Estimation of Stature from Combined Forearm-Hand Length Measurements in South Indian Adult Population

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KEYWORDS	ABSTRACT
Stature; forearm and hand length; South Indian adult population; Anthropometry	**Background:** Stature being one of the important aspects of anthropometric measurements, it serves as a key identifier in medico-legal investigations, particularly in cases involving incomplete or mutilated remains. This study explores the relationship between stature and the combined measurements of forearm and hand length in the South Indian adult population of Karnataka, aiming to establish reliable regression models for stature estimation. **Material and Methods**: A cross-sectional observational study was conducted on a cohort of 200 adults, 100 male and 100 female individuals, aged 25 to 35 years, from Shivamogga, Karnataka. The Stature and combined forearm-hand length of the left and right sides were measured. Statistical analysis was done to assess the correlations and develop gender-specific regression equations for stature prediction. **Results:** The mean stature of 162.09 cm (SD: 5.40cm), and 149.37 cm (SD: 5.896cm), was observed in males and females respectively. The mean for forearm-hand lengths of 46.16 cm (left) and 46.38 cm (right) was observed in males and 41.87 cm (left) and 42.27 cm (right) in females. A strong and statistically significant correlation was observed between stature and combined forearm-hand lengths for both genders. Separate regression equations for males and females were derived accounting for side-specific variations, and high predictive accuracy. **Conclusion**: This study underscores a strong correlation between stature and forearm-hand length. The regression equations obtained in this study provide a useful tool for estimating stature in anthropological and forensic fields, especially when incomplete skeletal remains are found.

Introduction:

Stature, also known as body height, is an important anthropometric feature that reflects the physical identity of an individual. It plays an important role in forensic medicine, anthropology and clinical medicine. Stature estimation helps to establish an individual's identity in circumstances like mass disasters and natural calamities where bodies have been decomposed, only fragments are found. In medico-legal investigation, stature estimation is an important

criterion in situations where criminals mutilate the dead body to hinder the identification and disposal of decomposed, disfigured remains. Furthermore, estimating the stature can also help in determining other factors like the gender and race of the deceased. This not only helps in identifying the individuality of a person but also plays a significant role in reconstructing the biological profile of an unknown person.

Anthropometry is a systematic technique for measuring body parameters by the most reliable and scientific method. [1] It is further divided into Somatometry, cephalometry, craniometry, and osteometry. [2] Among all the parameters stature exhibits a strong correlation with linear body measurements like limb measurements, foot length etc. Extensive research has been conducted on diverse populations to develop regression models that can predict the stature from these measurements. However, these models are specific to populations as genetic, environmental and nutritional factors influence these measurements contributing to the variations in anthropometric characteristics.

Forearm and hand length are important anthropometric parameters. In most situations, they remain relatively intact and are measurable in cases of skeletal remains. The forearm is a part of the upper limb and the hand is the distal segment of the upper limb. These combined lengths reflect the proportionality of the human body. Studies have been conducted in different populations to demonstrate the significant correlation between stature and combined forearm-hand length underscoring its significance in stature estimation. [3,4]

India is a diverse country, the South Indian population presents unique somatometric features, that require regional-specific studies to develop an accurate and reliable model to estimate stature. The present study aims to concentrate on the adult population of South India residing in Shivamogga, Karnataka. The results of this study will fill in the knowledge gap.

The objectives of this study are:
1. To assess the correlation between stature and combined forearm-hand length measurements in the South Indian adult population from Karnataka.
2. To derive gender-specific regression equations for estimating stature using forearm-hand length measurements for the south Indian adult male and female population of Karnataka.

Material and methods:

The present study was an observational study, conducted in the Department of Anatomy, Shivamogga Institute of Medical Sciences, Shivamogga, Karnataka, India. A cohort of 200 adults,100 Male and 100 female subjects aged between 25-35yrs from various offices and factories, institutions in and around Shivamogga were selected for the study on obtaining informed written consent. The study duration was 2 years. Ethical approval was obtained from the Institutional Ethical Committee.

Inclusion criteria:

Healthy male and female subjects aged between 25-35 years who consented to take part in the study, irrespective of their eating habits, socioeconomic background, religion and caste were included in the study.

Exclusion criteria
1. Subjects with skeletal abnormalities, fractures and deformities of the upper limb.
2. Subjects with amputated upper limbs were excluded from the study.

