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Correlation Between Living Stature and Ulna Length in Maharashtrian Adolescents Aged 17–19 Years: A Cross-sectional Study

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ABSTRACT

Background: When patients cannot stand or only partial remains are available, stature must be estimated from limb dimensions. The ulna is a practical choice because its bony landmarks are sub-cutaneous and its length stabilises by late adolescence. **Objective:** To derive sex-specific regression equations for predicting stature from percutaneous ulna length in Maharashtrian adolescents aged 17–19 years. **Methods:** A cross-sectional study was conducted on 70 first-year MBBS students (40 males, 30 females) at Government Medical College, Dharashiv. Standing height was taken with a Harpenden stadiometer. Ulna length—olecranon tip to ulnar styloid—was measured on both sides with a digital calliper; individual skin-fold thickness was deducted to approximate true bone length, and the two sides were averaged. Pearson's correlation quantified the height–ulna relationship; ordinary least-squares regression generated prediction equations, which were internally validated by 1000-sample bootstrap resampling. **Results:** Boys averaged 165.9 $\pm$ 4.4 cm in height and 27.28 $\pm$ 1.10 cm in ulna length; girls averaged 155.4 $\pm$ 3.9 cm and 24.79 $\pm$ 1.02 cm, respectively (both $p < 0.001$). Height correlated strongly with ulna length ($r = 0.79$ in boys, 0.73 in girls). The derived equations were: Boys – Stature = 58.98 + 3.92 $\times$ Ulna; Girls – Stature = 37.08 + 4.78 $\times$ Ulna. Standard error of estimate was ~2.7 cm, and 83 % of male and 80 % of female predictions lay within $\pm$5 cm of actual height. **Conclusion:** Percutaneous ulna length offers a quick, low-cost and acceptably accurate proxy for stature in Maharashtrian late-adolescents. The present sex-specific formulas can help clinical nutrition, anthropometry and forensic identification, though periodic re-validation in broader youth samples is advised.

KEYWORDS: Body Height, Ulna, Anthropometry, Adolescent, Regression Analysis, India

INTRODUCTION

Stature is an important biological measure in growth monitoring, nutritional surveys and medico-legal identification. [1] Accurate reconstruction of height becomes essential when a person cannot stand or when only partial skeletal remains are available. [2] For estimating height, regression equations that use the long-bone measurements are the standard method. [3] These equations, however, work best when they are developed for a specific age group and population because limb-to-stature proportions vary with genetics, climate and nutrition. [3]

A range of surrogate markers have been employed to measure height, such as knee height, leg length, ulna length, hand length and demispan. [4]Among upper-limb elements, the ulna is well suited for such work because its olecranon and styloid processes are subcutaneous and easily palpable along almost the entire shaft. The bone completes epiphyseal fusion around 18–20 years, so its length is practically fixed by late adolescence. [5]The measurement was designed such that it donot cross any joints in the belief that the fewer joints involved, the less likely it is affected by joint deformities and that the length of a long bone remains continually constant in any posture - sitting, standing or lying. In present study, the ulna bone which was utilised is an easily identifiable surface landmarks, making the measurement possible even in vulnerable postures. [6]

Empirical studies from West Bengal [7] and Pakistan [8] confirm a strong, linear ulna-stature relationship, reporting coefficients of determination (R^2) above 0.70. These findings support the ulna as a practical proxy when standing height is unobtainable. Data for Indian adolescents remain limited. Secular gains in height and marked socio-economic differences within the state may reduce the accuracy of formulas framed from adults or from other regions. [9]

Therefore, this cross-sectional study aimed to develop and internally validate sex-specific regression equations that estimate stature from percutaneous ulna length in Maharashtrian adolescents aged 17–19 years.

MATERIALS AND METHODS

Study design and setting: A descriptive cross-sectional study was conducted in the Department of Anatomy, Government Medical College (GMC) Dharashiv, Maharashtra, from July 2023 to December 2023.

Participants: All first-year MBBS students aged 17–19 years who had resided in Maharashtra for $\geq$10 years and whose parents were Maharashtrian by birth were eligible. Exclusion criteria were: (i) history of upper-limb fracture or congenital skeletal deformity, (ii) chronic illnesses affecting growth, and (iii) refusal of written informed consent. A numbered roster of eligible students was generated and simple random sampling (computer-generated numbers) selected the final sample to minimise selection bias.

Formal permission of head of institute was taken. Written informed consent was obtained from all participants; data were anonymised with coded identifiers.

Sample-size calculation: The required sample (n) was estimated with

$$n=((Z\_(1-\alpha/2\ )+ Z\_(1-(\beta)/2\ )\ )+(1-r\^{}2\ ))/r\^{}2$$

where r = 0.70 (anticipated Pearson correlation between ulna length and stature derived from a recent Indian dataset) [1], α = 0.05 and power = 80 %. The minimum n was 60; allowing 15 % non-response, 70 students were enrolled and complete data for all was obtained.

Variables in the study are Outcome: standing height (cm). Primary explanatory variable: mean ulna length (cm) and Covariate: sex (male/female).

