

Stature Estimation from Femur and Humerus Bone Using Radiographic Images in Eastern Uttar Pradesh

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www.jrasb.com || Vol. 4 No. 6 (2025): December Issue

Received: 19-11-2025

Revised: 23-11-2025

Accepted: 30-11-2025

ABSTRACT

This study developed region-specific regression models for stature estimation using femur and humerus measurements from CT scans of 300 individuals (150 males, 150 females) from Eastern Uttar Pradesh, a demographically diverse region, with ethical approval obtained. MS Excel, descriptive statistics, regression, and correlation analysis were used for the analysis. The findings suggested strong correlations between bone length and stature, with femur length being more predictive for females and humerus length for males. The proposed models demonstrated high accuracy and predictive power (high R^2 values), emphasizing the importance of population-specific approaches in forensic anthropology. These findings will continue to provide a reliable database for stature estimation in forensic and anthropological contexts, with potential for broader application in future studies incorporating larger samples and additional variables.

Keywords- Stature Estimation, CT scan, Regression, Correlation Coefficient, Statistics, Eastern Uttar Pradesh.

I. INTRODUCTION

Forensic anthropology, a specialized branch of biological anthropology, applies anthropological knowledge and methods to medico-legal contexts. This discipline focuses on the recovery, management, and analysis of skeletal remains to address questions of legal and humanitarian importance. By integrating principles from skeletal biology, archaeology, and cultural anthropology, forensic anthropology has become indispensable in solving complex forensic cases, particularly those involving unidentified, decomposed, or fragmentary human remains. The field aids in determining whether skeletal remains are human or non-human, the number of individuals present, and critical biological parameters such as age, sex, ancestry, and stature (Wood et al., 2002). Moreover, forensic anthropologists assist in identifying unique characteristics, analysing trauma, and estimating the time since death. These analyses are pivotal in helping legal

authorities establish identity and reconstruct events leading to an individual's demise (Ubelaker, 1997).

Among the various parameters estimated from skeletal remains, stature holds particular significance in forensic investigations. Stature estimation contributes directly to the identification of unknown individuals and has implications in both forensic and bioarchaeological contexts. While traditional anthropometric methods rely on direct measurement of skeletal remains, contemporary techniques have expanded to include radiographic imaging, offering a non-invasive means to estimate stature in both living and deceased individuals. In forensic cases, especially those involving mutilated or incomplete remains, accurate stature estimation provides valuable clues for narrowing down the identity of the deceased.

The humerus and femur are among the most reliable bones for estimating stature, given their strong correlation with overall body height. The femur, being the longest and strongest bone in the human body, accounts for a significant proportion of an individual's height.

Similarly, the humerus, as the longest bone in the upper limb, provides critical data for developing stature estimation models. Research has demonstrated that the lengths of these long bones can be used to derive regression models, enabling forensic anthropologists to estimate stature with a high degree of accuracy. However, the reliability of these models depends heavily on the population from which the regression equations are derived, as variations in limb-to-trunk ratios and other anatomical features differ across populations due to genetic, environmental, and nutritional factors (Trotter & Gleser, 1952; Patel et al., 2016).

The importance of population-specific regression models has been highlighted in numerous studies, underscoring the risks of applying generalized equations to diverse populations. For example, stature estimation equations developed for European or American populations often produce significant errors when applied to South Asian populations due to differences in body proportions. This discrepancy underscores the need for regionally tailored research that considers the unique anatomical characteristics of specific populations (Patel et al., 2016). In India, despite its vast and diverse population, limited studies have focused on developing regression models for stature estimation, particularly for the population of Eastern Uttar Pradesh. This region, characterized by distinct genetic, cultural, and environmental factors, represents a unique demographic whose skeletal characteristics may not align with those of other populations.