Methodology

Stature –

It is the vertical distance from the vertex to the floor. The subject was asked to stand erect on a horizontal resting plane, barefooted with shoulder and buttocks touching the wall. The palm turned inwards and the fingers pointed downwards. The anthropometer was placed in a straight

vertical position in front of the subject with the head oriented in eye–ear-eye plane (Frankfurt plane). In the mid-sagittal plane, the movable rod of the Anthropometer was brought in contact with the vertex [Figures 1 (a) & 1(b)].

Forearm and Hand measurements:
 Measurements of the forearm and hand was taken on both the right and left limbs of the subjects using sliding calipers. The combined lengths of the forearm and hand were measured as the distance between the tip of the olecranon process and the tip of the middle finger. Measurements were taken with the forearm in pronation, placed on flat, hard and horizontal surfaces with extended and adducted fingers, but without any abduction, adduction, flexion and extension of wrist joint so that the forearm would be directly in the longitudinal axis with the middle finger. Initially, forearm and hand measurements were taken separately and then calculated together as combined forearm and hand measurements.
Forearm length is measured from the olecranon process to the styloid process of ulna (figure 2). The hand length is measured from the midpoint between the styloid process of radius and ulna to the tip of the middle finger (figure 3).
The measurements were made by the same observer (author number one) from 10 a.m. to 12 p.m. to avoid diurnal variation. To reduce subjective errors, measurements were conducted three times and the average was calculated. A pre-structured proforma was utilised to collect data and enter subject records. The collected data was statistically analysed.

Figure No. 1 (a) Measurement of stature (Anterior view)

Figure No.1 (b) Measurement of stature (Lateral view)

Figure No.2 Measurement of forearm length [Arrow- Olecranon process of ulna; Arrow head – styloid process of ulna]

 Figure No.3 Measurement of hand length. [Arrow: midpoint between the styloid process of radius and ulna; Arrow head: Tip of middle finger].

Statistical Analysis:

Data was documented and compiled in Microsoft Excel. Statistical analysis was done using SPSS 23.0 version. Mean and standard deviations (SD) was calculated for the continuous variables, while ratios and proportions were calculated for the categorical variables. The chi-square test or Fisher's exact test was used to evaluate the differences in proportions between the qualitative variables. Regression equations were derived for males and females respectively on both left and right sides. A p-value <0.05 was considered statistically significant.

Results:

The study sample included 100 male and 100 female subjects with an age range of 25-35 years from Shivamogga, Karnataka. The results are presented in tables 1-7 and graphs 1-4.

The mean stature of males was 162.09 cm, with a standard deviation of 5.40cm in the range of 29 cm. the minimum and maximum being 150.00cm and 179.00 cm. Among males, the mean combined forearm-hand length on the left side was 46.16 cm and 46.38 cm on the right side (Table 1).

Table 1: Forearm and hand length measurements for males (in cm)

	Minimum	Maximum	Range	Mean	Standard Deviation
Age	25	40	15	30.55	3.09
Forearm & hand (right)	41.4	52.8	11.4	46.38	2.495
Forearm & hand (left)	40.7	53.2	12.5	46.16	2.55
Stature	150.00	179.00	29.00	162.09	5.40

The mean stature of females was 149.37 cm, and the standard deviation was 5.896cm and a range of 29 cm (maximum and minimum being 165 cm and 136 cm respectively). The mean combined forearm-hand lengths was 41.87 cm and 42.27 cm on the left and right hand sides respectively (Table 2).

Table 2: Forearm and hand length measurements for Females (in cm)

	Minimum	Maximum	Range	Mean	Standard Deviation
Age	25	35	10 9.9 9.8 29	30.52	3.39
Forearm & hand (right)	37.8	47.7		42.27	2.13
Forearm & hand (left)	37.0	46.8		41.87	2.08
Stature	136	165		149.37	5.896

The Pearson coefficients in males for forearm & hand length and stature showed a positive correlation coefficient on the left side and the right side was 0.807 and 0.808 respectively (Table 3). A p-value of <0.001 was observed for both sides indicating a strong and significant correlation.

Table 3: The Pearson correlation coefficients between forearm and hand measurements and stature in males.

	r-value	p-value
Forearm & hand (right)	0.808	p<0.001
Forearm & hand (left)	0.807	p<0.001

For females, the correlation coefficients were 0.830 on the left side and 0.849 on the right side, both highly significant with p-values < 0.001 (Table 4).

