

## Estimation of Human Stature Among North Indian Population Using Palpable Percutaneous Landmarks of Upper Limb

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### ABSTRACT

**Introduction:** There is a paucity of data regarding stature estimation using the upper limb bone length in North Indian population. The present study was conducted around the National capital region to develop a regression analysis-based formula to calculate the stature from the upper limb measurements.

**Materials and methods:** The study enrolled 1000 healthy participants after written informed consent (500 male and 500 female) of age group between 18–30 years between January 2025 to December 2025. The participants were undergraduate students of SGT University, Gurugram (Haryana). Length of the long bones and height of the participants were recorded percutaneously using a stadiometer. A linear regression model was used to estimate the extent of reliable prediction of the stature from the measurements of the bone length for all three bones.

**Results:** The mean height of male was 173.5cm and the mean height for female was 163.4cm. In both males and females, the lengths for humerus, radius and ulna were positively correlated with the stature on both sides and they were statistically significant. The standardized beta for humerus, radius and ulna were 0.343, 0.089 and 0.401 respectively. Using the regression model, stature equation was derived as  $38.564 + 1.386 \times (\text{Length of Humerus}) + 0.559 \times (\text{Length of Radius}) + 2.710 \times (\text{Length of Ulna})$ .

**Conclusions:** The value of standardized beta shows that the length of ulna serves as the most reliable and consistent parameter for estimation of stature among the North Indian population.

**KEYWORDS:** Regression Analysis, Stature Estimation, Long Bones, Upper Limb, Humerus.

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## INTRODUCTION

Forensic medicine delves upon stature estimation based on the skeletal remains, as an important tool for deriving the identification of an individual. Such part or complete bones additionally serve to identify the gender of the victim or casualty with the applications going beyond a crime scene to include mass casualty and natural events where identification becomes essential for personal reasons [1]. Researchers have tried to use a variety of methods for the purpose of estimating the stature from the long bones but there have been challenges in a one size fit all strategy since the estimates vary from region to region and between races [2].

The stature estimation is mainly based on two standard techniques: (1) the anatomical method where a complete skeleton is analyzed to ascertain the stature, or (2) the mathematical model based on the regression analysis where a single long bone (complete) is sufficient to predict the stature. This is especially useful when a complete skeleton is not available [3]. Another morphological criteria for sorting the bones for the purpose of associating the bone to an individual involves analysis of the bones' compatibility on the basis of their colour, texture, size and robustness [4].

The search of the available literature showed that a few studies have been conducted from regions around North India such as Faridabad [5], Himachal Pradesh [6,7], Allahabad [8] and Amritsar [9].

There is a paucity of data regarding stature estimation using the long bones of the upper limb among North Indian population from the Delhi capital region. Moreover, there is a substantial movement of the young workforce around the Indian capital region and periodic population-based studies could serve as a more effective tool to estimate the stature owing to possible changing population composition with time. In view of the above, the present study was conducted at a tertiary care center from North India around the National capital region to develop a new regression analysis-based formula to calculate

the stature from the upper limb measurements.

## MATERIALS AND METHODS

**Study design:** The present study was a prospective, cross-sectional study involving 1000 participants (500 male and 500 female) of age group between 18–30 years at a tertiary care center from North India between January 2025 to December 2025. The participants were students of the campus belonging to Haryana ( $n=627$ ), Delhi ( $n=214$ ), Uttar Pradesh ( $n=128$ ), Punjab ( $n=13$ ) and Rajasthan ( $n=18$ ). Only apparently healthy individuals were included in the study after informed consent and participants with documented musculoskeletal, congenital, nutritional or acquired deformity or amputated upper limb were excluded from the study. The study was approved by the institutional ethics committee vide letter No. IEC/FMHS/PhD/2024-5.

**Anthropometric measurement:** Anthropometric measurements were taken from the above-mentioned normal healthy volunteers by a single observer from the department of Anatomy from SGT University, Gurugram (Haryana). The study participants were asked to stand straight with their bare feet in approximation and maintaining the head in a Frankfort horizontal plane. A stadiometer (Model name: Prestige, item code: HM 006A, Hardik Medi-Tech, Sonapat, Haryana) was employed for the measurement of the height of the study participant from crown to heel.

The lengths of the long bones, viz. humerus, radius and ulna were measured by the standard measuring tape (Generic fiberglass measuring tape gauged for accuracy with the stadiometer reading to ensure precision among the two models). From the specific anatomical landmarks. The measurement of humerus was taken with extended elbow while the measurement of radius and ulna was taken with flexed elbow. The length of the three bones was measured using the following landmarks: (1) Length of Humerus: It was measured percutaneously between greater tubercle of humerus and the lateral epicondyle of humerus (**Fig 1**).

(2) Length of Radius: Head of radius to maximum prominent point of styloid process of the radius (Fig 2).

