Prediction of Stature from Foot Dimensions in A Jat Sikh Population of North India

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ABSTRACT: Establishing the identity of the victim is an important phase in investigation of medicolegal and forensic cases. Stature estimation plays an important and key role in such investigations. The present study examines the association of stature with different dimensions of feet among Jat Sikhs of Punjab – an endogamous group of North Indian population. Seven measurements on each foot along with stature were recorded on 200 subjects studied in Punjabi university, Patiala. The age of subjects ranges between 18 to 30 years. Univariate and multivariate linear regression equations were derived to estimate stature from these variables. Statistical analysis indicated that all foot measurements show statistically significant ($p<0.01$) variation in males, while in females, T1 to T5 lengths show statistically significant variation. Positive and significant correlation coefficients were found between various foot dimensions and stature. Foot length provides highest reliability and accuracy in estimating stature due to lowest SEE (standard error of estimate) exhibited by it. It is emerged out from the present study that foot length is a better predictor to estimate stature than foot breadth in males and females.

Keywords: Forensic anthropology; physical anthropology; stature estimation; foot dimensions; regression equations

Introduction

Identification of an unknown individual from its body parts is an essential phase of forensic investigations. Establishing the identity of dead person is required in cases of suicide, homicide, riots, explosive blasts, vehicular accidents, earth quakes, tsunami and floods. In disaster cases (natural and artificial), where only fragmentary remains are available, identification becomes tedious and complex task. Stature estimation is an integral and key part of identification process along with age, sex and race. It plays a key role in establishing the identity from unknown, decomposed and fragmentary remains in medicolegal cases [1]. Stature of a person is proportional to dimensions of various body parts. It is established that dimensions of lower extremity show higher association with stature than upper extremity [2,3]. Different body measurements can be used to estimate the stature [4-9].

Foot has potential significance in forensic anthropology due to its variability and individuality and can be used to establish the personal identity in cases of natural (e.g. earth quake, air plane crashes) and artificial mass disasters (e.g. bomb blast, train or bus accidents), homicide and kidnapping [10]. Major peculiarities and dimensions of foot remain stable during the life of person [11]. Systematic analysis of foot provides the significant information regarding the person to whom it belongs and thereby connecting him or her with scene of occurrence. Size of foot shows a specific biological correlation with stature. Therefore, it is possible to estimate the stature of a person from foot (or its parts) [10].

Different studies reported a statistically significant positive association of stature with foot measurements [2,3,11-21]. The importance of foot bones in estimating stature in forensic investigations is also reported [22-24]. Some studies suggest the use of stature-foot length index or multiplication factor methods to estimate stature from foot dimensions [12,16,25]. Although this method is easy and fast but estimation error (difference in calculated and measured stature) is large. These errors can be reduced by using regression equations. Krishan *et al.* also advocate the use of regression equations over multiplication factor method to estimate stature from dimensions of foot because extent of error in stature estimation by regression equations is less in comparison to multiplication factor method [26].

Body dimensions vary from person to person, male to female and in various racial groups. Therefore, regression equations derived from different body dimensions to estimate the stature in one population cannot apply to other and are gender and population specific [27-29]. Therefore, separate regression equations should be develop to calculate stature from different body dimensions for males and females in a particular population. The purpose of current study is to calculate the correlation of different foot measurements with stature and to develop regression equations for stature estimation from these measurements.

Materials and Methods

The study was conducted in Punjabi university, Patiala. The measurements were taken from 200 Jat Sikh (100 males and 100 females) university students. The age of subjects ranges from 18 to 30 years. Only healthy subjects, free from any abnormality of foot, were included in the study. Subjects with fractures of lower limbs or any other deformity were excluded from the study. Subjects were informed about the purpose of study and an informed consent was obtained before taking their measurements.

A total of seven anthrophometric measurements were taken on left and right foot of each subject. Along with these, stature of each subject was also recorded. Before taking the measurements, each subject was asked to remove his/her foot wear. All measurements were taken on a flesh foot. Standard anthrophometric instruments (anthropometric rod and sliding caliper) were used for recording the measurements. The measurements were taken in centimetres according to the techniques reported by Vallois [30].

Stature was measured as vertical distance between point vertex and floor. Technique: Stature was measured as a vertical length from floor to vertex when the subject was standing bare footed and with the head in the Frankfurt plane. The measurement was taken without wearing anything on head or foot, using an anthropometric rod. The subject's heels must not leave the ground during measurements.

Foot measurements were taken using landmarks and techniques described by Robbins [11]. Foot length measurements were recorded from most prominent part of heel backward to most distal part of each toe and denoted as respective T1, T2, T3, T4 and T5 as follows:

T1 Length is the distance between pternion and most distal part of first toe.
T2 Length is the distance between pternion and most distal part of second toe.
T3 Length is the distance between pternion and most distal part of third toe.
T4 Length is the distance between pternion and most distal part of fourth toe.
T5 Length is the distance between pternion and most distal part of fifth toe.