In recent years, advancements in radiographic imaging have revolutionized stature estimation methods. Radiographic techniques such as X-rays, CT scans, and MRI enable precise measurements of bone lengths without requiring the complete excavation or physical handling of skeletal remains. These methods are especially useful in forensic cases where bones are embedded in soft tissue or fragmented. High-resolution imaging provides accurate and reproducible measurements, reducing the potential for human error and enhancing the reliability of regression models (Kanchan et al., 2010). Furthermore, radiographic methods are invaluable in clinical and healthcare settings, where invasive procedures are not feasible. Studies have demonstrated that radiographic measurements are comparable in accuracy to direct physical measurements, making them a preferred choice in both forensic and archaeological contexts (Mahakkanukrauh et al., 2015).

The present study focuses on developing regression equations for stature estimation using radiographic measurements of the femur and humerus in the population of Eastern Uttar Pradesh, India. By addressing regional and population-specific variations, this research aims to provide accurate and reliable models for stature estimation, thereby contributing to forensic science and enhancing the accuracy of identification processes. Additionally, the study highlights the practical application of radiographic techniques in real-world

forensic investigations, where skeletal remains may be incomplete or inaccessible for direct measurement.

II. REVIEW LITERATURE

The relationship between human stature and skeletal or anthropometric measurements has been extensively studied across various populations, contributing significantly to forensic and anthropological research.

Pal et al. (2016) developed regression models for stature estimation from hand dimensions in 1662 Bengalee women aged 20–40 years. The study revealed a significant correlation between hand dimensions and stature, with multiple linear regression yielding more accurate estimates than simple regression. Sharma et al. (2016) examined tibial length in 400 Indian individuals and found a positive correlation with stature, providing reliable equations for forensic applications. Dixit et al. (2016), focusing on sternal length in a central Indian population, identified moderate reliability compared to long bones, indicating limited forensic utility. Pandey et al. (2017) studied ulna length in 300 students and derived gender-specific regression equations, demonstrating the ulna's utility in stature estimation. Similarly, Datta et al. (2018) highlighted the relevance of upper limb measurements for forensic identification in Uttarakhand, while Singh et al. (2019) explored foot dimensions in Jatt Sikh males, showing improved accuracy with multiple regression models. Nayak et al. (2019) examined finger length and found significant correlations with stature, creating reliable regression equations for South Indian populations. Uzun et al. (2019) extended the scope to upper extremity measurements in Turkish adults, demonstrating high accuracy in stature estimation. Lodhi et al. (2019) identified forearm length as a strong predictor of stature in the North Karnataka population, with regression equations showing high reliability. In Zhang et al.'s (2021) study, lower limb measurements were used to develop precise regression models for contemporary Han Chinese individuals, emphasizing the femur's predictive strength. More recent studies include Agarwala et al. (2021), who explored ring finger length as a novel parameter for stature estimation, and Shastri et al. (2021), who analysed femur characteristics, identifying strong correlations with femur length. Reddy et al. (2022) and Mer & Patel (2022) provided robust regression equations using hand, forearm, and finger measurements in South Indian and Gujarati populations, respectively. Kumar et al. (2023) validated femur length as a reliable predictor of stature in the Jammu population. Yadav et al. (2023) identified sex-specific predictors, such as leg and forearm lengths, to improve accuracy in the South Indian population.

These studies underscore the importance of population-specific regression models for forensic and medico-legal applications, demonstrating that regional

and demographic variations significantly influence the correlation between body measurements and stature.

III. RESEARCH OBJECTIVES

The objectives of this study are threefold:

- 3.1 To investigate the relationship between stature and the lengths of the femur and humerus.
- 3.2 To develop regression equations specifically tailored to the Eastern Uttar Pradesh population.
- 3.3 To evaluate the most suitable bone for stature estimation

IV. RESEARCH METHODOLOGY

4.1 Study Design

This study utilized a descriptive and analytical research design to develop population-specific regression models for stature estimation using femur and humerus measurements. Anthropometric and radiographic approaches were integrated for precision and reliability.