(3) Length of Ulna: Olecranon process to maximum prominent point of styloid process of ulna (Fig 3).



**Fig. 1:** Percutaneous measurement of length of Humerus.



**Fig. 2:** Percutaneous measurement of length of Radius.



**Fig. 3:** Percutaneous measurement of length of Ulna

### Statistical analysis

The data collected in the present study was analyzed by using SPSS software ver. 27 (IBM Corp., USA). The baseline data was entered in Microsoft Office Excel for Microsoft 365 suite (Microsoft Corp., USA) and the mean, standard deviation and range of data were recorded for all variables. Student t-test was employed for comparing the mean height, mean length of the humerus, radius and ulna between male and female participants whereas the Pearson correlation coefficient was used for determining the relationship between the height and bone length in the participants. A linear regression model was finally used to estimate the extent of reliable prediction of the stature from the measurements of the bone length for all three bones. p value of  $<0.05$  was considered statistically significant.

### RESULTS

A total of 1000 healthy personnel were included in the present study, comprising of 500 males and 500 females. The age of the participants was between 18 – 30 years. The mean height of male was 173.5cm and the mean height for female was 163.4cm. The present study estimated the relationship between the stature (height) of the participants and the different bones data. It was observed that in female participants, the bone lengths for humerus, radius and ulna were positively correlated with the stature on both sides and they were statistically significant implicating that they have a positive impact in determining the stature of the female.

In male participants, there was very high positive correlation of stature and lengths of humerus, radius and ulna for both the sides and also statistically significant leading to the interpretation that these bones have a very high positive role in the stature of the male. The correlation for stature and bony lengths for both the genders are discussed in **table 1**. Statistically significant ( $p < 0.001$ ) differences were found in the height and the upper limb bone length between males and females.

**Table 2** shows the values of R-square which shows the variation of the dependent variable

explained by the independent variables. The value of R-square is 61.6% which was excellent and shows that 61.6% of the variation in stature is explained by the three bones together a substantial proportion of the variance, but about 38.4% of the variation was still unexplained by these bones, likely due to other factors (genetics, other body parts, etc.).

**Table 1:** Descriptive statistics of upper limb bone length and stature in males and females.

Variable	r		P
	Females	Males	
Humerus Right Hand (HumR)	0.4195*	0.7114*	<0.01
Radius Right Hand (RadR)	0.2517*	0.7904*	<0.01
Ulna Right Hand (UlnR)	0.3043*	0.8261*	<0.01
Humerus Left Hand (HumL)	0.3507*	0.7972*	<0.01
Radius Left Hand (RadL)	0.2526*	0.7567*	<0.01
Ulna Left Hand (UlnL)	0.2812*	0.7286*	<0.01

r – correlation coefficient, \*considered significant at ≤ 0.05 (two-tailed)

**Table 2:** Overall linear regression model.

Model	R	R <sup>2</sup>	Adjusted R <sup>2</sup>	Std. error of the estimate
1	0.785 <sup>a</sup>	0.616	0.615	6.53843

a. Predictors: (constant), length of ulna right hand, length of humerus right hand, length of radius right hand

**Table 3** below shows multiple linear regression based on the standardized coefficients:

$$\text{Stature} = 38.564 + 1.386 \times (\text{Length of Humerus}) + 0.559 \times (\text{Length of Radius}) + 2.710 \times (\text{Length of Ulna})$$

This was the equation for overall linear regression. The coefficients change in stature (in the same units, probably cm) for a one-unit increase in the predictor, holding other variables constant:

- Humerus (B = 1.386): For every 1 cm increase in humerus length, stature increases by 1.386cm, holding radius and ulna constant.
- Radius (B = 0.559): For every 1 cm increase in radius length, stature increases by 0.559cm, holding humerus and ulna constant.
- Ulna (B = 2.710): For every 1 cm increase in

ulna length, stature increases by 2.710cm, holding humerus and radius constant.

**Table 3:** Multiple linear regression analysis predicting height from upper limb bone length of right side.

Model	Unstandardized Coefficients		Standardized coefficients Beta	t	Sig.
	Std. error	B			
(Constant)	38.564	3.664		10.526	<0.001
Length of Humerus Right forearm	1.386	0.139	0.343	9.977	<0.001
Length of Radius Right forearm	0.559	0.303	0.089	1.847	0.065
Length of Ulna Right forearm	2.71	0.31	0.401	8.744	<0.001

a. Dependent Variable: Stature

## DISCUSSION

Personal identification on the basis of stature, age, gender and ethnicity is employed by the forensic experts as cost effective tools [10] that aids the DNA based identification which is more cost intensive exercise. Identification is especially important in the events of mass casualties as previously described above. Among the different methods of identification, the estimation of an individual's stature on the basis of the measurement of specific parts of the body have been employed by the forensic anthropologists [11]. Studies have been conducted on stature estimation based on the arm or long bone measurements of the upper limb in individuals of varying ethnicity, regions or age groups [12].

