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Estimation of Stature among Healthcare Workers using Arm Span, Biacromial Breadth, and Forearm Length Dimensions: A Cross-sectional Study

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ABSTRACT

Introduction: Stature is one of the most commonly used anthropometric dimensions for identification purposes in forensic investigations and for assessing the development and growth of individuals. It is well-known that various anatomical anthropometric parameters can accurately estimate stature.

Aim: To estimate stature among healthcare workers in Himachal Pradesh using linear regression equations based on percutaneous anthropometric parameters of the upper limbs and trunk.

Materials and Methods: This cross-sectional study was conducted on healthcare workers at Dr. Rajendra Prasad Government Medical College, Kangra, Tanda, Himachal Pradesh for a one year (September 2021-August 2022) duration. The study included 360 healthy healthcare workers from the Himachal Pradesh population, 180 females and 180 males, aged 21 years and above. Stature, arm span, Biacromial Breadth (BAB), and forearm length dimensions were measured for each subject. Statistical analysis was done using Microsoft Excel and Epi-Info version 7.1 software. The Pearson Correlation Coefficient was used to determine the correlation between stature and different anatomical anthropometric parameters. Linear regression equations were developed to estimate stature, with significance set at p-value ≤0.001.

Results: The mean age of the study population was 41.33±28.91 years. The descriptive anthropometric parameters measured in the study were as follows: stature 162.4±6.85 and 149.4±7.15, arm span 165.67±7.5 and 150.31±8.33, right forearm length 26.68±1.33 and 24.36±1.59, left forearm length 26.47±1.30 and 24.30±1.55, BAB 34.11±2.16 and 31.74±2.32, respectively for males and females.

Conclusion: The regression equations derived from this study can be valuable for estimating stature in situations where accurate stature measurements are not feasible.

Keywords: Anthropometry, Anthropometric parameters, Regression, Upper limb

INTRODUCTION

Identification is an individual's birth-right. Anthropometry, which deals with measurements of humans, has been widely used in many clinical and forensic investigations. It provides us with the scientific basis for estimating various measurements in living and deceased individuals [1]. Of all the anthropometric dimensions, stature, measured as the standing height of the individual, is the most commonly used [2]. Apart from aiding in identification, stature measurement is essential for therapeutic purposes such as estimating nutritional status indicators, assessing children's growth, and adjusting drug dosages [3]. However, in some cases where patients are unable to stand, individuals have trunk or leg deformities or lower limb amputations, patients with contractures or fractures, and in mutilated bodies, measuring stature is difficult or impossible [4].

Although the anatomical method is the most precise method for stature estimation, it cannot be used by forensic experts when mutilated bodies or skeletal remains are found in cases of homicide to conceal identity or in cases of mass disasters. In such cases, the mathematical method can be used for stature estimation [5]. Stature reconstruction from the upper limb bones, mainly long bones, is of paramount medico-legal importance. A strong association is seen linking stature with the long bones of the upper extremity [6]. To derive regression formulas for estimating stature, long bones are usually assumed to be more precise than the bones of the foot and hand [7]. Karl Pearson developed the first formal stature regression formula to estimate stature [8]. A method of estimating stature from long bones was also developed by Trotter M and Gleser GC [9]. They derived regression equations from the length of long bones and calculated stature. This is the most common method for stature estimation. Inter-population comparison and estimation of stature from these formulas cannot be generalised as climate, heredity, and the nutritional status of a specific population have been reported to have an effect on stature [10].

Due to various ethnic and racial variations among the Indian population, area-wise, population-specific anthropometric studies are essential in India. The population of Himachal Pradesh is an admixture of two races, Mongoloid and Caucasian. Hence, the data of the country cannot be very reliable for the current population under study. Data for anthropometry of the population of Himachal Pradesh is limited in the literature. Therefore, the present study has attempted to determine stature from arm span, forearm length, and BAB measurements and then devise adequate gender-specific regression analysis for this purpose.

