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ORIGINAL ARTICLE

Stature and its Estimation Utilizing Hand and Foot Measurements in North Indian Population

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ABSTRACT

Background: Stature estimation from body measurements is an important part of forensic and medico-legal cases especially in victim identification, where mutilated and amputated body parts are encountered at the crime scene. Hand and foot dimensions are the important features in context of stature estimation. The present study was conducted to find out the correlation of length and breadth of hand and foot in the stature of the North Indians.

Methods: Anthropometric data from 413 males and 413 females were collected. Simple and multiple linear regression methods were used for estimation of stature from hand length, hand breadth, foot length and foot breadth measurements.

Results: Statistically significant results ($p < 0.001$) are obtained with each measurement when the derived model is tested for stature estimation. Hand length in both sexes showed highest correlation with the stature whereas foot breadth showed the lowest. Multiple regression models showed low standard error of estimate (SEE).

Conclusion: The results of this study showed that, from a forensic stand point, measurements of the hands and feet may be employed to estimate the stature of North Indian populations.

keywords | Forensic anthropology; Foot anthropometry; Hand anthropometry; Stature; North India.

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INTRODUCTION

Stature estimation plays a vital role in identification of human remains encountered in criminal cases and natural disasters. Since in normal human beings, the measurements of different body parts exhibit interse correlation as well as with stature of an individual. This phenomenon has been exploited by the forensic anthropologists to estimate the stature of the individual from different body parts or skeletal remains. However, the work of a forensic anthropologist is not just restricted to dried or skeletal

remains. Metric data collecting from living people has a long history in anthropology. The applications of anthropometric data has been utilized for various purposes such as to study the variation among different endogamous human populations, in garment and shoe industry to understand the body proportions and foot dimensions for designing of clothing and equipment. Additional anthropometric investigations have been carried out to assess the nutritive and medicinal condition of communities. The role of anthropometric measurements has been witnessed in sports to create a profile of athletes within specific sport and measure their fitness level. In a clinical environment, medical workers may utilize anthropometric measures to assess the height of the living (especially the elderly and crippled) who are unable to stand upright. Presumably, patients in a clinical situation are known to be a certain age, and the purpose of a height estimate in that setting is very different from one in a forensic setting. When the status of the deceased is unknown or uncertain for forensic investigations, stature would need to be calculated. As a result, including known age as a variable in the regression model is inappropriate since it could only be feasible to produce a very broad age estimate (especially in circumstances of body fragmentation). The identification of gender, race, age and stature are the difficult task for an anthropologist in order to establishing or developing the biological profile of an unknown individual.[1] This becomes more challenging in case of dismembered/partial /disfigured bodies and that's why searching the accurate method and developing various regression model from different body parts encountered at the crime scene becomes significant for estimating the above mentioned parameters of the individual characteristics.[2]

These findings play a major role and lead the forensic investigator to positive personal identification. Gender and stature are considered as the most important parameters for personal identification in forensics.[3] The anthropometry measurements are considered as an individual tool to determine the stature of living individuals.[4] Therefore, several studies have been attempted in the past to estimate stature from different body dimensions such as head, cephalometric facial dimensions[5], hand length[6], hand breadth[7], four fingers such as index, thumb, middle and ring[4], handprints[7], navicular height[3], foot length[8], foot breadth[9], malleol height[3], footprints[10], radius and ulna[11], cranium[12] and knee length[12] etc.