The present study observed a statistically significant difference between the length of the long bones of the upper limb and the stature among male and female participants using Mann-Whitney t-test and Linear regression equations. The height of the males was significantly taller than the females, as observed in previous studies [13].

The mean length of the three upper limb bones, namely humerus, radius and ulna were significantly larger in males as compared to females which is in accordance with the previous study by Patel [14]. Another study conducted by Krishan [15] in the age group of 17-20 years employed a linear and multiple regression models to estimate body stature on the basis of the measurements of hands and feet among the Rajput community in North

**Table 4:** Summary of previously published studies employing regression analysis for stature estimation.

Author	Age (yrs)	Region	Parameter Used	R <sup>2</sup> coefficient of determination	Findings
Mahakkanukrauch et al (2011) [19]	19-94 (M) 26-93 (F)	Thailand	Humerus , radius and Ulna for both gender	Hum.= 0.667 Rad.= 0.672 Ulna= 0.660 in male. Hum. = 0.552 Rad.= 0.616 Ulna = 0.567	Male humeral, radial and ulnar length are larger than females. Ulna bone is the most reliable predictor for stature estimation.
Mahakizadeh et al (2016) [20]	18-30	Iran	Upper limb length upto tip of middle finger	Male = 0.89	Strong correlation between hand length and height
Boonthai et al (2024) [21]	34-90	Thailand	Radius and ulna	Radius=0.509 Ulna=0.516	Ulna is more suitable predictor for stature than radius
Mehta et al (2015) [22]	18-30	India	Ulna in both gender	Rt ulna=0.569 Lt ulna=0.49	Ulna is the most suitable predictor for stature
Pandeya et al (2018) [23]	18-25	Nepal	Hand length and stature	0.25	Hand was more suitable predictor for stature
Pandey et al (2017) [24]	18-25	Southern India	Ulna in both gender	Male=0.45 Female=0.27	Ulna was the suitable predictor of stature
Present study 2016	18-30	North India	Humerus, radius, ulna	0.616	Ulna was the suitable predictor of stature followed by humerus and radius

India. Kim et al [16], also reported similar findings among Sudanese adults.

Supareet *a*[17]enrolled 400 participantsinthe age group of 18-24 years during their study from Maharashtra to examine the relationship between stature and arm span.Their findings showed a statistically significant correlation between stature and arm span in both gender (R = 0.89 [males] and 0.90 [females]). Authors concluded that arm span is an accurate predictor of height, offering a vital alternative for estimating stature in cases of physical deformities or mutilated remains. Hariharan *et a*l[18] measured the right ulna percutaneously in both sexes and linear equations were calculated.Therewas a positive correlation between height and ulnar length. As ulnar length increases height was also increases.Male ulnar length is slightly larger as compare to females. A brief summary of available literature is given in **table 4**.

The present study has a limitation that the sample population was heterogeneous owing to the study population comprising of a large group of young workforce that often migrates away from their permanent settlement. The study sample was enrolled among the population based on the present residence

status to ascertain the relationship of the stature and bone length in this sample that closely resembles the heterogenous population prevalent in this region.But, no in depth analysis of the ethnicity/ region of the study participants could be incorporated in the study due to constraints.

### CONCLUSION

Among the three long bones of the upper limb, length of ulna serves as the most reliable and consistent parameter for estimation of stature among the North Indian population.The regression equation derived in the present study is applicable to the population around the National Capital region and should serve as a tool for stature estimation for different applications, such as anthropology, anatomical studies, clinical and forensic analysis. The clinical utility of the regression model is its application in estimating stature in adults when direct height measurement is not feasible, such as in bedridden, immobilized, or physically disabled individuals.

**Ethical considerations:** The study was conducted in accordance with the Declaration of Helsinki, 2013 revision and the 2017 ethics guidelines of the Indian Council of Medical

Research (ICMR). The retrospective analysis of the available data was done post anonymization by the clinician and no individually identifiable data of the patient has been used for the study.

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### Author Contributions :

N.G and A.S were involved in study conception. N.G, and P.S.A were involved in study design and preparation of the data acquisition tools. N.G, S.C, P.S.A and S.S did the literature search. A.S and M.G collected the data. P.S.A and S.S analyzed the data. N.G, A.S and S.C prepared the manuscript. P.S.A, M.G and S.S did the proof reading and corrections of the manuscript. The manuscript has been read and approved by all the authors. All authors account for all aspect for the manuscript. All authors confirm that the requirements for authorship as stated in the author instructions have been met, and that each author believes that the manuscript represents honest work.

### Conflicts of Interests: None

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