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Anatomy

EVALUATION OF THE ACCURACY OF HUMAN HEIGHT USING LENGTH OF ULNA IN ADULTS AT A TERTIARY CARE CENTRE IN EASTERN GUJARAT, INDIA: A CROSS-SECTIONAL STUDY

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ABSTRACT **Background:** The assessment of stature and sex from skeletal elements is crucial in forensic anthropology, anatomy, and medicolegal investigations, particularly when complete bodies are unavailable. Long bones such as the ulna and tibia show a strong correlation with stature, but population-specific predictive models are limited for the Indian population. To assess the relationship between stature and ulnar length and to evaluate its accuracy of its measurement for sex determination in a young adult in Indian population. **Methods:** This observational cross-sectional study included healthy adults aged 18–25 years from a tertiary care teaching hospital in eastern Gujarat, India. Standing height, and ulnar length were measured using standardized anthropometric techniques. Data were analyzed using Pearson's correlation, simple and multiple linear regression, and discriminant function analysis. Statistical significance was set at $p < 0.05$. **Results:** A total of 500 healthy adults (250 males and 250 females) were recruited in the study. Males had significantly greater stature and long bone lengths than females ($p < 0.001$). Ulnar and showed significant positive correlations with height in both sexes. Furthermore, discriminant function analysis showed significant sex classification ability for ulnar length (Wilks' Lambda = 0.801; $\chi^2 = 110.18$; $p < 0.001$). **Conclusion:** Ulnar length is a reliable predictor of stature. The derived population-specific regression and discriminant models may be useful for stature estimation and sex determination in forensic and anthropological contexts within similar populations.

KEYWORDS : Ulnar Length, Sex Determination, Regression Analysis, Discriminant Function Analysis, Anthropometry

INTRODUCTION

Body height is an important anthropometric parameter for individual identification [1]. Human stature shows a consistent relationship with the growth of the limbs and trunk; however, these proportions vary with sex, age, and ethnicity. There is therefore a need for reliable alternative methods of height estimation, especially in situations such as mass disasters where stature must be reconstructed from skeletal remains [2]. Accurate measurement of height, along with body weight, is essential for assessing nutritional status and determining pharmacokinetic parameters. Furthermore, in cases of murder, accidents, or natural disasters that result in highly decomposed, fragmented, or mutilated human remains, estimation of stature provides valuable information for personal identification. In such circumstances, direct measurement of standing height is often difficult or impossible, highlighting the importance of indirect methods of stature estimation [2, 3].

Body height is most accurately measured in the standing position with the individual barefoot and the back against a stadiometer. The head should be aligned in the Frankfurt plane, with slight elevation achieved by gentle pressure over the mastoid processes and zygomatic bones. However, direct measurement of height using standard methods may be difficult or impractical in certain hospitalized patients, such as those who are bedridden, elderly, frail, or those with deformities of the limbs or spinal column [4]. For this purpose, several methods have been developed to estimate stature. Numerous formulas based on long bone length have been proposed; however, applying a formula derived from one population to another often leads to inaccuracies. For instance, individuals of African ancestry generally have relatively longer upper and lower limb bones, making formulae developed for such populations unsuitable for direct application to Asian populations [5, 6].

The ulna is a long bone of the forearm located medially, with the olecranon process at its proximal end forming the elbow joint with the humerus and a styloid process at its distal end. The ulna can be palpated along its entire length. Ossification of the ulna begins around the eighth week of fetal life, with fusion of the proximal epiphysis occurring by approximately 16 years and the distal epiphysis by around 20 years of age [7]. The ulna has easily identifiable surface landmarks, allowing measurements to be obtained even in compromised postures more readily than with many other bones. Consequently, it has been widely used for indirect estimation of stature, and several researchers have proposed linear regression models based on percutaneous ulnar length to predict height [8–11]. Despite the importance and practical application of stature–long bone correlations, there remains a notable lack of population-specific data for the Indian population. The present study aims to analyze the relationship between stature and the morphometric measurements of the tibia and ulna. The study also evaluates the accuracy of stature estimation using these long bone parameters and developing population-specific criteria for height prediction. Focusing on the Gujarati population, this study seeks to clarify how tibial and ulnar dimensions correlate with stature and to contribute to the development of reliable regression models for estimating height in this ethnic group.