4.2 Study Area and Population

The research was conducted in the outpatient and radiology departments of Sir Sunder Lal Hospital, Institute of Medical Sciences, Banaras Hindu University, Varanasi, Uttar Pradesh, from April to June 2024. Participants were residents of Eastern Uttar Pradesh, a region with a dense and genetically diverse population.

4.3 Sample Selection and Criteria

A purposive sampling method recruited 300 participants aged 20–50 years, equally stratified by sex and bone type:

- Femur measurements: 75 males and 75 females.
- Humerus measurements: 75 males and 75 females.

Inclusion Criteria:

- Born and residing in Eastern Uttar Pradesh.
- Free from skeletal abnormalities or surgeries involving the femur or humerus.
- Within the specified age range.

Exclusion Criteria:

- Non-residents of Eastern Uttar Pradesh.
- Individuals with skeletal deformities.
- Incomplete or low-quality radiographic data.

4.4 Data Collection

4.4.1 Anthropometric Measurement: Standing height was measured using a stadiometer (precision ± 0.1 cm), recorded as the average of three measurements.

4.4.2 Radiographic Imaging: High-resolution CT scans measured femur and humerus lengths.

Femur: From femoral head to distal condyles.

Humerus: From humeral head to trochlea.

4.4.3 Control Variables: Participant age, sex, and geographical origin were documented to account for variability.

4.5 Statistical Analysis

4.5.1 Descriptive Analysis: Mean, standard deviation, median, and range were calculated.

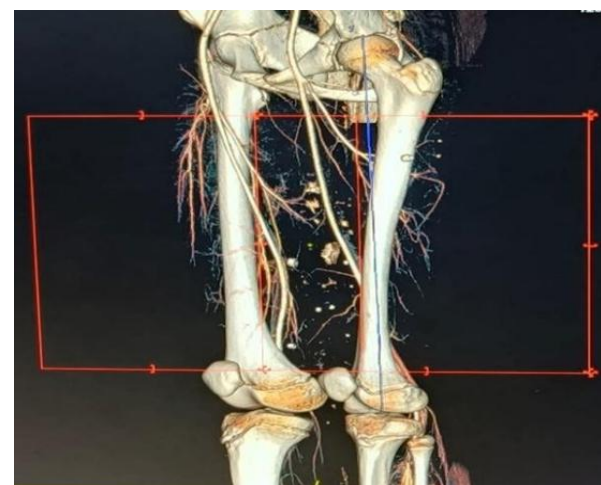
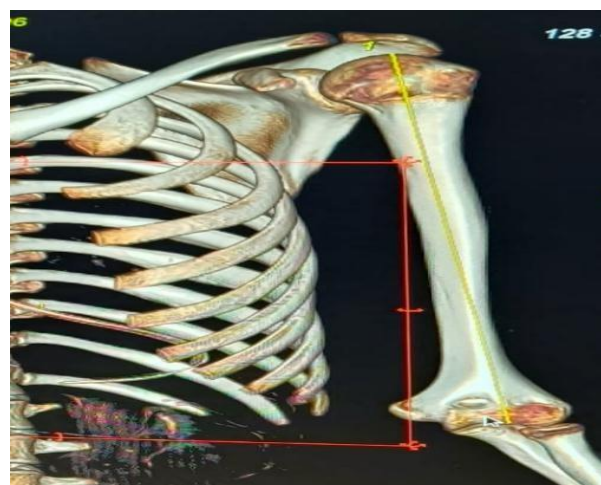
4.5.2 Correlation: Pearson's correlation coefficient assessed the relationship between bone length and stature.

4.5.3 Regression: Linear regression models predicted stature ($y = a + b x$), evaluated using R^2 , adjusted R^2 , and RMSE.

4.5.4 Inferential Analysis: ANOVA tested regression significance, and confidence intervals and SEM were calculated.

4.6 Ethical Consideration

The study was approved by the Institutional Ethics Committee of Banaras Hindu University. Informed consent was obtained, and participant confidentiality was maintained.