The various studies published from the different regions have established correlation relationship between stature and body dimensions including hand and foot anthropometry.[4,13–16] This motivates the anthropologist and forensic professionals to evaluate stature from hand and foot dimensions. Regression analyses such as linear or multiple regression are usually executed to estimate the parallel between stature and different body dimensions. Various regression models have been developed using hand and foot measurements in order to estimate stature for diverse races.[13,17–19] The stature is directly proportional to different body parts and hence, shows a definite biological and genetic relation with each other. The study of specific ethnic group becomes important as change in ethnicity brings differences in anthropometric relations.[20]

Kim et al[9] employed both simple and multivariate regression analysis to estimate stature in 5,195 people using hand length, hand breadth, foot length, and foot breadth. (2,750 men and 2,445 women) south-Korean adults. This study reported the highest correlation in foot length and least correlation was observed in hand breadth for both genders. They also observed that both the hand and foot measurements were statistically significant ($p < 0.01$) with stature. Thus, these methods are found to be highly reliable and could be use to predict the stature of individuals. Krishan and Sharma[13] also examined hand and foot measurements in 246 (123 males and 123 females) North Indian adults. Both simple and multiple regression analysis are performed for stature estimation. Hands and foot measurements were significantly and positively correlated ($p < 0.01$) with stature. Additionally, they looked at the fact that, compared to other measurements, foot length

had the strongest association with height and the lowest standard error of estimation. 250 Slovak students' (120 males and 130 females) height was predicted using hand length, hand breadth, foot length, and foot breadth by Uhrová et al.[8] The dimensions of the hands, feet, and stature were estimated using three distinct techniques, including stepwise regression, multiple regression, and linear regression. The height and measures showed a significant and positive correlation (p 0.01). The study reported that foot length of both the genders had higher correlation coefficient than any other measurements. Similarly, several studies using the hand and foot dimensions have been reported by researchers from different populations, race, regions, sex etc. These findings are very useful in forensic cases such as natural disasters, calamities, airplane crash where skeletal or body remains are found at the scene of crime.[21]

Therefore, the main objective of this research is to investigate the relationship between stature and different hand and foot dimensions such as hand length, hand breadth, foot length and foot breadth. The findings would help to deduce the linear and multiple equations for Indian people. This study will also explore significant correlation between stature and hand-feet dimensions.

MATERIALS AND METHODS

Material

The present research was conducted in the Department of Biology, Lok Nayak Jai Prakash National Institute of Forensic Science and Criminology, India. A total of 826 test subjects (413 males and 413 females) aging 18-69 years without having any physical/medical abnormality of hands and foot were measured. The average age of males was 34.65 years; while that of females was 35.95 years. The anthropological measurements were collected from the male and female subjects of the Jat Population of delhi and Khatri population of Delhi. Anthropometric rod and sliding calipers were used to take measurements.

The temperature of the environment during the data collection was ranged from 24°C to 32°C. All the measurement of the participants was taken in broad daylight to avoid diurnal variation. The information about the research study was given to each subject. They were questioned about their age, sex, medical history, ethnicity, and data was collected as per their consent. A written valid informed consent was taken from each of the participants. No subject in any way was forced to contribute to the data collection. This study was conducted in accordance with the Declaration of Helsinki, and was approved by the Institutional Ethical Committee.

Methods

Four anthropometric measurements such as hand length, hand breadth, foot length and foot breadth were measured using sliding caliper. The stature of each subject was measured using anthropometer instrument. The subjects were asked to stand upright, barefooted on the flat platform with heels placed together, buttocks and back touching the wall. Each participant was instructed to maintain head alignment with the Frankfort Horizontal plane. The individuals' height was measured in centimeters to the closest millimeter by placing the horizontal sliding bar on the vertex of their heads.[22] The accuracy and reliability is of great importance with forensic analyses therefore, each variable was measured by one researcher. All the required precautions were considered while measuring the subjects. All the measurements were taken three times and means of them were taken as the final value.

Landmarks

Stature: It is the vertical distance from highest point to the floor.[23]

Hand length: The distance measured the most forwarding points on the bracelet crease to the midpoint of the middle finger at metacarpo-phalangeal crease using sliding calipers.[23]

Hand breadth: The distance measured between metacarpal radial and metacarpal ulnar sliding calipers.[23]

Foot length: The distance measured from

pternion (most posterior point of the heel) to acropodion (most anterior point of the toe).[23]

Foot breadth: It reflects the distance between metatarsal tibiale (most prominent inner side) and metatarsal fibulare (most prominent outer side) of the foot.[23]

