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Stature prediction from Anthropometric Feet Dimensions: A Study of Relationship

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Abstract

Anthropologists and forensic medicine personnel estimate height of an individual as one of criteria to establish identity of an individual. It is also useful for physical assessment of status of nutrition in an individual by nutritionists and physicians. Stature prediction from incomplete and decomposing skeletal remains is one of most useful criteria in establishing the identity of an unknown individual. It is a useful tool in medico legal and forensic examination. *Study Design*: Descriptive cross-sectional study. *Place of Study*: Department of Anatomy, MGM medical college, Aurangabad, India. *Material*: 185 young and healthy college students aged between 18 to 24 years, without any disease or deformity were examined anthropometrically in respect to their height and foot dimensions. *Method*: Measurement of height and foot dimensions of right and left side was taken with a standard anthropometer and a Vernier caliper respectively. *Result*: The present study showed significant ($p<0.001$) positive correlation between the stature and feet dimensions with sexual dimorphism.

Keywords: Anthropometric Measurement; Skeletal Remains; Height; Stature; Foot Length; Foot Width; Stature.

Introduction

Since many years artists, scientists, anatomists, anthropologists and medico legal experts [1] has been studying dimensional relationship between body segments and stature for different reasons of which the prime importance is to establish the identity of individual. Other uses include ergonomic designing of machines and fashion designing.

The identity of an individual has to be established in cases of mutilated, decomposed, & amputated body fragments in recent times which may occur due to natural disasters like earthquakes, tsunamis, cyclones, floods or man-made disasters like terror attacks, bomb blasts, mass accidents, wars, plane crashes etc.

The determination of stature is an important step in the identification of fragmented/dismembered remains [2].

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Hence, personal identification of the victims [3] by estimation of stature from extremities and their parts plays avital role in identifying the dead in forensic examinations. Stature and body parts show significant biological correlation [4].

Also, evaluation of various anthropological parameters with proportions has an important role in sports medicine, designing of instruments and education [5].

Height of an individual is also affected by diverse factors such as race, gender and nutrition. An individual's height is also under the control of genes and environment [6].

The body size such as height and weight can be assessed by growth, nutritional status, body surface area and pulmonary function of children [7,8].

Natural height or stature of a person is usually taken in upright position. The foot dimensions can be used as a basis for estimating age-related loss in stature [9,10,11].

Hence, we attempted to study the correlation between stature and various dimensions of foot with a mention to gender, in Medical students in age group of 18-24 years by using linear univariate and multiple regression formulae.

Materials and Methods

Method of Data collection

The study was started after all necessary permissions from authorities and written consent from subjects were taken. Stature and foot dimensions were recorded of 185 students consisting of 81 males and 104 females in the age group of 18-24 years studying in MGM Medical College, Aurangabad, India.

Selection of male and female adult subjects for measurements was taken as below:

Inclusion Criteria

1. Healthy and normal adult subjects in the age group 18-24 years.
2. All students of MGM medical college in the age group of 18-24 year

Exclusion Criteria

1. Subjects with musculoskeletal deformities like kyphosis, scoliosis, poliomyelitis, trauma etc., hormonal disorders like gigantism, dwarfism, etc. and genetic disorders like Turner's syndrome, etc. which will affect the normal measurements of stature and foot dimensions.

The following instruments were used to carry out this study:

1. Anthropometer (Stadiometer).
2. Vernier (Sliding) calipers (digital type).
3. Steel tape.

Method of Measurements [12,13]:

1. *Stature:* Measurement was taken as vertical distance from vertex (the highest point on the top of head) to the floor in mid-sagittal plane with subject standing barefooted, on an even floor and the head being oriented in the Frankfurt's plane. Stadiometer (Anthropometer) was used for the measurement of Stature.
2. *Foot length:* Measurement was taken as the straight distance from the most posterior projecting point on the heel to the tip of the most anterior projecting toe when the subject is standing erect. It was measured with the help of Digital Vernier calipers.
3. *Foot breadth:* It was measured as distance between the most prominent point on the medial aspect of head of first metatarsal and the most prominent point on the lateral aspect of head of fifth metatarsal.

