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ORIGINAL ARTICLE

Estimation of Stature from Forearm Length in Medical Undergraduate Students of a Rural Tertiary Medical College

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ABSTRACT

Background: Accurate stature estimation is essential in forensic identification, clinical practice, and nutritional assessment, particularly when direct height measurement is unfeasible. Forearm length has emerged as a reliable anthropometric surrogate, yet population-specific regression equations are critically lacking for rural-dwelling young adults in India.

Objectives: To evaluate the correlation between forearm length and stature in healthy MBBS first-year students stratified by sex and age, and to derive a linear regression equation for stature estimation from forearm length.

Methods: A prospective observational cross-sectional study enrolled 300 first-year MBBS students (151 males, 149 females; age 18–24 years) using convenience sampling at a rural tertiary medical college. Stature and forearm length (radial head to ulnar styloid) were measured in duplicate following ISAK protocols. Pearson's correlation, sex-stratified analysis, and simple linear regression were performed using SPSS v23.

Results: Mean stature was 166.23 ± 8.73 cm and mean forearm length 25.05 ± 1.56 cm. A strong positive correlation between forearm length and stature was observed ($r = 0.86$, $p < 0.001$). Sex correlated strongly with stature ($r = 0.67$) and forearm length ($r = 0.58$), both $p < 0.001$. Age showed a weak but significant correlation with stature ($r = 0.14$, $p = 0.016$) but not with forearm length ($r = 0.07$, $p = 0.202$). The derived regression equation was: Stature (cm) = 45.612 + 4.814 × Forearm Length (cm) [$R^2 = 0.739$, SEE = 4.46 cm, $F = 844.889$, $p < 0.001$].

Conclusion: Forearm length is a strong, reproducible predictor of stature in young adult medical students from a rural Indian tertiary institution. The derived regression

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equation provides a practical, population-specific forensic and clinical tool.

KEYWORDS:

• Stature Estimation • Forearm Length • Anthropometry • Linear Regression • Forensic Anthropology • Medical Students • India

INTRODUCTION

Stature estimation is a foundational component of the biological profile in both forensic anthropology and clinical medicine. The ability to accurately predict height from individual body segments assumes critical importance in diverse scenarios, including forensic identification of dismembered or decomposed remains, assessment of nutritional status in immobilised patients, prosthetic fitting, and epidemiological surveillance of growth disorders.[1,2] Classical stature estimation formulae, such as those proposed by Trotter and Gleser using femoral and tibial measurements, were largely derived from North American cadaveric populations.[3] These equations frequently demonstrate systematic inaccuracy when applied to non-Western, South Asian, or rural cohorts, underscoring the need for population-specific anthropometric standards.[4]

From a global epidemiological perspective, approximately 149 million children under five years of age were stunted as of 2022, and adult height variation continues to be mapped across populations as a marker of long-term nutrition, disease burden, and socioeconomic development.[5] India's National Family Health Survey (NFHS-5, 2019–21) data document persistent inter-regional disparities in mean stature, with rural populations demonstrating systematically shorter heights compared to urban counterparts due to differences in nutritional intake, early-life infections, and socioeconomic vulnerability.[6] In resource-constrained rural healthcare settings, direct height measurement is often precluded by patient immobility, orthopaedic deformity, or the absence of calibrated stadiometers, necessitating validated surrogate anthropometric measures.[7]

Among the anthropometric surrogates studied, the forearm, anatomically bounded by the head of the radius proximally and the styloid process of the ulna distally, offers distinctive advantages. It is accessible, easily measured in both living subjects and skeletal remains, relatively resistant to nutritional stunting compared to weight-dependent measures, and demonstrates consistent proportional growth with stature through adolescence and early adulthood.[8] Multiple studies across geographically diverse populations have demonstrated strong positive linear correlations between forearm length and standing height, supporting the derivation of reliable regression equations for stature prediction.[9,10] Critically, however, these equations are inherently population-specific because regression coefficients reflect the interaction of genetic heritage, nutritional history, and environmental factors that define body proportions within each cohort.[11,12]

A recent study by Boonthai *et al.* (2024) developed population-specific stature estimation equations using forearm bone measurements in a Northeastern Thai cohort and demonstrated significantly stronger accuracy when sex-specific equations were employed (SEE: 4.87–5.35 cm) compared to pooled models.[13] Similarly, studies from the Indian subcontinent have reported correlation coefficients between forearm length and stature ranging from 0.82 to 0.97, with the highest values observed in sex-stratified analyses.[14] Ahmed *et al.* (2021) identified ulnar length as the best single predictor of stature among Saudi men, highlighting the importance of forearm bone measurements across different ethnic populations.[15] Despite this growing body of evidence, data specific to rural medical college populations in central India, a region characterised by tribal, semi-urban, and agrarian demographic profiles, remain sparse and represent an important knowledge gap.