Anthropometric measurements: Stature was measured between 09:00 am and 11:00 am with a calibrated Harpenden stadiometer; the better of two consecutive readings agreeing within $\pm$0.3 cm was recorded.

Ulna length: with the elbow flexed 90°, forearm pronated on a table, a vernier calliper stadiometer (precision 0.01 cm) measured the linear distance from the olecranon tip to the ulnar styloid on both sides shown in figure 1. Before each measurement, skinfold thickness over each landmark was determined using a Harpenden skinfold calliper; the average soft-tissue thickness (right + left)/2 was subtracted from each raw distance to approximate true bone length, thereby improving accuracy over fixed deductions. [10] The mean of the corrected right and left values represented the participant's ulna length.

Quality assurance: Two trained investigators performed all measurements. Inter- and intra-observer reliability, assessed in 10 % of participants, yielded intraclass correlation coefficients of 0.96 for height and 0.94 for ulna length, indicating excellent agreement. Investigators measuring ulna length were blinded to the recorded stature to reduce information bias. Instruments were calibrated weekly.

Statistical analysis: Data were double-entered and analysed with SPSS version 20. Normality was assessed with the Shapiro–Wilk test. Sex-stratified Pearson correlation coefficients (r) and coefficients of determination (R^2) quantified linear associations. Simple linear regression (Stature = β_0 + β_1 · Ulna length) produced sex-specific prediction equations with 95 % confidence intervals and standard error of estimate. Assumptions (linearity, homoscedasticity, normality of residuals) were checked graphically; robust regression was pre-specified if violations occurred. Internal validation used bootstrap resampling (1000 iterations). A two-tailed p < 0.05 denoted statistical significance.

Data-sharing and transparency: The STROBE checklist and data-analysis scripts are available in the institutional repository upon reasonable request.

RESULT

Seventy first-year MBBS students met the eligibility criteria and completed all measurements (40 males, 30 females). The mean age of the cohort was 18.0 $\pm$ 0.6 years and did not differ by sex (p = 0.14). Summary anthropometry is shown in Table 1.

Variable	Males (n = 40)	Females (n = 30)	p -value*
Height, cm	165.9 $\pm$ 4.4	155.4 $\pm$ 3.9	<0.001
Corrected ulna length, cm	27.28 $\pm$ 1.10	24.79 $\pm$ 1.02	<0.001
Height : ulna ratio	6.09 $\pm$ 0.25	6.27 $\pm$ 0.26	0.007

Values are mean $\pm$ SD. *Independent-samples t-test after confirming normality with Shapiro–Wilk (all p > 0.05).

Table 1: Gender wise average values of Ulna, Height and their ratio in adolescents.

The mean length of ulna in males was 27.28 cms (SD+1.10) and in females was 24.79 cms (SD+1.02) respectively. The difference between mean length of ulna is statistically significant between male and female. Adolescent males were on average 10.5 cm taller (95 % CI 8.2–12.7 cm) and had ulnae 2.49 cm longer (95 % CI 1.99–2.99 cm) than females.

Correlation between ulna length and stature: Scatter-plot inspection showed a linear relation in both sexes without influential outliers. (Figure 1) Pearson's correlation coefficients were strong and highly significant and Height and length of ulna was found to be positively correlated in both males and females. (Table 2).

Sex	r (95 % CI)	R^2	SEE, cm
Male	0.79 (0.63 – 0.88)	0.63	2.70
Female	0.73 (0.52 – 0.86)	0.53	2.67
Combined	0.88 (0.80 – 0.92)	0.77	2.44

SEE = standard error of estimate of the regression.

Table 2: Gender wise correlation coefficients of Height and length of ulna in adolescents

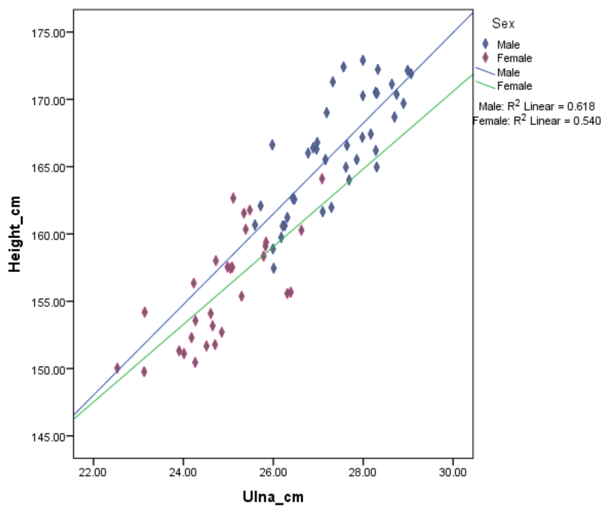

Figure 1: Scatterplot withSex-specific regression lines showing linear positive correlation between Height and length of ulna in adolescents.

The linear arregression equation for estimation of height from ulna was calculated from sex specific regression equation as in Table 3. The prediction formulae for estimation of height from ulna was calculated as

Stature (cm) = 58.98 + 3.92 × ulna length (cm) in males and

Stature (cm) = 37.08 + 4.78 × ulna length (cm) in females

Bootstrap analysis demonstrated minimal optimism, supporting use of these equations in similar settings. 83% of males and 80% of females estimates lies within ± 5cm of actual stature.