Fig. 1:

Fig. 2:

Fig. 3:

The measurements were taken from foot of both sides of the body. Both, male and female readings for each parameter were obtained, separated and analyzed. Measurements were taken at a fixed time between 3:00 p.m. and 5.30 p.m. to minimize diurnal variation and were taken in a room with reasonable light. Measurements were done and recorded only by me, to eliminate inter observer error in methodology. All the measurements were recorded thrice and then their mean was calculated for accuracy.

The height, foot length and foot breadth of subjects was used to assess the relationship between the foot dimensions and stature. Analysis was done for all parameters by calculating mean, STD error of mean, STD deviation, Maximum, Minimum separately, Skewness and Kurtosis. Then correlation and coefficients between these anthropometric measurements were calculated. The regression

equations of stature as dependable variable were fitted with foot dimensions as independent variables. The effectiveness of these regression equations was tested. Stature (Height) was considered to be independent for every parameter and correlation was checked between the height and other parameters. Univariate and multivariate regression formulas were derived for each parameter later on. The data were subjected to statistical analysis using statistical package for social sciences (SPSS).

Observation

The following things were observed as shown in table 1 below:

Table 1 shows that values here are showing negatively skewed distribution in males and positively skewed distribution in females with platykurtic distribution.

One way ANOVA shows F value as 170.143 with 0.00 significance suggesting statistically significant difference in male and female height as shown in Table 2.

Foot length is showing positively skewed distribution of values in both males and females. Kurtosis shows platykurtic distribution.

One way ANOVA shows F value as 20.010 with 0.00 significance suggesting statistically significant difference in male and female foot length.

Foot breadth is showing positively skewed distribution of values in both males and females. Platykurtic distribution is observed in kurtosis.

Table 1: Height (in centimetre's)

	Male	Female
Mean	171.116	157.578
Std. Error of Mean	0.843	0.637
Std.Deviation	7.684	6.348
Maximum	188	175
Minmum	147	141
Skewness	-0.283	0.228
Kartosis	0.660	-0.090

Table 2:

One-way ANOVA			Sum of Squares	DF	Mean Square	F	Sig.
Ht (cm)	Between Groups	(Combined)	8561.364	1	8561.364	170.143	0.000

Table 3: Foot Length (in centimeter's)

	Male		Female	
	Right	Left	Right	Left
Mean	25.46	25.455	23.307	23.333
Std. Error of Mean	0.132	0.132	0.125	0.479
Std.Deviation	1.186	1.191	1.430	1.367
Maximum	28.34	28.1	29.5	29.4
Minmum	22.7	22.67	20.2	20.1
Skewness	0.100	0.142	1.413	1.250
Kartosis	0.009	-0.073	4.853	3.793

Table 4:

One-way ANOVA			Sum of Squares	DF	Mean Square	F	Sig.
FL (cm)	Between Groups	(Combined)	144.210	1	144.210	20.010	0.000

Table 5:

	Male		Female	
	Right	Left	Right	Left
Mean	9.628	9.603	8.792	8.731
Std. Error of Mean	0.070	0.067	0.055	0.057
Std.Deviation	0.642	0.616	0.574	0.590
Maximum	11.24	10.95	10.2	10
Minmum	8.3	8.37	7.16	7.04
Skewness	0.214	0.111	0.013	0.069
Kartosis	-0.093	-0.458	-0.190	-0.281

Table 6:

One-way ANOVA			Sum of Squares	DF	Mean Square	F	Sig.
FB (cm)	Between Groups	(Combined)	30.647	1	30.647	84.346	0.000

One way ANOVA shows F value as 84.346 with 0.00 significance suggesting statistically significant difference in male and female foot breadth.