Table 4: The Pearson correlation coefficients between forearm and hand measurements and stature in females.

	r-value	p-value
Forearm & hand (right)	0.849	p<0.001
Forearm & hand (left)	0.830	p<0.001

Regression Equations for Males and Females

For males, the regression equation for estimating stature based on the forearm and hand length showed a constant of 83.087 and a regression coefficient of 1.711 for the left side, while for the right side, the constant was 80.965 with a regression coefficient of 1.749. The coefficients of determination (r^2) for males were 0.652 for the left side and 0.653 for the right side (Table 5).

Table 5: Regression Analysis for Males

	Constant	Regression coefficient	r^2	p-value
Forearm & hand (right)	80.965	1.749	0.653	p<0.001
Forearm & hand (left)	83.087	1.711	0.652	p<0.001

For females, the regression equation for the left side showed a constant of 50.729 and a regression coefficient of 2.356, while for the right side, the constant was 50.213 with a regression coefficient of 2.346. The coefficients of determination (r^2) for females was 0.69 for the left side and 0.72 for the right side (Table 6).

Table 6: Regression Analysis for Females

|	Constant	Regression coefficient	r^2	p-value
Forearm & hand (right)	50.213	2.346	0.720	p<0.001
Forearm & hand (left)	50.729	2.356	0.690	p<0.001

These regression equations can estimate the stature based on the forearm and hand measurements for both males and females (Table 7).

Table 7: Regression Equations for Estimation of Stature.

x = length of forearm and hand length

| Regression Equations for estimation of Stature	Right	Left
Male Female	Stature= 80.965+1.749 (x) Stature= 50.213+ 2.346 (x)	Stature=83.087+1.711(x) Stature=50.729+2.356(x)

Graph 1- Scatter plot representing the correlation between stature and Left forearm and hand length for males
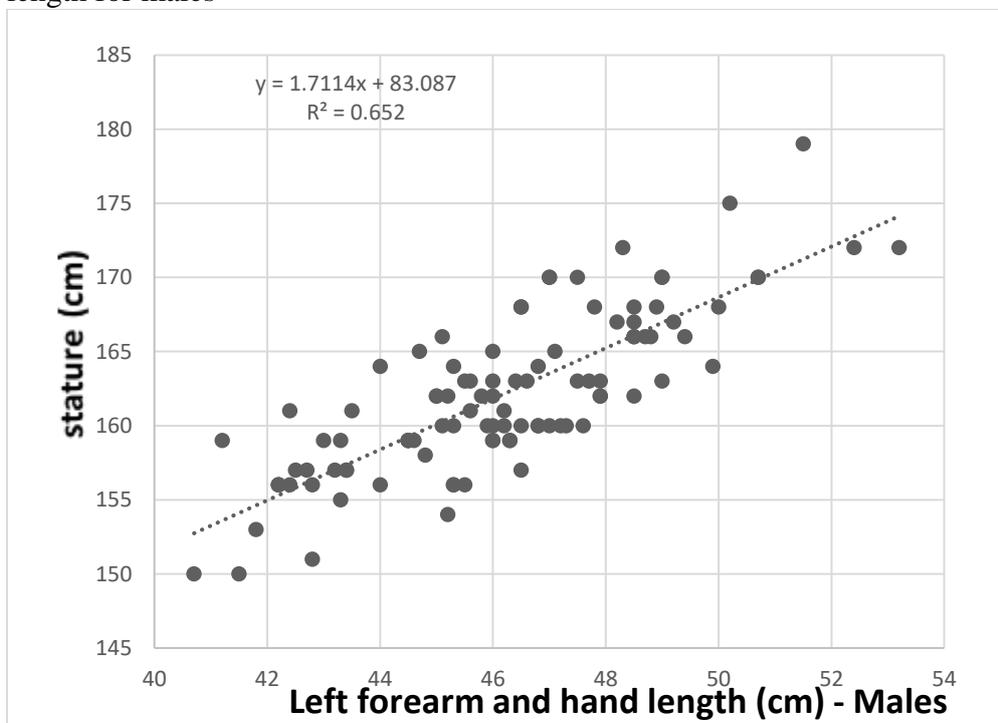