MATERIALS AND METHODS

This cross-sectional study was conducted in the Department of Anatomy at Dr. Rajendra Prasad Government Medical College, Kangra in Tanda, Himachal Pradesh, India for one year from 2021 to 2022, after obtaining ethical committee approval for the study (No. HFW-H DRPGMC/Ethics/2021/25). It included 360 healthy healthcare workers from the Himachal Pradesh population, with 180 females and 180 males, aged above 21 years.

Sample size calculation: Participants were selected using simple random sampling method. In a study published by Aggarwal AN et al., among North Indian subjects, the mean height and arm span ratio among males and females was 0.9819±0.0239 and 0.9711 [11]. With the above values and taking α as 0.05 and 95% power a sample size of 282 (141 in each group) was obtained.

Inclusion criteria: Only healthy healthcare workers belonging to both male and female genders, of Himachal Pradesh population with age above 21 years, free from any developmental defects or skeletal abnormalities were included in the study.

Exclusion criteria: Healthcare workers with any orthopaedic deformity like bone fracture, hormonal disorders like gigantism and acromegaly, genetic disorders like noonan syndrome, osteogenesis imperfecta or any other disorders that could directly affect the measuring part of the current study and stature of an individual were excluded.

Study Procedure

Study participants were explained the study purpose in their local language and informed consent was taken.

Calibrated Stadiometer (SDM210) (Lifeyelid enterprises) with length of 20 cm to 205 cm (graduation.1cm) was used [Table/Fig-1] to measure stature in centimeters. Stature was measured from vertex to the floor in standing position with the subject standing bare foot on the baseboard of stadiometer and Frankfurt's plane parallel to the ground [12].

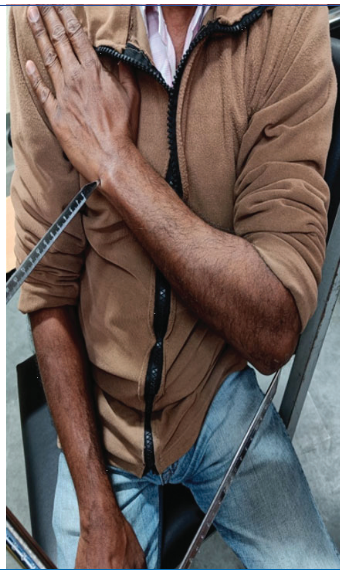
[Table/Fig-1]: Stature measurement.

Arm span was measured [Table/Fig-2] in centimeters as the distance from the tip of the middle finger of one arm to the tip of the middle finger of the other arm, with the subject standing erect against the wall and arms outstretched, palms facing forwards [13].

Forearm length was measured [Table/Fig-3] in centimeters as the distance between the tip of the styloid process of the ulna and the tip of the olecranon process in a fully flexed elbow, with the palm facing over the opposite shoulder [14]. BAB was measured [Table/Fig-4] in centimeters by first feeling the outside edge of the acromial process and then measuring the distance between the tips of the right and left acromion processes of the shoulders [15].

Arm span, forearm length, and BAB measurements were taken using an Anthropometer with a length of 0-210 cm (BAI 101 Biotech and Scientific Instruments). All measurements were taken thrice, and the mean was calculated for each reading to avoid errors. To minimise errors due to stature and daytime variations, the measurements were taken by one person using the same measuring instruments before noon at a specified fixed time [16-18].

[Table/Fig-2]: Arm span measurement.



[Table/Fig-3]: Forearm length measurement.

[Table/Fig-4]: Biacromial Breadth (BAB) measurement.

STATISTICAL ANALYSIS

Microsoft Excel and Epi-Info version 7.1 software were used for statistical analysis. Mean and standard deviation were used to present quantitative variables, while qualitative variables were presented in the form of percentage and frequency. Pearson's correlation coefficient was calculated to determine the correlation between stature and arm span, forearm length, and BAB. The coefficient of determination (R2) was calculated to determine the strength of association among the parameters considered [19]. Gender-specific regression equations, as well as separate ones for combined cases, were developed by a linear regression model to predict stature from an individual's arm span, forearm length, and BAB.