Methodology

Study Design and Settings : This is an observational cross-sectional study to evaluate the relationship between stature and selected limb measurements among young adults carried out in the Department of Anatomy, Parul Institute of Medical Sciences & Research, Parul University, Vadodara, Gujarat, India. Ethical approval was obtained from the Institutional Ethics Committee, and the trial was prospectively registered with the Clinical Trials Registry of India. The study was conducted in accordance with the principles of the Declaration of Helsinki and informed consent was taken from all the participants of the study.

Participant Selection

Healthy adults aged 18–25 years with no known musculoskeletal abnormalities were included in the study. Individuals were excluded if they were below 18 years or > 25 years of age, had a history of injury, deformity, or surgical intervention involving the upper or lower limbs, or had any growth-related or skeletal disorders that could affect anthropometric measurements.

Study Procedure

Data collection was carried out twice weekly over a period of one year. All measurements were obtained by trained personnel using standardized anthropometric techniques to minimize inter-observer error.

Anthropometric Measurements

Height Measurement: Standing height was measured using a stadiometer. Participants were instructed to stand erect with heels together, feet flat on the floor, and the back against the vertical surface of the stadiometer. The head was positioned in the Frankfurt horizontal plane to ensure proper alignment. The movable headpiece was lowered to touch the highest point of the head, and height was recorded in centimeters.

Ulnar Length Measurement: Ulnar length was measured on both the right and left sides. The participant's elbow was flexed, with the palm placed over the opposite shoulder. The distance from the tip of the olecranon process to the tip of the styloid process of the ulna was measured using a measuring tape and recorded in centimeters.

Sample Size

A total of 500 students (250 males and 250 females) from the MBBS and Nursing programs at Parul Institute of Medical Sciences & Research were included in the study. The sample comprised 150 final-year MBBS students (Batch 2021–22), 150 MBBS interns (Batch 2020–21), 100 third-year nursing students, and 100 nursing interns. For limb-specific analysis, anthropometric measurements were recorded separately for the right and left sides in both male and female participants.

Statistical Analysis

Data was entered in excel sheet and analyzed using Statistical Package for the Social Sciences (SPSS) version 23.0. Descriptive statistics were calculated for all variables. The relationship between stature and limb measurements was assessed using Pearson's correlation coefficient. Linear regression analysis was performed to derive regression equations and multiplication factors. The statistical significance of the models was evaluated using t-tests and F-tests, with a p-value of < 0.05 considered statistically significant.

RESULTS

A total of 500 students were included in the study, with participants equally distributed by gender, comprising 250 males and 250 females. The mean age was comparable between both genders, with no statistically significant difference (p = 0.882). Statistically significant gender differences were observed in stature and long bone measurements. Males had a significantly greater mean height (165.69 ± 6.46 cm) compared to females (157.07 ± 6.61 cm; p < 0.001). Mean ulnar length also differed significantly, with males showing longer ulnae (27.68 ± 2.52 cm) compared to females (25.65 ± 1.65 cm; p < 0.001). These results demonstrate clear sexual dimorphism in stature and long bone dimensions, supporting the need for gender-specific models in stature estimation (Table 1).

Table 1: Comparison of Age, Stature, and Long Bone Measurements Between Male and Female Participants

Variables	Gender*	Mean	Std. Deviation	P value
Age (Years)	Male	21.49	2.500	0.882
	Female	21.42	2.272	
Height (cm)	Male	165.689	6.4604	<0.001
	Female	157.068	6.6136	
Length of Ulna (cm)	Male	27.675	2.5238	<0.001
	Female	25.650	1.6484	

*250 males and 250 females

The regression analysis revealed a statistically significant positive relationship between ulnar length and height in both females and males (p < 0.001).