4.a CT Scan Image of Humerus and Femur Bone of subjects

4.7 Research Gap:

Although numerous studies have explored stature estimation using long bones, limited research has specifically focused on the Eastern Uttar Pradesh population, which exhibits distinct genetic and environmental characteristics. Existing regression models, primarily developed for Western and other South Asian populations, often fail to account for regional

variations, leading to inaccuracies in forensic applications. Despite advancements in radiographic techniques, prior studies have not extensively utilized CT scans for femur and humerus-based stature estimation in this region, highlighting a critical research gap that necessitates the development of population-specific regression models for improved forensic accuracy and applicability.

V. LIMITATION OF THE STUDY

- Sample size of 300 may not fully represent the diversity of Eastern Uttar Pradesh.
- Age range of 20–50 years excludes younger and older populations.
- Further research with larger, diverse samples and additional variables is needed to improve model accuracy and generalizability.

VI. DATA ANALYSIS AND INTERPRETATION

6.1 Relationship Between Stature and Limb Bones (Femur, Humerus)

Table no. 6.1.1, Correlation Between Stature and Femur Length (Male)

	<i>height(m)</i>	<i>femur length</i>
height(m)	1	
femur length	0.612902	1

The above Table shows the analysis of 75 male subjects, revealed a moderate positive correlation ($r = 0.6129$) between stature and femur length. This suggests that as femur length increases, stature tends to increase proportionally, indicating its reliability as a predictor.

Table no. 6.1.2, Correlation Between Stature and Femur Length (Female)

	<i>height(f)</i>	<i>femur length</i>
height(f)	1	
femur length	0.917788	1

The above table shows the analysis of 75 female subjects, revealed a strong positive correlation ($r = 0.9178$) was observed between femur length and stature. This high correlation indicates that femur length is an excellent predictor of stature in females, with a near-proportional relationship.

Table no. 6.1.3, Correlation Between Stature and Humerus Length (Male)

	<i>height(m)</i>	<i>humerus length</i>
height(m)	1	
humerus length	0.782091	1

The above table shows the analysis of 75 male subjects, shows the strong correlation between humerus length and stature ($r = 0.7821$). This signifies a robust relationship, highlighting humerus length as a reliable indicator of stature in males.

Table no. 6.1.4, Correlation Between Stature and Humerus Length (Female)

	<i>height(f)</i>	<i>humerus length</i>
height(f)	1	
humerus length	0.683256	1

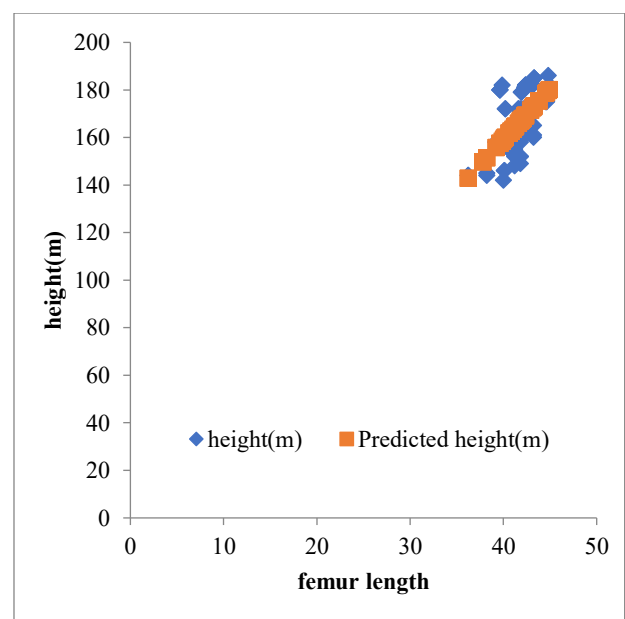
The above table in the case of 75 females, a moderate to strong correlation ($r = 0.6833$) was found between humerus length and stature. While this indicates a positive relationship, the predictive power of humerus length for stature is slightly lower in females compared to males.