STATISTICAL ANALYSIS

Data was manually entered into Microsoft Excel Spreadsheet and was analyzed using Statistical Package for Social Sciences (SPSS) 23.0 tool. A significance level of $p<0.05$ was considered for data analysis. The Shapiro -Wilk Test was applied to evaluate the normal distribution of data. For measurements of males and females, descriptive statistics were performed on stature, hand, and foot dimensions (cm). To find the significant differences between males and females for each parameter, the Mann-Whitney test was used. Measurements of the hands and feet were used to calculate the stature using linear and multiple regression analysis. Using Pearson correlation coefficient, a relationship between stature and hand foot measurements was deduced.

RESULT

Descriptive Statistics

Descriptive statistics such as mean, median, standard deviation, minimum and maximum for stature, hand foot measurements for males and females are illustrated in Table 1. The mean value of measured dimensions has greater range of value for males than that for female. The hand and foot measurements for both males and females were not distributed normally as shown in Table 2. Hence, non-parametric test such as Mann-Whitney test was conducted to assess the sexual dimorphism as presented in Table 1. All the measured parameters were found to be statistically significant between both the genders. The largest difference in U value (U = 35788.00) was observed in foot length whereas stature displayed the smallest difference in U value (U = 22178.00).

Table 1: Descriptive statistics for stature, hand and foot dimensions (cm) in males and females.

Variable	Male (n= 413)					Female (n= 413)						
	Mean	SD	Median	Min	Max	Mean	SD	Median	Min	Max	Mann-Whitney test (U)	P
S	168.43	8.19	168.2	145	193.8	156	7.19	155.4	135.1	181	22178	.000**
HL	18.46	1.07	18.5	15.2	22.1	17.12	0.94	17.1	14.5	20.3	28716	.000**
HB	8.22	0.53	8.2	6.2	9.6	7.46	0.46	7.5	6.1	8.8	23384	.000**
FL	24.55	2.08	24.9	18.1	28.6	22.62	1.4	22.6	17.4	26.5	35788	.000**
FB	9.41	0.8	9.4	6.9	11.5	8.51	0.65	8.5	6.1	10.8	32605	.000**

Note: S (Stature), HL (Hand length), HB (Hand breadth), FL (Foot length), FB (Foot breadth).

SD: standard deviation

** The t-test was significant at the <0.05 level

Table 2: Measures of Shapiro-Wilk test to check normality for stature, hand and foot dimensions in males and females.

S. No.	Variable	Test		Measures of Shapiro-Wilk Normality	
		Male	P- value	Female	P- value
1	Stature	0.99	0.005	0.972	<0.001
2..	HL	0.987	0.001	0.862	<0.001
3	HB	0.983	<0.001	0.992	0.023
4	FL	0.962	<0.001	0.973	<0.000
5	FB	0.031	<0.001	0.992	0.024

Note: S (Stature), HL (Hand length), HB (Hand breadth), FL (Foot length), FB (Foot breadth).

Correlation analysis

Table 3 shows the correlation coefficients of hand and foot dimensions with stature in males and females. Measured dimensions were found to be positively significant (P-value <0.01) with stature. The correlation coefficient value between stature and hand-foot measurements ranged from +0.216 to +0.489 in males and from +0.052 to +0.436 in females. Hand length showed the highest correlation coefficients for both males and females (r=0.489 for males and r= 0.436 for females) whereas foot breadth showed the lowest correlation coefficients were for males as well as females (r=0.216 for males and r= 0.052 for females).

Table 3: Correlation values of different body dimension with stature among males and females of North Indian population.

S. No.	Variable	Value of correlation	Value of correlation
		Male	Female
1	HL	0.489**	0.436**
2	HB	0.271**	0.178**
3	FL	0.352**	0.166**
4	FB	0.216**	0.052**

Note: S (Stature), HL (Hand length), HB (Hand breadth), FL (Foot length), FB (Foot breadth).