Beyond forensic utility, forearm-based stature estimation offers significant clinical applications. In bedridden patients, individuals with bilateral lower-limb amputations, or those with severe spinal deformities, forearm length provides a non-invasive and rapid surrogate for height that assists in body mass index calculation, pharmacokinetic dosing, and nutritional assessment.[16] Increasing recognition that race and geography substantially affect the validity of universal stature equations has further strengthened the need for geographically anchored normative data.[17,18]

The present study was therefore designed to address this gap by: (i) characterising the anthropometric profile of first-year MBBS students at a rural tertiary medical college; (ii) quantifying the Pearson's correlation between forearm length and stature in the overall cohort and according to sex and age subgroups; and (iii) deriving a validated linear regression equation for stature estimation from forearm length in this population. The findings aim to contribute a population-specific reference tool relevant to forensic medicine, clinical anatomy, and rural healthcare practice in India.

MATERIALS AND METHODS

Study Design and Setting

This was a prospective, observational, cross-sectional study conducted over a six-month period at the Department of Anatomy of a rural tertiary medical college affiliated with a recognised Indian university. The study was conducted in accordance with the principles of the Declaration of Helsinki (2013 revision) and received approval from the Institutional Ethics Committee (IEC) prior to commencement. Written informed consent was obtained from each participant before enrolment.

Study Population and Sample Size

The target population comprised healthy first-year MBBS students aged 18 to 24 years. A sample of 300 students was enrolled (151 males, 149 females), providing adequate statistical power (>80%) to detect a Pearson's correlation of $r \geq 0.80$ at $\alpha = 0.05$. Convenience sampling was employed, wherein students were recruited on a voluntary basis during scheduled anatomy practicals. Inclusion criteria required participants to be healthy, aged 18–24 years, free of any musculoskeletal or neurological disorder known to affect limb growth, and willing to provide written informed consent. Exclusion criteria encompassed skeletal deformities, fractures, prior orthopaedic surgeries affecting the forearm or spine, pregnancy, and refusal to participate.

Anthropometric Measurements

All measurements were performed by trained investigators following the anthropometric protocols recommended by the International Society for the Advancement of Kinanthropometry (ISAK). Two consecutive measurements were recorded for each parameter, and the arithmetic mean was used for analysis to minimise random error. Stature was measured using a calibrated Holtain anthropometer with the participant standing erect in the Frankfurt Plane—heels together, shoulders relaxed, and vertex aligned with the measuring headpiece; recorded to the nearest 0.1 cm. Forearm length was defined as the straight-line distance from the head of the radius (palpated at the lateral elbow in 90° flexion) to the tip of the ulnar styloid process (palpated at the medial wrist), with the forearm supinated and placed on a flat horizontal surface; recorded to the nearest 0.1 cm. Weight was recorded using a calibrated digital scale (SECA 813) to the nearest 0.1 kg.

Statistical Analysis

All statistical analyses were performed using IBM SPSS Statistics version 23. Descriptive statistics (mean, standard deviation, minimum, maximum) were computed for all variables. Pearson's correlation coefficient (r) was calculated to examine bivariate associations between stature, forearm length, age, and sex. Simple linear regression was performed with average stature as the dependent variable and average forearm length as the independent predictor using the Enter method; model fit was assessed by R^2, adjusted R^2, F-statistic, and standard error of the estimate (SEE). All tests were two-tailed; a p-value < 0.05 was considered statistically significant.

Ethical Considerations

Participation was entirely voluntary and participants could withdraw at any time without consequence. All data were anonymised; personal identifiers were replaced with unique study numbers. Data records will be securely archived for a minimum of three years post-publication. No financial incentives were provided.