Sensitivity analyses: Repeating the regressions with robust (Huber) estimators and with the right-side ulna alone changed β_1 by <0.05 and R^2 by <0.01, confirming that averaging sides and ordinary least-squares were adequate.

DISCUSSION

This study provided sex-specific regression equations that predict stature from percutaneous ulna length in Maharashtrian adolescents aged 17 – 19 years. Ulna

Model	Intercept (β_0)	Slope (β_1)	95 % CI for β_1	p for β_1
Male	58.98	3.92	2.96 – 4.88	<0.001
Female	37.08	4.78	3.61 – 5.95	<0.001
Combined	51.06	4.21	3.60 – 4.82	<0.001

Table 3: Sex-specific regression equations of height and length of ulna in adolescents aged 17–19 years

length had positive correlation with stature in both sexes. The correlation coefficients reached 0.79 in boys and 0.73 in girls, accounting for 63 % and 53 % of height variance, respectively. These is comparable to the findings in Vietnamese [4] and New-Zealand [5] teenagers, where coefficients above 0.70 have been recorded.

We experienced slightly challenging in locating the anatomical landmark in a relatively non-obese population. The measurement will be even more convenient in the malnourished patients. Locating the anatomical landmarks required no special training, apart from prior indication of the landmarks by sight and palpation. This will enable the use of these equations in nursing homes, hospitals and the community.

Sex-specific linear models were derived for Boys: Stature = 58.98 + 3.92 × Ulna length, and for Girls: Stature = 37.08 + 4.78 × Ulna length. The standard error of estimate was about 2.7 cm; 83 % of boy-predictions and 80 % of girl-predictions fell within ±5 cm of true height. Comparable precision has been achieved with fibula-plus-ulna in older adults and with knee-height equations used in clinical nutrition. [6, 11] The male slope aligns with the Sudanese adult constant, whereas the female slope is midway between New-Zealand data and values from Indo-Mauritian children suggesting that limb–trunk proportions differ by ethnicity and age. [3, 5, 12]

A similar finding was reported by Pandey et al. [13], who documented a statistically significant right–left difference in ulna length among central-Indian adults and confirmed a clear positive correlation between ulna length and stature. This observation supports our decision to average both sides for routine use while showing that, if only one forearm can be assessed, clinicians should consider the small but consistent side variation.

Gauld and colleagues examined 2343 healthy Melbourne school children and adolescents (5 to 19 years) and showed that ulna length is a reproducible, precise predictor of stature across childhood and adolescence, comparable to the present study's results and extend their applicability across a wider age range. [14]

Gul and colleagues [1] found the sex-specific equations as Stature (cm)=70.369 + 3.698 × Ulna for males and 18.562 + 5.617 × Ulna for females in 100 healthy adults (50 males and 50 females) at Nishtar Medical University, Multan. Interestingly, their male slope (3.698) is a little lower than this study's value (3.92), while their female slope (5.617) is higher than ours (4.78). Such variation clearly shows that we should use sex-wise, region-wise formulas; even within South Asia as the constants change with genetics, diet and local environment, so one "universal" equation will not give reliable results everywhere.

Such cross-population shifts are not confined to India; Numan et al. [15] demonstrated that hand–stature equations varied appreciably among the three major Nigerian ethnic groups, once again proving that every population demands its own limb-based formula for reliable use.

Estimation of stature is important in calculating body mass index, which is used for assessment of nutrition. However, its measurement is not always feasible in elder or frail bedridden patients or with vertebral column deformities. In such cases, ulna-based equations are alternative for estimating stature and, in turn, BMI. [6] Trotter and colleagues later observed that cadaveric height tends to rise by roughly 2.5 cm after death, a factor that must be kept in mind while applying living-person formulas to skeletal or post-mortem material. [16]

The above method of stature estimation can be used by forensic scientists and law enforcement agencies. The precaution which must be considered is that these formulae are applicable to the population from which the data have been collected due to inherent population variations in these dimensions, which may be attributed to genetic and environmental factors like climate, nutrition etc.

LIMITATIONS

This study has a few clear limitations. We studied only 70 healthy first-year MBBS students in narrow age range from one college which limits generalisability to all adolescents with wider age ranges and regions. The design was cross-sectional and the model was not validated in an outside group. Ulna length was corrected for skin-fold thickness and averaged from both sides whereas in routine settings, a single reading or an uncalibrated calliper could widen the error. Lastly, nutritional changes affect the growth and improving every decade, these constants should be rechecked from time to time.

CONCLUSION

Ulna length proved to be a handy proxy for height in late-adolescent Maharashtrians. We derived simple, sex-wise equations that predict stature within about $\pm$5 cm for most boys and girls. Because the bone is easy to palpate and the measurement can be taken with the patient sitting or lying down, these formulas will help clinicians, nutritionists and forensic teams whenever standing height is not possible. Even so, the numbers apply best to similar local youth and should be updated as growth patterns change.

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