Following regression formulae has been derived using SPSS of one variable and multivariables. They are as follows:

Univariate Analysis

1. Foot Length (Equ.Uni-1)

R Value = 0.399 F Value = 35.833

Height = 129.514 + [1.383 * (Right foot length)]

2. Foot Breadth (Equ.Uni-2)

R Value = 0.627 F Value = 122.196

Height = 86.036 + [8.453 * (Right Foot breadth)]

Multivariate Analysis

1. Height versus Right Foot Length and Left Foot length. . (Equi. Muti-1)

R Value = 0.432 ANOVA is significant

Height = 122.285 + [1.242 * (Right Foot length)] + [0.433 * (Left Foot length)]

2. Height versus Right Foot breadth and Left Foot breadth. . (Equi. Muti-2)

R Value = 0.645 ANOVA is significant

Height = 83.690 + [2.684 * (Right Foot breadth)] + [6.056 * (Left Foot breadth)].

3. Height versus Right Foot breadth, Left Foot breadth, Right Foot Length and Left Foot length. (Equi. Muti-3)

R Value = 0.658 ANOVA is significant

Height = 78.428 + [2.218 * (Right Foot breadth)] + [5.424 * (Left Foot breadth)] + [0.430 * (Right Foot Length)] + [1.93 * (Left Foot length)].

Discussion

Ancient Egyptians (Richer and Hale, 1971) [13] were one of the first people to use anthropological rules for stature prediction. Studies done by Pearson (1899) [14], Trotter and Glesser (1952) [15] have shown the prediction of stature from skeletal remains or mutilated limbs done mostly from long bones.

In India, Athwale et al (1963)[16], Patel et al (1964)[17], Joshi et al (1964, 65) [17,18], and Jasuja et al (1991, 1993, 1997)[19,20], studied stature estimation by significant dimensional relationship of length of foot, hand, hand with forearm, arm, upper extremity, length of head, height of head, Crown to rump and rump to heel ratio etc. They concluded that there exists significant correlation between body segments and height. There also exists a population variation in anthropometric dimensions. Stature is partly determined by length of bones in upper limb and lower limb. It may also be influenced by many other factors such as genetics, environment, gender, age and physical activity [21]. In addition, it is also true that, the rate or growth in males and females varies during the course of development till the ossification being complete and skeletal maturity attained by the age of 25 years.

All parameters show significant sexual dimorphism in this present study. There was a strong positive correlation between foot breadth and stature ($p < 0.01$). Hence these can be successfully used for estimation of stature. Anatomists, archaeologists, anthropologists, design engineers and forensic scientists can now predict height of an individual more accurately by the regression equations derived from this study. The only condition is, these formulae are applicable to the Indian region population from which the data has been collected. It is due to the inherent population variation in these dimensions, which may be attributed to genetic, lifestyle differences and environmental factors like nutrition, climate etc.[22].

The feet provide a firm base to support the vertical height of a person. This implies that increase in the height is associated with an increase in foot dimensions [23]. From this study both in males and females, foot breadth is the best parameter for estimation of stature. The relatively low estimate of standard error of mean for the foot breadth in males (±0.068) and for foot breadth in females (±0.056) ensures better accuracy in stature estimation.

The evidence of a positive linearity between the anthropometric parameters and estimation of stature helps in formulation of regression equations which can be successfully utilized for stature estimation in Indian population. In the present study, males showed higher mean values in all parameters studied when compared with mean values of female parameters.

Stature estimation studies by Kaur [30] and OP Jasuja [25] has reported significant higher mean values for males amongst Indians but both their study groups were from North India. Danborno B [27] also reported higher value as the study was conducted on Nigerians which belongs to different race groups. Fusion of epiphysis of bones occurs earlier in females than in male leads to differences of mean in stature between males and females. Males have about two more years of bone growth than females [21].

This present study was done in medical students of all India region of age group 18-22 years and the mean of stature came as 171.11 cm in males and 157.57 cm in females.