In males, the relationship between ulnar length and height was weaker but still statistically significant (R = 0.371), accounting for 13.7% of the variability in stature ($R^2 = 0.137$; Adjusted $R^2 = 0.134$). The model demonstrated a standard error of estimate of 6.01 cm and was highly significant (F = 39.355). The male regression equation (Height = 133.42 + 0.949 × ulnar length [cm]) indicates that height increases by approximately 0.95 cm for every 1 cm increase in ulnar length (Figure 1; Table 2).

In females, ulnar length showed a moderate correlation with height (R = 0.503), explaining 25.3% of the variation in stature ($R^2 = 0.253$; Adjusted $R^2 = 0.250$). The regression model was statistically significant (F = 83.872) with a standard error of estimate of 5.73 cm, indicating moderate predictive accuracy. The derived regression equation (Height = 105.33 + 2.017 × ulnar length [cm]) suggests that each 1 cm increase in ulnar length corresponds to an approximate 2.02 cm increase in height in females (Figure 2; Table 2). Collinearity diagnostics showed ideal values in both genders (Tolerance = 1.000; VIF = 1.000), confirming the absence of multicollinearity and the stability of the regression models (Table 3).

Table 2: Regression Model for Height and Ulna for male and female

Gender	R	R^2	Adjusted R^2	Std. Error of the Estimate	F Change	p-value
Female	.503a	0.253	0.250	5.7287	83.872	0.000
Male	.371a	0.137	0.134	6.0122	39.355	0.000

Table 3: Collinearity Statistics[a]

Gender	Tolerance	VIF
Female	1.000	1.000
Male	1.000	1.000

a. Predictors: (Constant), Length of Ulna (cm)

Ulnar length showed a significant ability to discriminate between males and females, with a standardized discriminant coefficient of 0.469. The derived discriminant function was D = 0.469(UL) − 12.513. Group centroids were positive for males (0.476) and negative for females (−0.474), with a sectioning point of 0.001, indicating effective separation between the sexes. The model demonstrated moderate discriminative power, as reflected by an eigenvalue of 0.227 and a canonical correlation of 0.43. Wilks' Lambda was 0.815, and the chi-square test was statistically significant ($\chi^2 = 101.431$; $p < 0.001$), confirming that ulnar length is a significant predictor for sex determination in the study population (Table 4).

Table 4: Sex Estimation Model Based on Length of Ulna

Variable	Ulnar length
UL	0.469
Constant	-12.513
Male	0.476
Female	-0.474
Sectioning Point	0.001
Eigen value	0.227
Canonical Correlation	0.43
Eilk Lambda	0.815
Chi Square	101.431
p-value	<0.001

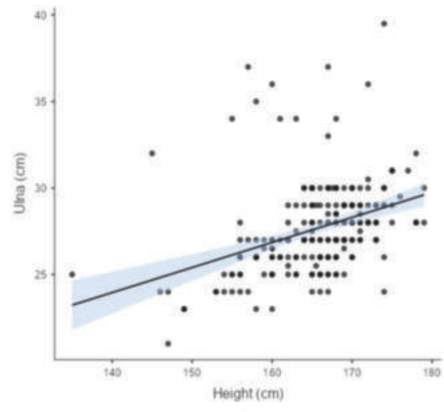

Figure 1: This Scatter Plot for Male Showing the Relationship Between Height (cm) on the X-axis and Ulna Length (cm) on the y-axis