Graph 2- Scatter plot representing the correlation between stature and right forearm and hand length for males
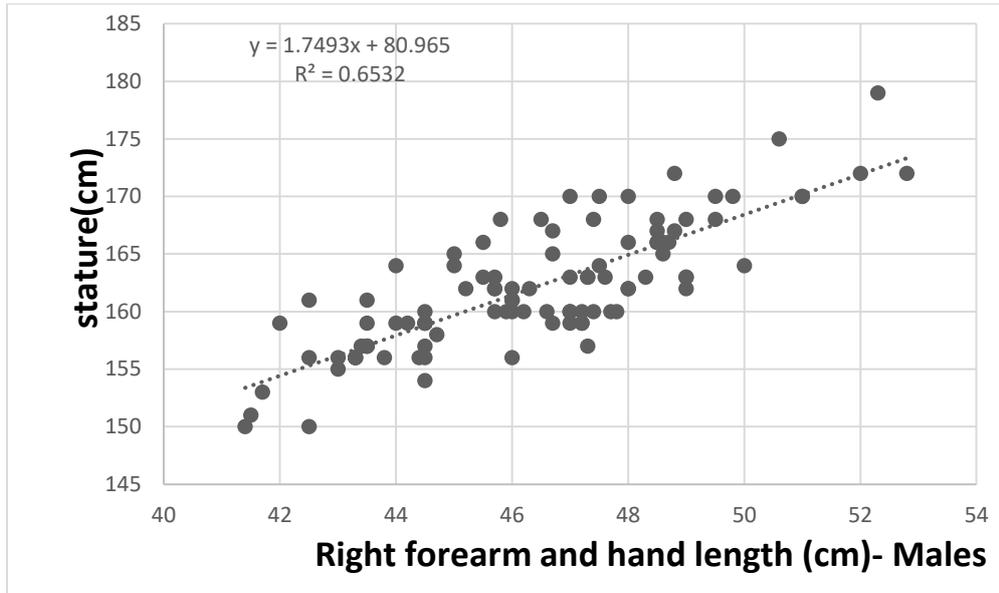
Graph 3- Scatter plot representing the correlation between stature and left forearm & hand length for females
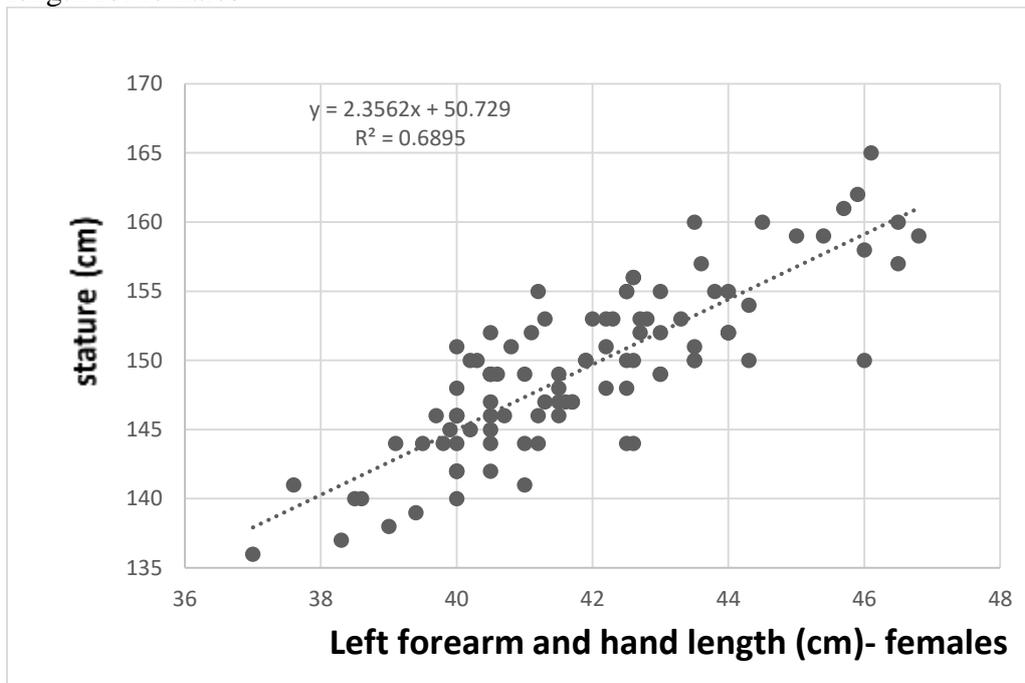
Graph 4- Scatter plot representing the correlation between stature and right forearm and hand length for females