Table 7: Stature

Sr. No.	Name of the author	Sex	Min. Stature	Max. Stature	Mean	± SD	± SE
1.	Thakur[24] (1975)	-	-	-	167.4	6.4	-
2.	Jasuja[25] (2004)	Male	166.2	185.6	175.2	5.24	0.957
		Female	152	167.9	159.7	5.17	0.945
3.	Patel[26] (2007)	Male	-	-	170.96	5.13	-
		Female	-	-	156.14	5.15	-
4.	Danborno B[27] (2008)	Male	-	-	173.73	7.13	-
		Female	-	-	160	6.22	-
5.	Ilayperuma[28] (2009)	Male	-	-	170.14	5.22	-
		Female	-	-	157.55	5.75	-
6.	Rahul[29] (2013)	Male	157	192	169.97	5.71	-
		Female	139	167	154.2	7.15	-
7.	Kaur et al[30] (2013)	Male	-	-	175.98	6.76	-
		Female	-	-	160.91	5.75	-
8.	Srivastava[31] (2014)	Male	-	-	170.9	-	0.371
		Female	-	-	156.21	-	0.49
9.	Present Study (2014)	Male	147	188	171.11	7.68	0.84
		Female	141	175	157.57	6.34	0.63

Table 8: Foot Length

Sr. No.	Authors	Measurement's	Sex	Side	Min	Max	Mean	± SD	± SE
1	Patel[26] (2007)	Foot Length	Male	-	-	-	24.4	0.99	-
			Female	-	-	-	22.3	1.12	-
2	DanbornoB [27](2008)	Foot Length	Male	Right	-	-	28.4	1.73	-
				Left			26.4	1.6	
			Female	Right	-	-	24.5	9.08	-
				Left			24.7	1.1	
3	Srivastava[31] (2014)	Foot Length	Male	-	-	-	25.1	-	0.12
			Female	-	-	-	22.7	-	0.1
4	Present Study (2014)	Foot Length	Male	Right	22.7	28.3	25.5	1.18	0.13
				Left	22.7	28.1	25.5	1.19	0.13
			Female	Right	20.2	29.5	23.3	1.43	0.13
				Left	20.1	29.4	23.3	1.36	0.48

Table 9: Foot Breadth

Sr. No.	Authors	Measure-Ments	Sex	Side	Min	Max	Mean	± SD	± SE
1	DanbornoB[27] (2008)	Foot Breadth	Male	Right	-	-	9.02	0.72	-
				Left			9.09	0.94	
			Female	Right	-	-	8.23	0.63	-
				Left			8.11	1	
2	Arti[32] (2013)	Foot Breadth	Male	Right	8.7	11.6	10.48	0.51	-
				Left	8.7	11.7	10.55	0.52	
			Female	Right	8.2	11.1	9.33	0.53	-
				Left	8.3	11.2	9.39	0.53	
3	Srivastava[31] (2014)	Foot Breadth	Male	-	-	-	9.36	-	0.06
			Female	-	-	-	8.36	-	0.05
4	Present Study (2014)	Foot Breadth	Male	Right	8.3	11.24	9.62	0.64	0.07
				Left	8.37	10.95	9.6	0.61	0.067
			Female	Right	7.16	10.2	8.79	0.57	0.055
				Left	7.04	10	8.73	0.59	0.057

Mean foot lengths reported by DanbornoB [27]in Nigerian population are on the higher side then the Indian counterparts. This is seen by the mean foot length values reported in the Gujarat medical students in India by Patel [26], in the Bundelkhand region in India by Srivastava [31] and in the present study. The sexual dimorphism is evident by female values being lower than the males in all of the above studies including the present one.

Arti [32] reported high values of mean foot breadth which she studied in medical students at Nagpur India. These values are higher than the mean values reported by Danborno B [27] which was studied in the Nigerian students which is quite unusual. Whereas in study by Srivastava [31] in the Bundelkhand region India and also in the present study the mean values are nearer to each other. It is also closer to the mean values reported by DanbornoB [27] suggesting that there is less difference in foot breadths in spite of the difference in race.