Foot breadth at Ball (BAB) *i.e.* Foot breadth at ball was measured as straight distance from most medially projecting point on the head of the first metatarsal to most laterally projecting point on the head of fifth metatarsal.

Foot breadth at Heel (BAH) *i.e*. Foot breadth at heel was measured as straight distance between the medial calcaneal concavity to lateral calcaneal tubercle.

Statistical Package for Social Sciences (SPSS) version 16.0 was used to analyse the recorded data. Descriptive statistics including mean, standard deviation, minimum and maximum values for stature and different foot dimensions of both sides were calculated separately for both sexes. Bilateral asymmetry between various foot measurements was calculated separately for both sexes and paired *t*-test was used to test it [31]. Karl Pearson's correlation coefficients were calculated between stature and different foot measurements. Univariate and multivariate linear regression equations were developed to estimate stature from various foot dimensions. The univariate linear regression equation to estimate stature is given by stature (S) = b x + a ± SEE, where, 'a', 'b' and 'x' denotes constant, regression coefficient of the independent foot measurement and SEE is Standard Error of Estimate. The SEE determines the difference between estimated and actual stature. Greater reliability in estimated stature is indicated by low value of SEE. Multivariate linear regression equations were calculated to estimate stature from foot length (T1 to T5) and foot breadth dimensions.

Results and Discussion

Means and standard deviations along with maximum and minimum values of stature and right/left foot dimensions in males and females are presented in Table 1. It was observed that all foot dimensions (of both sides) and stature values were higher for males than females. It may be due to later maturity of males than females. Other studies come to similar observations that male foot measurements and stature are larger than females in different human populations [1,4,10,12,16,20,21,25,32-38].

Table 1: Descriptive Statistics for stature and foot measurements (cm) in males and females

Variable (cm)	**Male (n=100)**								**Female (n=100)**							
	Minimum		**Maximum**		**Mean**		**S.D.**		**Minimum**		**Maximum**		**Mean**		**S.D.**	
	L	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**
T-1 Length	21.3	21.2	30.4	29.8	25.8	25.6	1.41	1.41	20.3	20.0	26.4	25.6	23.5	23.3	1.15	1.17
T-2 Length	21.4	21.0	30.1	30.0	25.3	25.2	1.49	1.52	20.0	19.2	26.1	25.6	23.1	23.0	1.22	1.25
T-3 Length	21.1	20.3	28.7	28.9	24.4	24.2	1.46	1.47	19.5	18.8	25.1	24.6	22.3	22.1	1.11	1.24
T-4 Length	19.5	19.4	27.5	27.9	23.1	22.9	1.38	1.45	18.6	17.8	24.1	23.8	21.2	21.0	1.01	1.21
T-5 Length	18.3	18.0	24.8	24.8	21.6	21.3	1.24	1.26	16.5	16.5	22.0	22.0	19.7	19.6	1.00	1.02
Breadth at Ball	8.9	8.8	11.8	11.6	10.0	9.9	0.51	0.54	8.1	8.2	10.5	10.5	9.2	9.2	0.44	0.42
Breadth at Heel	5.6	5.5	7.9	7.5	6.5	6.4	0.42	0.42	5.0	4.9	6.6	6.7	5.7	5.7	0.36	0.34
Stature	154.0		188.5		172.3		5.75		146.3		171.5		159.7		4.86	

The mean differences, standard deviations and ‘t’ values of bilateral differences (left-right) in various foot dimensions in both sexes are presented in Table 2. The T2 length (0.10) and T3 length (0.22) showed minimum and maximum mean difference in males whereas T5 length (0.12) and T1 and T3 lengths (0.17) showed minimum and maximum mean difference in females. All foot length measurements showed statistically significant ($p<0.01$) differences in males. However, only T1 to T5 lengths showed statistically significant differences in females. Sen and Ghosh also observed significant variation in foot length of both sides [37]. Foot measurements of left side showed predominance over the right side in both sexes in the present study (Table 2). Similar observations that foot dimensions of left side are larger than right side in males and females were reported in earlier studies [36-37]. It may be due to high strain on left lower limb than on right lower limb during walking and weight bearing process [39]. However, in some studies, foot measurements of right side gave higher mean values than left side in males and females [4,12,16,33,36]. Breadths at ball and heel showed statistically significant ($p<0.01$) difference in males while in females these measurements did not indicate significant asymmetry. However, statistically insignificant bilateral difference was observed in foot dimensions in some studies [4,11,12,16,33-35,40-42].