Plot: y = 2.3461x + 50.213, R^2 = 0.7204; X-axis: Right forearm and hand length (cm)- females; Y-axis: stature (cm)
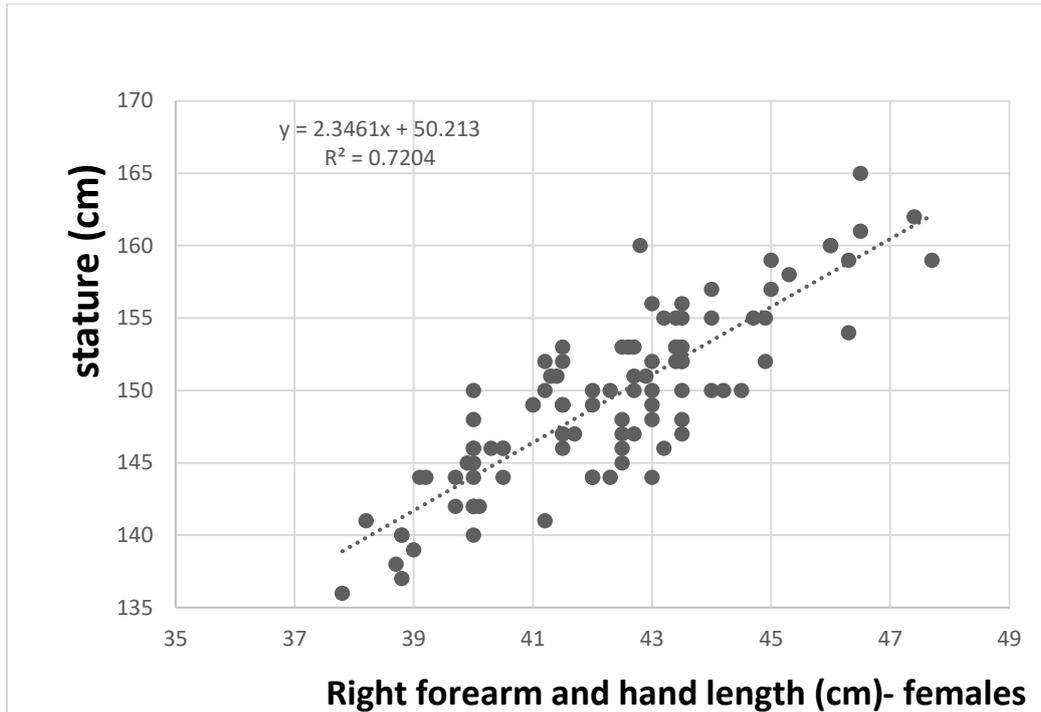
Discussion:

Stature is an important anthropometric parameter that can be helpful in determining physical characteristics like age, gender and race of an individual who can be an offender or a victim. In situations where the whole dead body is found, estimating the stature becomes easy. However, when only fragments of body parts, decomposed or mutilated parts are found it becomes a challenging task. In physical anthropology, stature is one of several biological factors that is measured and is significant for both individuals and populations. [5]

The present study was conducted on 200 subjects aged 25-35 years residing in Shivamogga, Karnataka. The mean stature for males was 162.09±5.4cm, while for females it was 149.37±5.896cm. The Pearson correlation coefficients demonstrates a strong correlation between stature and forearm and hand length measurements being statistically significant (p-value <0.001). Independent regression equations for the right and left sides were developed for both genders, indicating a strong predictive ability for stature estimation from combined lengths of forearm and hand.

The results of the present study align with similar findings of Amit K, Srivastava AK, and Verma AK. [3] The study was conducted on 200 healthy male and female students aged 19-25 years from North India. Regression equations were developed based on the length between the Olecranon process and the tip of the middle finger. Slightly higher mean for forearm and hand length was reported. Both the studies found a statistically significant correlation between these parameters and stature. However, there was a difference in regression equations which reflect population-specific variations. The results have been compared and tabulated in Tables 8- 10.