Now comparing mean value of stature according to different equations derived from our formulae we get:

In our study these formulas do give a good predictive value as illustrated by the chart above with the regression formulas as below. But also, these give a lesser (r) value. The best formulae which also gives good r value that can be used are:

1. Height = 83.690 + [2.684 * (Right Foot breadth)] + [6.056 * (Left Foot breadth)]. (Equ. Muti-2)

Table 10:

Actual Height (Cms)	Equi (Uni-1)	Equi (Uni-2)	Equi(Multi-1)	Equi (Multi2)	Equi(Multi-3)
164.34	163.242 R =0.399	163.702 R=0.627	163.130 R=0.432	163.924 R = 0.645	176.795 R=0.658

Table 11: Comparisons of studies of Foot Length (FL)

Sr. No.	Author	Year	Population	Sex	Correlation Coefficient(r)	Regression Equation
1.	Giles E[33]	1991	US Army	Male	0.68	S=82.21+3.45(FL)
2.	Giles E[33]	1991	US Army	Female	0.69	S=75.07+3.61(FL)
3.	SanliS. G[22]	2005	Turks	Male	0.72	S=37.23+2.58(FL)
4.	SanliS. G[22]	2005	Turks	Female	0.69	S=74.31+1.73(FL)
5.	Kewal Krishan[34]	2007	Rajput	Male	0.73	S= 68.09+4.05(FL)
6.	Kewal Krishan[34]	2007	Rajput	Female	0.74	S= 71.94+3.70(FL)
7.	Ilayperuma I[35]	2008	Galle SriLanka	Male	0.73	S= 79.04+3.59(FL)
8.	Ilayperuma I[35]	2008	Galle SriLanka	Female	0.72	S= 65.54+3.94(FL)
9.	Present Study	2014	Medical Students	-------	0.39	S=129.51+1.383(FL)

Table 12: Comparisons of studies of Foot Breadth (FB)

Sr. No.	Author	Year	Population	Sex	Correlation Coefficient(r)	Regression Equation
1.	Kewal Krishan[34]	2007	Rajput	Male	6.19	S=135.24+3.47(FB)
2.	Kewal Krishan[34]	2007	Rajput	Female	4.17	S=135.41+2.37(FB)
3.	Present Study	2014	Medical Students	-------	0.627	S= 86.03+8.45(FB)

2. Height = 86.036 + [8.453 * (Right Foot breadth). (Equ. Uni-2).

In the data, the mean value of stature is 164.34, if stature is calculated according to Univariate regression equation of:

1. Giles E [33] it is 166.3926,
2. Sanli S. G [22] it is 100.184
3. Kewal Krishan [34] it is 166.9131
4. Ilayperuma I [35] it is 166.6387
5. Present Study it is 163.2562

This shows that in the present study foot length has more closeness to the actual values.

So, the univariate regression equation; Stature = 129.514 + [1.383 * (Right foot length)], derived from this study has better predictive value in the estimation of stature than the others.

Actual mean stature from our data pool is 164.34Cms.

In the Present study the calculated stature from regression formula is 163.15 and that from Kewal Krishan [34] is 166.91.

This shows that the univariate regression equation, Height = 86.036 + [8.453 * (Right Foot breadth)], derived from this study has better predictive value in the estimation of stature than the other studies above.

In case of multivariate regression equation, the present study has derived and analyzed it. No studies were found who have attempted to derive or analyze the multivariate equation.

Conclusion

It is found that there exists a significant sexual dimorphism in male and female population. It is well predicted in foot dimensions. Males have higher values than the females in dimensions of foot.

The multivariate regression formulas used to calculate the stature from the foot dimensions in both sexes gives a better prediction of stature than the univariate type. Foot breadth is more positively related in lower limb than foot length.

Both univariate and multivariate regression formulae are equally sensitive for prediction of stature in case of lower limb. The multivariate formula (equi. multi. 2) with correlation coefficient (r) of 0.645: Height = 83.690 + [2.684 * (Right Foot breadth)] + [6.056 * (Left Foot breadth)] is more sensitive in prediction than the others. In case of univariate type, the following gives a good predictive value of stature than the others. (equi.uni. 2) with correlation coefficient (r) of 0.645: Height = 86.036 + [8.453 * (Right Foot breadth).

The regression equations derived from present study give a better predictive value than the formulas that have been derived by other authors as evident from the correlation coefficient. These formulas can be used effectively to estimate the stature of the individual in case mutilated bodies and also can be used effectively in ergonomics such as furniture designing, machine designing and sports as well as forensic cases.

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