RESULTS

The observations were conducted on 180 males and 180 females, totaling 360 subjects [Table/Fig-5]. All the studied anthropometric parameters, including stature, arm span, forearm length (right and left sides), and BAB, were found to be higher in male subjects compared to females (p-value <0.001) [Table/Fig-6]. Pearson's correlation coefficient (r) indicated a positive correlation (p-value <0.001) between stature and the parameters studied [Table/Fig-7]. Higher R^2 (coefficient of determination) values indicated that stature can be accurately predicted from arm span, forearm length, and BAB in decreasing order. Left forearm measurements significantly predicted stature compared to right forearm.

Gender	Mean age (in years)	SD
Males (n=180)	41.07	10.3
Females (n=180)	41.58	7.34
Total	41.33	8.91

[Table/Fig-5]: Distribution of cases according to their age (n=360).

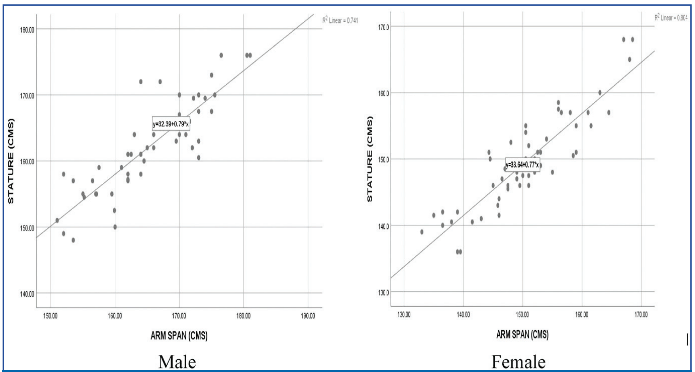
Variable (in centimeters)	Male (N=180)		Female (N=180)		Combined (N=360)		#p-value
	Range	Mean±SD	Range	Mean±SD	Range	Mean±SD	
Stature	148-176	162.4±6.85	136-168	149.4±7.15	136-176	155.9±9.56	**<0.001**
Arm span	151-181	165.67±7.5	133-168.5	150.31±8.33	133-181	157.99±11.04	**<0.001**
Right forearm length	24.7-30	26.68±1.33	21.1-27.7	24.36±1.59	21.1-30	25.52±1.87	**<0.001**
Left forearm length	24.3-29.9	26.47±1.3	21.2-27.9	24.3±1.55	21.2-29.9	25.38±1.8	**<0.001**
Biacromial breadth (BAB)	28.5-38.7	34.11±2.16	26.2-36.4	31.74±2.32	26.2-38.7	32.93±2.53	**<0.001**

[Table/Fig-6]: Descriptive statistics of anthropometric parameters measurements in study subjects.
#p-value between male and female; Independent student t-test of significance for comparing means and standard deviation; N: Number of subjects; SD: Standard deviation