Table 2: Mean differences, standard deviations and values of ‘t’ of bilateral differences (Left-Right) in various foot measurements (cm) in males and females

Variables (cm)	**Males (n=100)**			**Females (n=100)**		
	Mean Differences (Left-Right)	**S.D.**	**t-value**	**Mean Differences (Left-Right)**	**S.D.**	**t-value**
T-1 Length	0.19	0.25	7.78*	0.17	0.44	3.91*
T-2 Length	0.10	0.34	3.07*	0.13	0.37	3.57*
T-3 Length	0.22	0.39	5.61*	0.17	0.37	4.70*
T-4 Length	0.15	0.32	4.73*	0.16	0.41	3.93*
T-5 Length	0.20	0.29	7.17*	0.12	0.36	3.32*
Breadth at Ball	0.10	0.21	4.90*	0.04	0.21	1.92
Breadth at Heel	0.06	0.20	3.06*	0.05	0.25	1.96

*p<0.01

Correlation coefficients between stature and different foot measurements on both sides in males and females are presented in Table 3. All correlation coefficients were positive and were statistically significant at $p=0.01$ level. Correlation coefficients of foot length dimensions were higher than foot breadth dimensions in males and females irrespective of sides. Similar observations were reported in earlier studies [4,16]. Strongest correlation with stature was exhibited by T1 length in males and females on both sides while breadth at ball shows weakest correlation with stature in males for both sides. In females, breadth at ball ($r=0.405$) showed the weakest correlation with stature on right side while the breadth at heel ($r=0.364$) showed the weakest correlation with stature on left side. In males, the breadth at heel showed stronger correlation with stature than breadth at ball on both sides. In females, the breadth at heel ($r=0.429$) showed stronger correlation with stature than breadth at ball ($r=0.405$) on right side while, on left side, breadth at ball ($r=0.407$) showed stronger correlation with stature than breadth at heel ($r=0.364$). Statistically significant positive correlations of foot length and foot breadth with stature were also reported in literature [4,12-14,25,32,43-44].

Table 3: Correlation coefficients of various foot measurements with stature in males and females

Variable	Male (n=100)		Female (n=100)	
	L	R	L	R
T-1 Length	0.809*	0.779*	0.742*	0.763*
T-2 Length	0.799*	0.758*	0.708*	0.732*
T-3 Length	0.776*	0.764*	0.664*	0.677*
T-4 Length	0.769*	0.749*	0.678*	0.698*
T-5 Length	0.770*	0.754*	0.664*	0.678*
Breadth at Ball	0.426*	0.487*	0.407*	0.405*
Breadth at Heel	0.569*	0.568*	0.364*	0.429*

It was observed that foot length dimensions showed high degree of association with stature than foot breadth (at heel and ball) dimensions. This strong positive association between stature and various foot dimensions indicates that foot dimensions and subject's stature are directly proportional to each other. Therefore, regression equations can be developed to estimate stature from various foot dimensions. Univariate and multivariate linear regression equations to estimate stature from different length and breadth measurements of left and right foot in both sexes are presented in Tables 4-7. Accuracy in predicted stature using multivariate linear regression equations was evident from lower values of the standard error of estimate. It was indicated that multivariate linear regression equations could be a better marker than univariate linear regression equations to estimate stature.

Table 4: Univariate and Multivariate Linear Regression equations for estimation of stature through various length/breadth measurements of left foot in males (n=100)

S.No.	Variable	Regression Equations	R	R^2	S.E.E.
1.	T1L	3.291 × (T1L) + 87.328	0.809	0.654	3.3979
2.	T2L	3.081 × (T2L) + 94.325	0.799	0.638	3.4752
3.	T3L	3.044 × (T3L) + 97.831	0.776	0.602	3.6415
4.	T4L	3.187 × (T4L) + 98.656	0.769	0.591	3.6945
5.	T5L	3.577 × (T5L) + 95.110	0.770	0.593	3.6852
6.	BABL	4.751 × (BABL) + 124.587	0.426	0.182	5.2250
7.	BAHL	7.715 × (BAHL) + 122.165	0.569	0.324	4.7483
8.	T1L, T2L	2.038 × (T1L) + 1.260 × (T2L) + 87.810	0.816	0.666	3.3566
9.	T1L, T2L, T3L, T4L, T5L	2.011 × (T1L) + 0.461 × (T2L) + 0.661 × (T3L) – 0.158 × (T4L) + 0.436 × (T5L) + 86.779	0.818	0.669	3.3936

Table 5: Univariate and Multivariate Linear Regression equations for estimation of stature through various length/breadth measurements of right foot in males (n=100)