RESULTS

1. Demographic Characteristics and Age Distribution

A total of 300 MBBS first-year students were enrolled, with ages ranging from 18 to 24 years. The age groups of 18 years (16.0%), 21 years (15.7%), and 23 years (15.3%) were most represented, while 22-year-olds constituted the smallest proportion (12.0%) (Table 1). Among participants, 151 (50.3%) were male and 149 (49.7%) were female, reflecting near-equal sex representation (Table 2). The broadly uniform age and sex distribution minimises demographic confounding in subsequent anthropometric analyses.

Table 1: Distribution of Study Participants According to Age (N = 300)

Age (Years)	Frequency (n)	Percentage (%)
18	48	16.0
19	40	13.3
20	42	14.0
21	47	15.7
22	36	12.0
23	46	15.3
24	41	13.7
Total	300	100.0

Broad representation across all age groups (18–24 years) minimises age-related bias in anthropometric correlation analyses.

Table 2: Distribution of Study Participants According to Sex (N = 300)

Sex	Frequency (n)	Percentage (%)
Male	151	50.3
Female	149	49.7
Total	**300**	**100.0**

Near-equal sex distribution (50.3% male, 49.7% female) supports balanced sex-stratified anthropometric analyses.

2. Descriptive Statistics of Anthropometric Variables

The mean stature across the full cohort was 166.23 ± 8.73 cm (range: 143.7–190.0 cm) and mean forearm length was 25.05 ± 1.56 cm (range: 20.3–28.8 cm). Repeated measurements showed excellent intra-observer reproducibility, with near-identical means between first and second stature readings (166.22 vs. 166.23 cm) and forearm readings (25.05 vs. 25.06 cm), confirming measurement reliability. Mean body weight was 64.78 ± 10.06 kg. Full descriptive statistics are presented in Table 3.

Table 3: Descriptive Statistics of Anthropometric Variables Among Study Participants (N = 300)

Variable	N	Min	Max	Mean ± SD	Range
Age (years)	300	18	24	20.95 ± 2.02	6
Weight (kg)	300	37.6	90.9	64.78 ± 10.06	53.3
Average Stature (cm)	300	143.7	190.0	166.23 ± 8.73	46.3
Average Forearm Length (cm)	300	20.3	28.8	25.05 ± 1.56	8.5

SD: standard deviation; Min: minimum; Max: maximum. Average values represent the arithmetic mean of two successive measurements. Stature: measured from vertex to floor with Frankfurt Plane alignment using a calibrated Holtain anthropometer. Forearm Length: measured from the head of the radius to the tip of the ulnar styloid process with forearm supinated.

3. Correlation Between Forearm Length and Stature (Primary Objective)

A strong, statistically highly significant positive correlation was consistently observed between stature and forearm length across all three measurement pairs. The Pearson correlation coefficient was $r = 0.86$ ($p < 0.001$) for first measurements, second measurements, and averaged values alike (Table 4), confirming both the strength and reproducibility of this bivariate association. This finding indicates that forearm length alone accounts for approximately 74% of the variance in stature, establishing it as a highly reliable single-segment predictor.

Table 4: Pearson's Correlation Between Stature and Forearm Length (N = 300)

Variables Compared	r	p-value	Interpretation
$Stature_1$ vs. $Forearm_1$	0.86	< 0.001*	Strong positive
$Stature_2$ vs. $Forearm_2$	0.86	< 0.001*	Strong positive
Avg. Stature vs. Avg. Forearm	0.86	< 0.001*	Strong positive

r: Pearson's correlation coefficient; *Statistically significant at $p < 0.001$ (two-tailed); Avg.: arithmetic mean of two successive measurements; $Stature_1$/$Forearm_1$: first measurement; $Stature_2$/$Forearm_2$: second measurement.

4. Correlation of Age and Sex with Stature and Forearm Length (Secondary Objective)

Age demonstrated a weak but statistically significant positive correlation with stature (r =

0.14, p = 0.016) but not with forearm length (r = 0.07, p = 0.202) (Table 5), suggesting a marginal residual growth contribution to height within the 18–24 year band while forearm length has largely stabilised. Sex demonstrated a strong and highly significant positive correlation with both stature (r = 0.67, p < 0.001) and forearm length (r = 0.58, p < 0.001) (Table 6), confirming that males showed substantially greater values for both parameters. These findings affirm sex as the dominant determinant of anthropometric variability in this cohort and highlight the future necessity for sex-specific regression models.

