthropological and medicolegal investigations, stature is an innate trait that plays a crucial role in describing a person [14].

The assessment of stature using measurements of the human skeleton and long bones has been the subject of numerous research. There are several ways to estimate stature, but regression analysis is the quickest and most accurate method [3].

Accurate measurement of long bone length using available fragments is crucial in estimating an individual's stature. Among these bones, the femur and tibia hold utmost significance in determining height [15].

In 2013, Jeong and Meadows Jantz studied the stature of the Korean population using 105 participants and derived a regression equation in the process. The findings this study concluded that the length of long bones exhibits a stronger correlation with stature [16].

In a study by Rameswarapu Suman Babu (2016), 100 dried adult human femurs from both sexes were collected for morphometric assessments. The average femoral length and inter-trochanteric crests were found to be 41.66 cm and 5.98 cm, respectively. 0.64 was the Pearson's correlation coefficient. R-squared had a value of 0.426. The values were derived from the equation for 100 randomly chosen bones. The results of this work demonstrated the construction of precise osteometric standards for estimating stature from the femur of a recent South Indian population. As a result, this study comes to the conclusion that femur inter trochanteric crest length can be employed as a better alternative variable when evaluating body stature length utilizing regression formula [15].

In 2016, Naema Mahmoud elhosary et. al. concluded that linear regression equations were sex and ethnic specific and could not be applied to other ethnic groups (or populations) in their comparative research of height estimate from tibial length in the adult populations of Egypt and Bengali [17].

In order to find regression formulae for estimating the stature of males and females by measuring the length of the femur, a study was conducted on 200 medical students. From the maximum femur length, it was found that there was a statistically significant correlation between femur length and stature in both groups ($p < 0.001$). Femur length regression equations were statistically analyzed for males and females ($r=0.620$ and $r=0.602$, respectively) and were found to be significantly dependable in estimating the living stature of an individual [7].

Regression equations are demographic, sex specific, and ethnically specific. Therefore, when it comes to identifying unknowns, regression equations must be applied with utmost care, taking into account the specific characteristics of the population and even considering different sexes separately [18].

In order to evaluate the regression equation, which is population- and sex-specific, 150 girls from 12 districts of Maharashtra participated in the current study. In which the average of all variables, including stature, tibia length, and femur length, were determined for the n=150 samples. The correlation was made between the stature and anthropometric parameter (i.e., femur and tibial length). The Regression equation derived were $y = 2.1515x + 75.798$ and $y = 2.2967x + 80.146$ for femur and tibia respectively, where X is the femoral or Tibia length and y is the Stature of individual. The Pearson's correlation coefficient was 0.92 for femur and 0.77 for tibia which indicates that there is a significant positive correlation between right femur bone length and stature also with right tibia bone length and stature.

As individual height is influenced by ethnicity, it is crucial to note that regression formulae obtained in a specific population should not be indiscriminately applied to another. The utilization of regression formulae from a particular population in a different population can potentially lead to underestimation or overestimation of stature. Therefore, it is highly recommended to employ regression formulae derived from population-specific studies for accurate results in such cases [15].

5. CONCLUSION

Stature plays a crucial role in establishing the identification of an unknown person or a deceased individual. In this study, we focused on estimating stature by utilizing a regression equation derived from the lengths of the right

femoral and tibial bone. Our findings revealed a strong positive correlation between stature and bone length of females from the Maharashtra population. These results highlight the potential of femur and tibia bone lengths as reliable predictors for estimating the living height of an individual. This information can prove invaluable in forensic investigations, particularly in cases of mass disasters where bodies may be decomposed or mutilated due to various factors. In conclusion, the study underscores the importance of considering bone length, specifically the femur and tibia, in estimating stature. The implications of our findings extend to forensic investigations and anthropological research, offering valuable tools for professionals in these fields.

CONSENT

All authors declare that written informed consent was obtained from the participants.

ETHICAL APPROVAL

All authors hereby declare that all experiments have been examined and approved by the appropriate ethics committee and have therefore been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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