6.2 Proposed Regression Equations for Stature Estimation

Table no. 6.2.1, Regression Equation for Height and Femur Length (Male)

<i>Regression Statistics</i>	
Multiple R	0.612902
R Square	0.375649
Adjusted R Square	0.367096
Standard Error	10.08349
Observations	75

The regression analysis for 75 males yielded a moderate correlation ($r = 0.6129$) with an R^2 value of 0.3756, indicating that 37.6% of the variance in height is explained by femur length. The regression equation is: Height (y) = $-12.3755 + 4.2882 \times \text{Femur Length}$ (Eq.1)

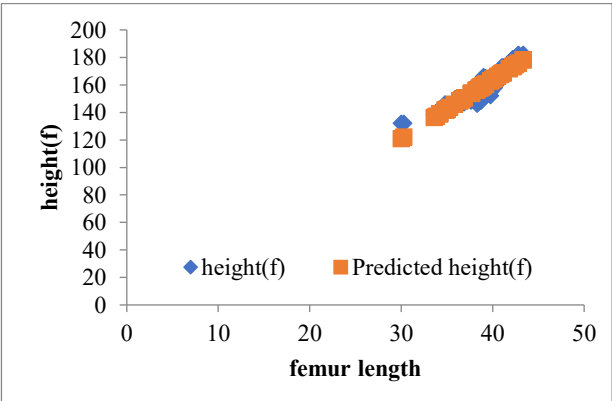


6.2.a Femur Length Line Fit Plot (male)

Table no. 6.2.2, Regression Equation for Height and Femur Length (Female)

Regression Statistics	
Multiple R	0.9177876
R Square	0.842334078
Adjusted R Square	0.840174271
Standard Error	5.300895605
Observations	75

For 75 females, a strong correlation ($r = 0.9178$) with an R^2 value of 0.8423 was observed, meaning 84.2% of the variance in height is explained by femur length. The regression equation is:
Height (y) = $-8.0672 + 4.2971 \times \text{Femur Length}$ (Eq.2)

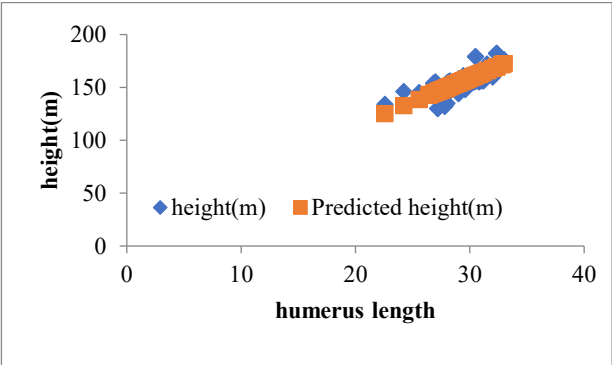


6.2.b Femur Length Line Fit Plot (female)

Table no. 6.2.3, Regression Equation for Height and Humerus Length (Male)

Regression Statistics	
Multiple R	0.782091471
R Square	0.611667069
Adjusted R Square	0.606347439
Standard Error	7.332839028
Observations	75

In males, a strong correlation ($r = 0.7821$) with an R^2 value of 0.6117 indicated that 61.2% of the variance in height is explained by humerus length. The regression equation is:
Height (y) = $22.3725 + 4.5478 \times \text{Humerus Length}$ (Eq.3)

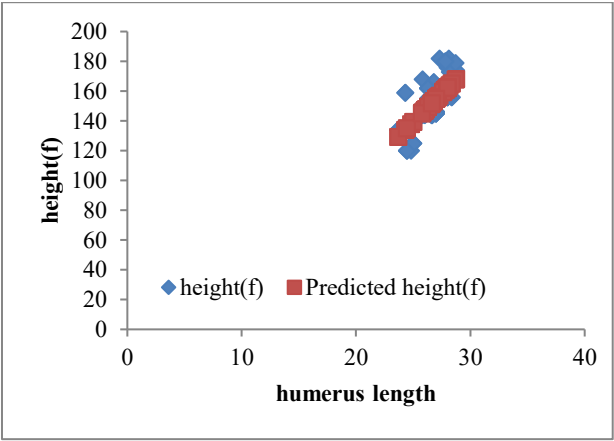


6.2.c Humerus Length Line Fit Plot (male)