Table 5: Pearson's Correlation Between Age and Anthropometric Variables

Variables Compared	r	p-value	Significance
Age vs. Avg. Stature (cm)	0.14	0.016*	Significant
Age vs. Avg. Forearm Length (cm)	0.07	0.202	Not significant

r: Pearson's correlation coefficient; *p < 0.05 (two-tailed); Avg.: arithmetic mean of two successive measurements.

Table 6: Point-Biserial Correlation Between Sex and Anthropometric Variables

Variables Compared	r	p-value	Significance
Sex vs. Avg. Stature (cm)	0.67	< 0.001*	Highly significant
Sex vs. Avg. Forearm Length (cm)	0.58	< 0.001*	Highly significant

Sex coded as binary variable (male = 1, female = 0); r: point-biserial correlation coefficient; *p < 0.001 (two-tailed); Avg.: arithmetic mean of two successive measurements.

5. Linear Regression Model for Stature Estimation

Simple linear regression with average forearm length as the sole predictor explained 73.9% of the total variance in average stature (R = 0.860, R^2 = 0.739, Adjusted R^2 = 0.738, SEE = 4.46 cm). The overall model was highly significant (F = 844.889, df = 1, 298, p < 0.001). The unstandardised regression coefficient for forearm length was B = 4.814 (SE = 0.166, t = 29.067, p < 0.001) and the constant was 45.612 (SE = 4.163, t = 10.957, p < 0.001), yielding the following predictive equation (Table 7):

Stature (cm) = 45.612 + 4.814 × Forearm Length (cm)

This equation indicates that for every 1 cm increase in forearm length, stature increases by approximately 4.81 cm. The minimal difference between R^2 and Adjusted R^2 (0.739 vs. 0.738) confirms model parsimony and stability for application within comparable populations.

Table 7: Linear Regression Analysis: Model Summary, ANOVA, and Coefficients for Stature Estimation from Forearm Length

Parameter	R	R²	Adj. R²	SEE (cm)	F-value (p)
Model Summary	0.860	0.739	0.738	4.46	844.889 (< 0.001*)
Predictor	**B**	**SE(B)**	**β**	**t**	**p-value**
Constant	45.612	4.163	–	10.957	< 0.001*
Forearm Length (cm)	4.814	0.166	0.860	29.067	< 0.001*

R: correlation coefficient; R^2: coefficient of determination; Adj. R^2: adjusted coefficient of determination; SEE: standard error of the estimate (cm); B: unstandardised regression coefficient; SE(B): standard error of B; β: standardised regression coefficient; t: t-statistic; F: F-ratio (ANOVA); *p < 0.001 (two-tailed); df = 1, 298. Dependent variable: Average Stature (cm); Predictor: Average Forearm Length (cm); method: Enter.

DISCUSSION

The present study demonstrated a strong positive linear correlation between forearm length and stature (r = 0.86, p < 0.001) among 300 first-year MBBS students at a rural tertiary medical college and generated a predictive regression equation: Stature (cm) = 45.612 + 4.814 × Forearm Length (cm) [R^2 = 0.739, SEE = 4.46 cm]. Sex significantly influenced both stature and forearm length (p < 0.001), while age showed only a weak association with stature within the 18–24 year age group. These findings are consistent with contemporary anthropometric literature.

The observed correlation coefficient of r = 0.86 represents one of the stronger single-segment anthropometric associations reported in Indian student populations. Bal and Bapuli (2022) reported an even higher correlation (r = 0.97) among Kolkata medical students, possibly due to greater demographic homogeneity and differences in anatomical landmark selection.[14] Karmalkar and Nikam (2021), studying a broader adult cohort aged 18–50 years, documented a lower correlation (r = 0.75) between ulnar length and stature [21], likely reflecting increased age-related anthropometric variability. Internationally, Boonthai *et al.* (2024) derived stature estimation equations in a Northeastern Thai population with SEE values ranging from 4.87 to 5.35 cm, comparable to the present SEE of 4.46 cm[13] Together, these findings reinforce that forearm dimensions remain reliable predictors of stature across South and Southeast Asian populations.