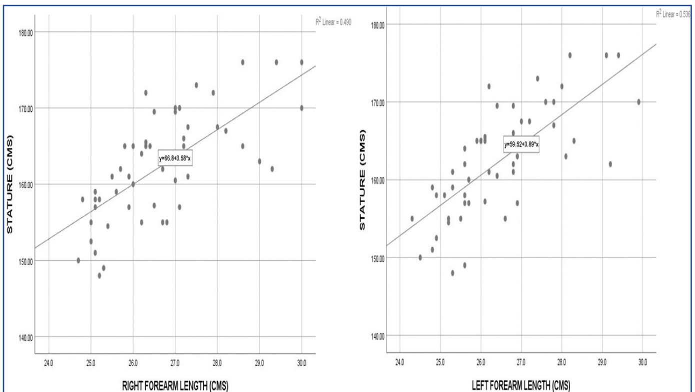
Variable	r	R^2	Regression equation Y=A+BX	p-value
Arm Span (AS)				
Male	0.861	0.741	Stature=32.39+0.78×AS	**<0.001**
Female	0.897	0.804	Stature=33.64+0.77×AS	**<0.001**
Combined	0.937	0.878	Stature=27.72+0.81×AS	**<0.001**
Right Forearm Length (RFAL)				
Male	0.7	0.490	Stature=66.79+3.58×RFAL	**<0.001**
Female	0.711	0.506	Stature=71.89+3.18×RFAL	**<0.001**
Combined	0.828	0.685	Stature=48.08+4.22×RFAL	**<0.001**
Left Forearm Length (LFAL)				
Male	0.732	0.536	Stature=59.52+3.88×LFAL	**<0.001**
Female	0.752	0.565	Stature=65.45+3.45×LFAL	**<0.001**
Combined	0.845	0.714	Stature=41.51+4.5×LFAL	**<0.001**
Biacromial Breadth (BAB)				
Male	0.542	0.294	Stature=103.97+1.71×BAB	**<0.001**
Female	0.458	0.209	Stature=104.68+1.4×BAB	**<0.001**
Combined	0.642	0.412	Stature=76.19+2.42×BAB	**<0.001**

[Table/Fig-7]: Regression equation for estimating stature from anatomical anthropometric parameters in study subjects.
r: Correlation coefficient, R^2: Coefficient of determination; Y: stature in cm (dependent variable); A: constant; B: Regression coefficient of variable (linear regression model) and X: independent variable (arm span, forearm length, BAB in cm);AS: Arm span; RFAL: Right forearm length; LFAL: Left forearm length; BAB: Bi Acromial breadth

Following regression analysis, equations were derived for estimating stature from arm span, forearm length, and BAB for males, females, and combined cases [Table/Fig-7]. Scatter plots illustrating the linear correlation of stature and arm span in males and females,



[Table/Fig-8]: Scatter plots depicting linear correlation of stature and arm span in males and females.



[Table/Fig-9]: Scatter plots depicting linear correlation of stature and forearm length in males.

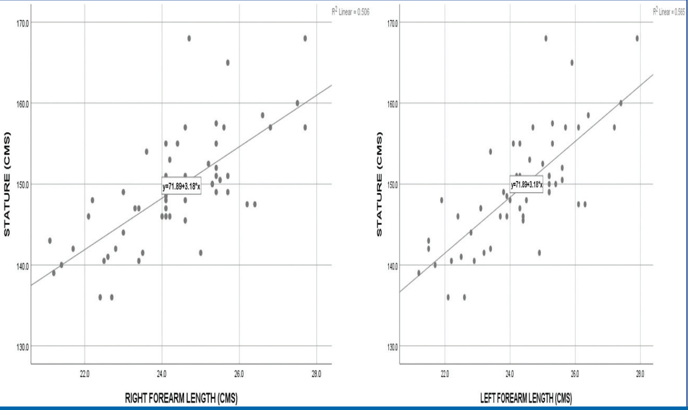
stature and forearm length in males, and stature and forearm length in females are presented in [Table/Fig-8-10].

The accuracy of measured stature was assessed by comparing the mean value of measured stature using the regression formula with the mean value of the actual stature of the study subjects. The similarity of their values demonstrated that the regression equations formulated in the present study could be utilised as a reliable tool for estimating stature from arm span, forearm length, and BAB measurements. For example, in a female with measured parameters as follows: arm span=163 cm, right forearm length=27.5 cm, left forearm length=27.4 cm, and BAB=35.2 cm, the estimated stature obtained using these measurements in the regression equations was 159.2 cm, 159.3 cm, 159.9 cm, and 154 cm, respectively. The actual stature of that female was 160 cm, confirming that the derived equations can be accurately used for stature estimation.