Table no 8-Comparison of descriptive statistics of stature and combined forearm-hand length with correlation coefficient(r) in the present study and those of Amit K, Srivastava AK, and Verma AK. [3]

PARAMETERS	Present study				Amit K, Srivastava AK, and Verma AK.[3]			
	Male		Female		Male		Female	
STATURE								
Mean	162.09		149.37		170.905		156.49	
Standard deviation	5.40		5.896		6.020		4.65	
Forearm & hand length, correlation coefficient								
	Right	Left	Right	Left	Right	Left	Right	Left
Mean	46.38	46.16	42.27	41.87	46.8	46.8	42	42
Standard deviation	2.495	2.55	2.13	2.08	2.254	2.246	1.79	1.77
r	0.808	0.807	0.849	0.830	0.9055	0.901	0.880	0.872

Table no 9: Comparison of regression equations derived for estimation of stature from forearm-hand length for males in this study and those of Amit K, Srivastava AK, and Verma AK. [3]

x= Length of forearm and hand length

	The regression equation for the right side	**The regression equation for the left side**
Amit K, Srivastava AK, and Verma AK.[3]	Stature =56.64+2.42x	Stature =56.64+2.42x
Present study	Stature= 80.965+1.749x	Stature=83.087+1.711x

Table no 10: Comparison of regression equations derived for estimation of stature from forearm-hand length for females in this study and those of Amit K, Srivastava AK, and Verma AK . [3] x= Length of forearm and hand length

x= Length of forearm and hand length

	The regression equation for the right side	The regression equation for the left side
Amit K, Srivastava AK, and Verma AK.[3] Present study	Stature-= 60.3+2.29x Stature= 50.213+ 2.346x	Stature= 60.3+2.29x Stature=50.729+2.356x

Similarly, Ilayperuma et al. [6] demonstrated a substantial significant correlation between ulna length and stature in the Sri Lankan population with a highly predictive accuracy regression equation. Choudhary et al. [7] reported the combined length of the forearm and hand length as a reliable predictor among students of the Jammu region. The findings in these studies [6,7] agree with using the upper limb measurements in stature estimation, while differences in regression models indicate the relevance of ethnic and regional factors.

Saxena S K et al. [8] and Chikhalkar B G et al. [9] demonstrated a significant inference about the relationship between stature and body parameters. Saxena SK et al. [8] observed a considerable association between hand and sole measurements in the Nigerian population. Chikhalkar et al. [9] reported forearm and foot length as the most predictive variables of the six body parameters assessed in the Mumbai population. These findings align with the results of the present study and confirm the reliability of forearm and hand length as effective stature estimators.

Yadav Swathi et al. [10] and Shetty et al. [11] emphasized the importance of lower limb measurements with leg length indicating it as the most effective predictor in the South Indian population. However, the present study concentrates on forearm and hand length which provides an alternative approach especially when lower limb measurements are not available.

The findings of the present study coincide with those of Dinakaran et al. [12] who observed a significant relationship between stature and nasal dimensions in Tamil Nadu. Similarly, numerous studies have been conducted to estimate stature from various body parameters, suggesting that anthropometric measurements are reliable and adaptable when tailored to specific demographic characteristics. [13-25] These studies have proved that no single parameter universally applies to all populations. The versatility highlights how important it is to design anthropometric research for a particular demographic group to achieve accurate results in stature estimation.

A study [26] conducted on the estimation of stature from hand dimensions of North and South Indians, on 500 right-handed-dominant medical students aged between 20 and 30 years who were from northern and southern parts of India observed that the hand length measurements were more reliable for estimating stature than the hand-breadth. The correlation coefficient ranged from 0.673 to 0.752 indicating a moderate correlation, which is lower than the strong correlation observed in the present study. In a study conducted in Southern China, foot length was observed as the most reliable parameter compared to upper limb measurements in the Han population.[27] Ahmed AA[28] observed that the bilateral ulnar length was the most reliable predictor among the 13 parameters of the upper limb with the pronounced asymmetry with the hand measurements for stature estimation in right-handed Saudi men aged 18-24 years. A multiparameter model with predictive accuracy was developed which was superior to the single

parameter. These findings suggest that though the present study validates the significance of forearm-hand length in predicting stature, they may not always be the most relevant or reliable measurements for other regional or ethnic populations. This highlights that population-specific research is required to develop reliable models ideal for particular body parameters.

The limitations of this study were that genetic, nutritional and environmental factors that influence the anthropometric parameters were not taken into consideration. The sample size was 200 subjects, which cannot completely represent the diversity in the South Indian population. Further research with a large and more diverse sample is recommended to address these limitations.

Conclusion:

The study demonstrated a strong correlation between stature and forearm-hand length in the South Indian adult population of Karnataka with a high predictive accuracy of gender-specific regression equations. According to the results of this study, forearm-hand length proved to be a reliable anthropometric parameter in medico-legal and forensic scenarios, highlighting the necessity of population-specific models. Despite the limitations, the study offers useful information for stature estimation, recommending future research to develop these models.

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