The biological basis of this association lies in coordinated long-bone growth regulated through growth hormone and IGF-1 mediated endochondral ossification during puberty and adolescence.[19] Forearm epiphyseal fusion is generally completed by 18–22 years, making forearm length relatively stable during early adulthood and explaining its persistent correlation with stature despite minimal age-related variation.

The regression coefficient obtained in this study (B = 4.814) indicates that stature increases by approximately 4.81 cm for every 1 cm increase in forearm length. Ahmed *et al.* (2021) similarly identified ulnar length as a strong predictor of stature among Saudi males, although multi-parameter models demonstrated slightly higher predictive accuracy.[15] Madadin and Menezes (2022) also confirmed the utility of upper-limb dimensions in stature estimation among Eastern Saudi males using population-specific equations.[19] The R^2 value of 0.739 in the present study exceeds the values reported by Boonthai *et al.*[13] and Karmalkar and Nikam[21], possibly due to the relatively homogeneous nature of the present cohort consisting of medical students from a single institution.

Sex showed a strong positive association with both stature (r = 0.67) and forearm length (r = 0.58), confirming established patterns of sexual dimorphism in skeletal growth. Male participants demonstrated greater anthropometric dimensions, likely due to prolonged pre-pubertal growth and testosterone-mediated skeletal expansion[20] Mulu and Sisay (2021) similarly reported stronger height correlations among male Ethiopian adolescents compared to females.[21] Mbagwu *et al.* (2025) additionally observed significant socioeconomic and sex-based differences in adolescent anthropometric parameters in Nigerian schoolchildren.[22] These findings support the need for sex-specific regression equations, as pooled models may reduce predictive precision. Boonthai *et al.* (2024) demonstrated that sex-stratified equations achieved substantially lower SEE values than combined models.[13]

Age demonstrated a weak but statistically significant correlation with stature (r = 0.14, p = 0.016) but not with forearm length (r = 0.07, p = 0.202). This likely reflects residual late growth among some male participants, while forearm dimensions had already stabilised. Wang *et al.* (2024) reported consistent forearm-to-height proportionality across age groups using Kinect DK validation studies[8], supporting the relative stability of forearm measurements as anthropometric predictors. Baum and Man (2024) further highlighted that universal stature equations often perform inconsistently across ethnic populations[17], emphasising the value of locally derived regression models such as the present equation.

Clinically, the derived equation has practical applications in bedridden, orthopaedic, critically ill, or amputee patients where direct stature measurement is difficult. Forearm length can provide a rapid surrogate for height estimation required for BMI calculation, nutritional assessment, and medication dosing.[7,16] Pinto *et al.* (2025) further demonstrated the forensic relevance of forearm bone measurements for biological sex estimation in skeletal samples[18], highlighting the broader medico-legal utility of forearm anthropometry.

Several limitations should be acknowledged. The study was conducted at a single institution using convenience sampling, limiting generalisability. Sex-specific regression equations were not derived. Important covariates such as nutrition, socioeconomic status, physical activity, and parental stature were not assessed. Inter-observer variability was also not formally evaluated. Future studies should include larger multi-centric populations, sex-specific modelling, and multivariate anthropometric predictors to improve predictive accuracy.

CONCLUSION

This study establishes that forearm length is a robust, reproducible, and practically accessible predictor of stature in young adult first-year MBBS students from a rural tertiary medical college in India. The derived linear regression equation, Stature (cm) = 45.612 + 4.814 × Forearm Length (cm) [R^2 = 0.739, SEE =

4.46 cm], provides a validated and population-specific tool for forensic and clinical stature estimation when direct height measurement is not feasible. Sex was identified as a strong determinant of both stature and forearm length, and the development of sex-stratified equations should be prioritised in future studies. These findings add to the growing evidence supporting forearm anthropometry as a reliable forensic and clinical surrogate for stature estimation in the South Asian rural population.

DECLARATIONS

Ethics Approval and Consent to Participate: The study received approval from the Institutional Ethics Committee in accordance with the Declaration of Helsinki (2013 revision). Written informed consent was obtained from all participants.

Availability of Data: De-identified data are available from the corresponding author on reasonable request.

Conflicts of Interest: The authors declare no conflicts of interest.

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