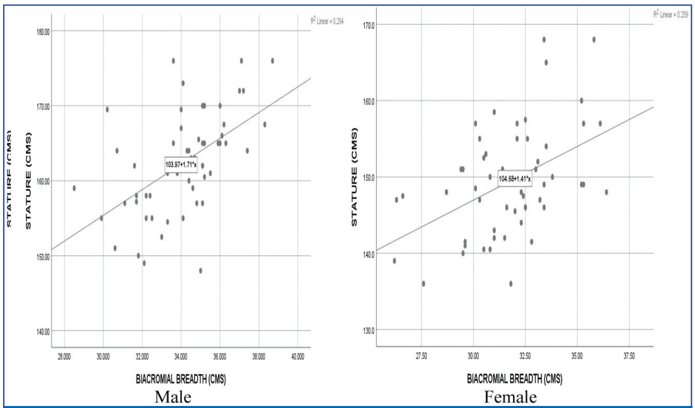
[Table/Fig-11] showed scatter plot diagrams depicting linear correlation of stature and Biacromial Breadth (BAB) in males and females.

DISCUSSION

All parts of the body exhibits biological correlation, where the size of one part can be used to estimate the size of another. Similarly, stature can be accurately estimated from various body parts. Several factors, including age, sex, and race, influence skeletal development and various body measurements [20,21]. Stature estimation is crucial for identification purposes in anthropological studies and medico-legal examinations. Stature estimation can be performed



[Table/Fig-10]: Scatter plots depicting linear correlation of stature and forearm length in females.



[Table/Fig-11]: Scatter plots depicting linear correlation of stature and Biacromial Breadth (BAB) in males and females.

accurately even in fragmentary remains and in dismembered and mutilated bodies [10]. Various researchers have attempted to estimate stature from different body parts.

Anthropometric measurements in males were found to be greater than in females, which can be attributed to the genetic make-up of males. The pubertal age of males is typically two years later than that of females, providing them with additional growth opportunities [10]. The same regression equations cannot be applied to both male and female cases due to the higher mean values of parameters observed in male subjects compared to females (p-value <0.001).

The correlation coefficient (r) for stature and arm span was 0.861 in males and 0.897 in females, which was statistically highly significant (p-value <0.001) and indicated a strong correlation. Similar findings have been reported in other studies conducted globally [Table/Fig-12] [10,22-25]. A similar study on estimation of stature from outstretched arm span and measurement of components of upper limb in the natives of Gujarat [26] to further support the findings.

While some researchers, like Potdar AB et al., only took one-sided forearm measurements for stature correlation [27], the present study involved measurements from both sides for improved stature correlation. Although a significant correlation with stature was observed in both right and left forearm measurements, the left forearm measurement showed a more significant correlation with stature compared to the right. A comparison with different studies on forearm measurements is depicted in [Table/Fig-13] [28,29].

A review of the literature revealed that very few researchers have attempted to correlate BAB with stature [Table/Fig-14] [15,30-32]. In current study, a higher correlation coefficient (r) was observed in male cases compared to females. This difference could be explained by the fact that in males, the shoulder growth spurt at the beginning of puberty is more distinct, leading them to develop broader shoulders compared to females [30].

Various factors such as nutritional status, sex, and age influence stature and body dimensions. Additionally, genetic, environmental,