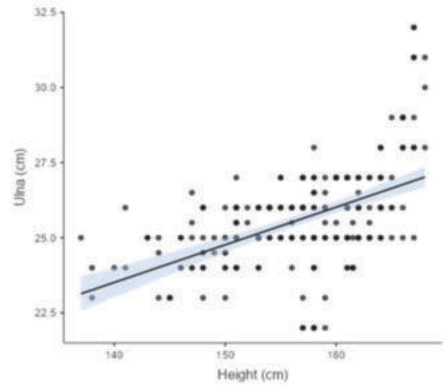

Figure 2: This Scatter Plot for Female Showing the Relationship Between Height (cm) on the X-axis and Ulna Length (cm) on the y-axis

DISCUSSION

Height is influenced by factors such as age, gender, and race, and therefore varies across different populations [12]. In this study, the ulna was chosen because it is subcutaneous and its surface landmarks are easily measurable. Measuring ulna length can be particularly useful in cases where deformities affect the lower trunk or lower extremities [12]. Estimating height using ulna length proved to be more accurate and reliable compared to other methods involving the foot [13], tibia [14], or skull [15].

In the present study, 500 students were evaluated, with an equal distribution of males and females. I study observed a significant gender-based differences that were evident in stature and long bone dimensions. Males exhibited a considerably greater mean height (165.69 ± 6.46 cm) than females (157.07 ± 6.61 cm; $p < 0.001$). Similarly, the mean tibial length was higher in males (35.66 ± 4.11 cm) compared to females (34.01 ± 2.86 cm; $p < 0.001$), and ulnar length was also significantly greater in males (27.68 ± 2.52 cm) than females (25.65 ± 1.65 cm; $p < 0.001$).

In this study, ulnar length showed a significant positive association with height in both sexes, with a weaker correlation in males and a moderate correlation in females. A study by Gul et al., also reported statistically significant correlations and regression models for estimating stature from ulnar length in males, females, and the overall population ($p < 0.001$) [7]. Barbosa et al. demonstrated that ulna length can reliably predict height across age groups and populations, with minimal error and strong correlation, supporting its practical use for accurate stature estimation, consistent with the present study [8]. Furthermore, studies by Mondal et al. and Prasad et al. also support the utility of ulnar length for stature estimation across different Indian populations, reinforcing the need for population- and gender-specific regression models for precise height prediction [9, 16].

A study by Agnihotri et al., validated the linear relationship between stature and long-bone lengths and highlighted improved accuracy when ulnar and tibial measurements were combined [17]. Another similar observation is seen in the study by Lemtur et al., who reported significant sexual dimorphism and positive linear correlations between stature and both ulnar lengths in males and females [18].

This study further demonstrated that ulnar length a statistically significant capacity to differentiate between males and females in the study population. The discriminant function derived from ulnar length effectively separated the sexes, with distinct group centroids for males and females and a clearly defined sectioning point, indicating reliable classification. Although the discriminative strength of the model was moderate, as evidenced by the eigenvalue and canonical correlation, the statistically significant Wilks' Lambda and chi-square values underscore the robustness of ulnar length as a predictor of sex. These findings support the utility of ulnar length as a practical and dependable parameter for sex estimation, particularly in forensic contexts where limited skeletal elements are available. These were similar to the observation seen in the study by Banyeh et al. which showed that height can be reliably estimated using ulna (UL) providing the highest accuracy for sex classification (82.9%) [19].

However, this study has certain limitations. It is conducted among young adults (18–25 years) from a single region, restricting generalizability to other age groups and populations. Measurements from living subjects may introduce minor soft-tissue variability, and external validation was not performed. Future multicentric studies with broader age ranges and diverse populations are needed to strengthen and validate these predictive models.

CONCLUSION

The study demonstrates a strong, sex-specific relationship between stature and ulnar length in young Indian adults. Ulnar length serves as a statistically significant and practical parameter for sex estimation, demonstrating reliable discriminatory ability between males and females in the studied population. These observations highlight the utility of ulnar length measurements in forensic, anthropological, and clinical applications for stature reconstruction and sex estimation.

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