** Significant at 0.001% level

Linear Regression Analysis

In order to estimate stature from hand and foot dimensions of male and female, the linear regression analysis were conducted as shown in Table 4. We also calculated standard error of estimate (SEE) for both males and females that helps in prediction of deviation of the estimated stature from the actual stature as shown in table 4. In males, standard error of estimate varied (hand length) from ± 7.157 to ± 8.013 (foot breadth) whereas in female, varied from ± 6.488 (hand length) to ± 7.198 (foot breadth). To estimate stature from given dimensions, the coefficient of determination was also calculated and found to be statistically significant for all the derived equations in males and females. The coefficient of determination value varied from + 0.046 to + 0.239 in male and from + 0.002 to + 0.189 in female. Hand length showed higher value of coefficient of determination lower in foot breadth in males and females.

Table 4: Simple linear regression equation for stature estimation from males and females.

Males			Females		
Regression equation	**R^2**	**SEE**	**Regression equation**	**R^2**	**SEE**
S = 3.744*HL+ 99.278	0.239	7.157	S = 2.886*HL+106.648	0.189	6.488
S = 4.180*HB+ 134.050	0.073	7.899	S = 2.739*HB+135.545	0.031	7.093
S = 1.385*FL+ 134.401	0.124	7.679	S = 0.852*FL+136.725	0.027	7.108
S = 2.199*FB+ 147.723	0.046	8.013	S = 0.574*FB+151.110	0.002	7.198

Note: S (Stature), HL (Hand length), HB (Hand breadth), FL (Foot length), FB (Foot breadth).

SEE- Standard Error of Estimate; *Significant ($p < 0.001$)

Multiple Regression Analysis

Different combinations of multiple regression equations were derived for both the gender are presented in Table 5. These equations are formulated for better or accurate stature prediction using hand and foot measurements. Regression coefficients were found to be positively significant (P-value < 0.001) with stature for all measurements. Correlation coefficient varied from +0.353 to +0.492 in males and from +0.175 to +0.436 in females. The larger value of R was found between stature and male hand length-foot breadth dimensions and the lower value of R was found between stature and female foot length and foot breadth dimensions. The value of the coefficient of determination was varied from +0.125 to +0.261 for males and +0.031 to 0.197 for females. In males, standard error of estimate varied from ± 7.151 cm to ± 7.685 cm whereas in female, varied from ± 6.494 cm to ± 7.106 cm. Using linear regression equations, the comparison between actual stature and estimated stature from hand-foot measurements are calculated as shown in in Table 6. It was observed that minimum and maximum values of estimated stature in male and female showed greater variations than the actual minimum and maximum stature values. However, the mean values of both actual and estimated stature were close to each other. This is due to the fact that regression equations are calculated from measures of central tendency.

Table 5: Multiple linear regression equation for estimation stature from hand and foot dimension.

Gender	Multiple Regressionequation	R	R^2	SEE
Males	S =3.527*HL. + 974* HB+ 95.286	.492	.242	7.151
	S = 1.386*FL-.006* FB+ 134.467	.353	.125	7.685
Females	S = 2.944*HL- 0.301*HB+ 107.915	.436	.190	6.494
	S = 1.047*FL- 0.720*FB+ 138.444	.175	.031	7.106

Note: S (Stature), HL (Hand length), HB (Hand breadth), FL (Foot length), FB (Foot breadth)

*Significant ($p < 0.001$)

Table 6: Comparison of actual stature and estimated stature (in cm) from hand and foot measurements

Variable	Males			Females		
	Estimated Stature			Estimated Stature		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean
HL	156.18	182.02	168.39	148.495	165.233	156.05
HB	159.96	174.17	168.40	152.25	159.64	155.97
FL	159.46	174.01	168.40	151.54	159.30	155.99
FB	162.89	173.01	168.41	154.61	157.30	155.99
Actual Stature	145.00	193.80	168.43	135.10	181.00	156.00

Note: S (Stature), HL (Hand length), HB (Hand breadth), FL (Foot length), FB (Foot breadth)