Study	Sex	r	R^2	Regression equation
Supare MS et al., [10] (2015)	Male	0.89	0.79	Stature=31.26+0.806×AS (cm)
	Female	0.90	0.81	Stature=33.54+0.77×AS (cm)
Uzun Ö et al., [22] (2018)	Male	0.785	0.716	Stature=420.527+0.755×AS (cm)
	Female	0.807	0.751	Stature=432.536+0.736×AS (cm)
Mumtaz SH et al., [23] (2019)	Male	0.766	-	Stature=33.340+0.784×AS (cm)
	Female	0.887	-	Stature=20.796+1.109×AS (cm)
Sarma A et al., [24], (2020)	Male	0.988	0.976	Stature=1.060+0.954×AS (cm)
	Female	0.991	0.983	Stature=0.150+0.962×AS (cm)
Rai P et al., [25] (2021)	Male	0.781	0.610	Stature=40.75+0.7348×AS (cm)
	Female	0.837	0.700	Stature=47.001+0.6712×AS (cm)
Present study	Male	0.861	0.741	Stature=32.39+0.78×AS (cm)
	Female	0.897	0.804	Stature=33.64+0.77×AS (cm)

[Table/Fig-12]: Comparative data of different studies on stature estimation from arm span [10,22-25].

Study	Sex	Forearm length LFAL/RFAL	r	R^2	Regression equation
Londhe S et al., [28] (2019)	Male	RFAL	0.514	-	Stature=95.82+2.887×RFAL (cm)
		LFAL	0.501	-	Stature=116.5+2.128×LFAL (cm)
	Female	RFAL	0.598	-	Stature=99.46+2.427×RFAL (cm)
		LFAL	0.615	-	Stature=95.08+2.632×LFAL (cm)
Dongre SS et al., [29] (2021)	Male	RFAL	0.969	0.941	Stature=126.42+1.4296×RFAL (cm)
		LFAL	0.979	0.959	Stature=128.32+1.3817×LFAL (cm)
	Female	RFAL	0.974	0.949	Stature=127.26+1.3852×RFAL (cm)
		LFAL	0.984	0.967	Stature=128.52+1.3711×LFAL (cm)
Present study	Male	RFAL	0.7	0.490	Stature=66.79+3.58×RFAL (cm)
		LFAL	0.732	0.536	Stature=59.52+3.88×LFAL (cm)
	Female	RFAL	0.711	0.506	Stature=71.89+3.18×RFAL (cm)
		LFAL	0.752	0.565	Stature=65.45+3.45×LFAL (cm)

[Table/Fig-13]: Comparative data of different studies on stature estimation from forearm length [28,29, Present study].

Study	Sex	r	R^2	Regression equation
Ozaslan A et al., [15] (2011)	Male	0.42	0.17	Stature=125.11+1.226×BAB (cm)
	Female	0.26	0.07	Stature=133.16+0.822×BAB (cm)
Patel SH et al., [32] (2015)	Male	0.31	-	Stature=140.01+0.71×BAB (cm)
	Female	0.23	-	Stature=137.31+0.50×BAB (cm)
Parul et al., [30] (2019)	Male	0.492	-	Stature=122.37+1.389×BAB (cm)
	Female	0.313	-	Stature=130.84+0.746×BAB (cm)
Yadav S et al., [31] (2023)	Male	0.369	-	Stature=45.72+3.108×BAB (cm)
	Female	0.206	-	Stature=135.16+0.549×BAB (cm)
Present study	Male	0.542	0.294	Stature=103.97+1.71×BAB (cm)
	Female	0.458	0.209	Stature=104.68+1.4×BAB (cm)

[Table/Fig-14]: Comparative data of different studies on stature estimation from Biacromial Breadth (BAB) [15,30-32].

and racial factors play a role in influencing an individual's skeletal growth [33].

Limitation(s)

The derived equations are specific to the population studied, and if applied to other populations, they may not yield accurate results. Furthermore, the equations will provide accurate results only when applied to individuals older than 21 years. Additionally, the equations have limited applicability in individuals with any disorder or defect that affects skeletal growth.

CONCLUSION(S)

Among all the parameters studied, stature is most accurately determined by arm span, followed by forearm length, and least by BAB in both sexes. The gender-specific and combined regression equations derived in the study to estimate stature from arm span, forearm length, and BAB can be effectively used in individuals for whom precise measurement of stature is not feasible. This will assist in identification and can be beneficial to anthropologists, medico-legal experts, and anatomists.

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