Table no. 6.2.4, Regression Equation for Height and Humerus Length (Female)

Regression Statistics	
Multiple R	0.683256
R Square	0.466839
Adjusted R Square	0.459535
Standard Error	10.07207
Observations	75

Among females, a moderate correlation ($r = 0.6833$) with an R^2 value of 0.4668 showed that 46.7% of the variance in height is explained by humerus length. The regression equation is:
Height (y) = $-52.4476 + 7.6761 \times \text{Humerus Length}$ (Eq.4)



6.2.d Humerus Length Line Fit Plot (female)

6.3 Evaluation of the Most Suitable Bone for Stature Estimation

6.3.1 Femur Length

Based on the values derived out of the analysis of femur, it was found majorly the following highlights between the genders:

- **Males:** Moderate correlation ($r = 0.6129$) and $R^2 = 0.3756$, indicating femur length explains 37.6% of height variance.
- **Females:** Very strong correlation ($r = 0.9178$) and $R^2 = 0.8423$, making femur length an excellent predictor, explaining 84.2% of height variance.

6.3.2 Humerus Length

Based on the values derived out of the analysis of Humerus, it was found majorly the following highlights between the genders:

- **Males:** Strong correlation ($r = 0.7821$) and $R^2 = 0.6117$, showing humerus length explains 61.2% of height variance, outperforming femur length.
- **Females:** Moderate correlation ($r = 0.6833$) and $R^2 = 0.4668$, with humerus length explaining 46.7% of height variance, less reliable than femur length.

Based on the above analysis out of the data collected it can be concluded that Femur length is the most reliable bone for stature estimation in females, while humerus length is a better predictor for males.

VII. FINDINGS

- The correlation between stature and femur length in males was found to be a moderate positive correlation, with a value of $r = 0.6129$ (**Table 6.1.1**).
- The correlation between stature and femur length in females showed a strong positive correlation, with a value of $r = 0.9178$ (**Table 6.1.2**).
- The correlation between stature and humerus length in males was determined to have a strong positive correlation, with a value of $r = 0.782$ (**Table 6.1.3**).
- The correlation between stature and humerus length in females ranged from moderate to strong, with a value of $r = 0.6833$ (**Table 6.1.4**).
- Based on the tables above, equations have been derived between stature and the femur/humerus bone of the subjects (**Eq. 1, 2, 3, and 4**).
- With the analysis we could found that when it comes to overall subjects, it showed a very strong correlation between stature and femur length in females ($r = 0.9178$) and explaining 84.2% of the variance in height (**Table 6.2.2**) means there is a very strong connection between femur length and height. When the femur length changes, height also changes in a very predictable way. 84% of variance means that 84% of the differences in subjects heights can be explained just by measuring their femur length. It shows how much femur length influences height. The remaining 16% could be due to other factors like genetics, nutrition, or measurement errors.

VIII. CONCLUSION

This study examined how the height of people in Eastern Uttar Pradesh can be estimated using the length of their thigh bone (femur) and upper arm bone (humerus). Femur length emerged as the most reliable predictor, with a strong correlation ($r = 0.9178$) in females and moderate correlation ($r = 0.6129$) in males. The humerus also contributes, with strong correlation in males ($r = 0.7821$) and moderate correlation in females ($r = 0.6833$), but is less effective than the femur. The derived regression equations effectively convert these bone measurements into estimated heights. Consequently, by measuring an individual's femur or humerus length and substituting that value into the appropriate equation, one can accurately estimate stature. It simplifies the process of height estimation based on bone measurements. The derived regression equations enable accurate stature estimation, particularly in forensic contexts involving unidentified or fragmented remains. The findings underscore the need for population-specific models, with femur length being especially accurate for females.

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