DISCUSSION & CONCLUSION

In this study of North Indian Population, the stature and hand-foot anthropometric measurements were larger for males than females. The similar findings were also reported by other researchers.[8,9,13,24] Sanli et al.[25] in Turkey population, Mohamadon et al.[20] in Malaysian population, Geetha and Swathi[26] in Indian population have reported larger stature, hand length, hand breadth, foot length and foot breadth in males than females. Another study by Kim et al.[9] in Korean population revealed that stature, hand length, hand breadth, foot length and foot breadth were higher in males and lower in females. Both male and female have different body measurements/ sizes as their growth are affected by various factors such as biological, genetic etc. This recommends that it is imperative to derived/formulate regression equations by categorizing genders when estimating statures through different anthropometric body measurements.

In the current study, the average hand length for men was 18.46 cm and for women it was 17.12 cm. In a research on the Korean population, Kim et al.[9] found that the average hand length was 18.42 cm for men and 17.05 cm for women. A research on the Kori community in North India[12] found that the average hand length was 17.63 cm for women and 18.43 cm for men. In this study, the average hand breadth was 7.46 cm for women and 8.22 cm for men.[27] Adults in Turkey were the subject of a research by Ozaslan et al.[27] who found that the average hand width was 7.57 cm for women and 8.29 cm for men. In the population of Uttar Pradesh[28], the mean hand breadth was 8.31 cm for men and 7.24 cm for women. Men's average foot length in this research was 24.55 cm, while women's average foot length was 22.62 cm. According to a research by Ahmed[29], men's average foot length is 26.43 cm, while women's average foot length is 24.06 cm. Males' average foot width is 9.41 cm, while girls' average foot width is 8.51 cm. Males had a mean foot breadth of 9.79 cm in the Korean population[9], whereas females had a mean foot breadth of 8.79 cm. In this study of North Indians population, significant differences were found in both sexes. These findings are consistent with previous studies.[9,29]

Previously, several studies have been conducted on hand and foot anthropometric measurements that showed positive correlation with the stature.[24,25,30] In the present study, Female and male hand lengths had the most positive correlation with height, whereas foot breadth had the weakest. These results are well supported by earlier research, which also showed a greater association between hand size and height than between foot size.[31,32]

In present study, regression equations have been deduced which can be used to determine unknown stature values for known body measurements such as hand length, hand breadth, foot length and foot breadth. In linear regression analysis (Table 4), the lowest SEE with the highest coefficient of determination values were observed in hand

length in both gender (R^2 = 0.239 in males and 0.189 in females; SEE ±7.157 cm in males and ±6.488 cm in females). Therefore, when utilising the regression equations obtained from our sample, employing foot length will produce the most accurate stature prediction. Therefore, using the regression equations obtained from our sample, hand length is thought to be the most accurate measurement for estimating height.

Hand length and hand breadth in both genders were the lowest SEE with the greatest coefficient of determination and coefficient of association in the multiple regression analysis (Table 2) (R^2 = 0.242 in males and 0.190 in females; SEE ±7.151 cm in males and ±6.494; R = 0.492 cm in males and 0.436 cm in females). The output of the multiple linear regressions displays the lowest SEE for hand length and hand breadth dimensions. In comparison to the simple linear regression models, multiple regression models have higher coefficient of determination, higher coefficient of correlation and lower SEE, therefore the more reliable stature are to be found with multiple regression equations. These findings were similar with the findings of other researchers.[13,20] Therefore, in case of mutilated body or amputated body where both hands and foot are found, the stature could be determined with these equations. However, using multivariate regression stature may be estimated from the different dimensions in situations of dismembered body parts when just a foot or hand are present.

The results of this study led to the conclusion that height assessment in forensics and criminal investigations might be done using hand and foot anthropometric measurements. However, it is important to remember that the population from which the data were gathered should be used when using the regression equations in particular. This study's age range of participants is a drawback; hence, comparable research in various age groups is required. The left hand and left foot were not measured for this study. Consequently, it is hard to confirm bilateral differences between both hands and both feet.

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