S.No.	Variable	Regression Equations	R	R^2	S.E.E.
1.	T1R	3.162 × (T1R) + 91.300	0.779	0.606	3.6249
2.	T2R	2.866 × (T2R) + 100.075	0.758	0.575	3.7670
3.	T3R	2.978 × (T3R) + 100.106	0.764	0.583	3.7274
4.	T4R	2.961 × (T4R) + 104.326	0.749	0.561	3.8272
5.	T5R	3.430 × (T5R) + 99.006	0.754	0.569	3.7910
6.	BABR	5.143 × (BABR) + 121.187	0.487	0.237	5.0456
7.	BAHR	7.815 × (BAHR) + 122.000	0.568	0.322	4.7540
8.	T1R, T2R	2.391 × (T1R) + 0.757 × (T2R) + 91.956	0.781	0.610	3.6244
9.	T1R, T2R, T3R, T4R, T5R	2.469 × (T1R) – 1.312 × (T2R) + 2.296 × (T3R) – 0.548 × (T4R) + 0.466 × (T5R) + 89.075	0.796	0.634	3.5695

Table 6: Univariate and Multivariate Linear Regression equations for estimation of stature through various length/breadth measurements of left foot in females (n=100)

S.No.	Variable	Regression Equations	R	R^2	S.E.E.
1.	T1L	3.128 × (T1L) + 86.027	0.742	0.550	3.2820
2.	T2L	2.825 × (T2L) + 94.373	0.708	0.502	3.4544
3.	T3L	2.897 × (T3L) + 95.050	0.664	0.441	3.6591
4.	T4L	3.238 × (T4L) + 91.083	0.678	0.460	3.5957
5.	T5L	3.217 × (T5L) + 96.227	0.664	0.441	3.6577
6.	BABL	4.494 × (BABL) + 118.129	0.407	0.165	4.4703
7.	BAHL	4.837 × (BAHL) + 131.859	0.364	0.132	4.5581
8.	T1 L, T2L	2.489 × (T1L) + 0.655 × (T2L) + 85.909	0.744	0.554	3.2839
9.	T1 L, T2L, T3L, T4L, T5L	2.158 × (T1L) + 2.751 × (T2L) – 3.662 × (T3L) + 1.409 × (T4L) + 0.488 × (T5L) + 87.505	0.760	0.578	3.2462

Table 7: Univariate and Multivariate Linear Regression equations for estimation of stature through various length/breadth measurements of right foot in females (n=100)

S.No.	Variable	Regression Equations	R	R^2	S.E.E.
1.	T1R	3.155 × (T1R) + 85.939	0.763	0.582	3.1623
2.	T2R	2.834 × (T2R) + 94.543	0.732	0.536	3.3319
3.	T3R	2.637 × (T3R) + 101.325	0.677	0.458	3.6029
4.	T4R	2.790 × (T4R) + 101.045	0.698	0.487	3.5055
5.	T5R	3.228 × (T5R) + 96.398	0.678	0.459	3.5986
6.	BABR	4.694 × (BABR) + 116.471	0.405	0.164	4.4733
7.	BAHR	6.078 × (BAHR) + 125.018	0.429	0.184	4.4192
8.	T1R, T2R	2.492 × (T1R) + 0.669 × (T2R) + 86.070	0.766	0.586	3.1628
9.	T1R, T2R, T3R, T4R, T5R	2.434 × (T1R) + 2.515 × (T2R) – 2.675 × (T3R) + 1.087 × (T4R) - 0.310 × (T5R) + 87.405	0.779	0.606	3.1343

This study shows that foot length dimensions had higher correlation coefficients with stature than foot breadth dimensions in both sexes. Foot length could provide the highest reliability and accuracy in estimating stature due to lowest SEE (standard error of estimate) exhibited by it. SEE values for foot breadth dimensions were higher than foot length dimensions in both sexes (Tables 4-7). Therefore, foot length could be the best variable to estimate stature. It was also observed that SEE values for all foot measurements were lower for females than for males (Tables 4-7). It indicated that accuracy in predicted stature would be lower among males than in females.

The results of the current study indicate that a strong association is present between various foot measurements and stature, hence, foot dimensions can be used to estimate stature by forensic scientists and anthropologists in establishing the identity in medico legal cases. These regression equations, however, are population specific and cannot be applied to other populations due to variation in associated genetic and environmental factors like nutrition, climate *etc.* [45-47].

Conclusion

In the present study, univariate and multivariate linear regression equations to estimate stature from various foot dimensions of both sides for Jat Sikh males and females were derived. A positive and strong association between stature and different foot length dimensions was observed in males and females. Foot length measurements could provide good reliability in estimating stature in medico legal cases. Foot length measurements gave greater association with stature than foot breadth measurements in both sexes irrespective of sides. The foot length dimensions provide enhanced estimation of stature than foot breadth dimensions in both the sexes. Prediction of stature could be more reliable and accurate in Jat Sikh females than in Jat Sikh males. Therefore, it is suggested that foot length is a better predictor to estimate stature than foot breadth. However, it should be cautioned that these equations are population specific and cannot be applied to other population. Therefore, population specific studies are suggested in different areas of world that may be useful in examining dismembered human remains in medico legal cases.

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