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Estimation of Stature from Foot Measurements

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Abstract

Estimation of stature from body parts is crucial in identification of disfigurement human remains in forensic investigation. The objectives of the present study were to understand the correlations of foot measurements with stature and to derive regression equations to estimate the stature from different foot measurements in adult Bengali females. The present cross-sectional study in the Birbhum district of West Bengal was conducted on one hundred adults Bengali females. Anthropometric measurement includes stature, five foot length measurements from each toe (i.e.T_1, T_2, T_3, T_4, and T_5), foot breadth at the ball and foot breadth at the heel. The mean age was 22.35 (SD, 1.55) years. The mean stature was 153.47 (SD, 4.77) cm. The result of the paired *t* test revealed that there were significant bilateral asymmetry in T_3, T_4, T_5 length and FBB. Results of the Pearson's correlation coefficient of stature with different foot measurements revealed that all foot measurements were significantly and positively correlated with stature. However, the highest correlation was observed between stature and left foot T_4 length. Equations were derived by using simple and multiple regression analysis for the estimation stature. The overall lower standard error of estimate for foot length measurements indicated that foot lengths provide comparatively higher reliability and accuracy in estimating stature. However, the standard error of estimate of multiple regression model indicated that the multiple regression model tend to estimate stature more accurately than linear regression models.

Key words: Female; Foot Length; Foot Breadth; Stature; Forensic Anthropology.

Introduction

Stature is considered as one of the most important variable in forensic investigation for personal identification. Because along with age, sex and ancestry, estimation of stature is also assist to narrow-down the group of possible victim for identification in the forensic investigation (Krishan et al., 2011; Parekh et al., 2014). Estimation of stature become vital in mass disasters like bomb blasts, train accidents, plane crashes, earthquakes, etc (Mansur et al., 2012). Since, in those situations a forensic investigator has to depend mostly on body parts for personal identification. The disfigurement of the dead body can also be done by scavenging animals as well as by criminals to destroy the traces of identity and to facilitate the disposal of the dead body (Rani et al., 2011; Rajesh et al., 2015). Whatever may be the situations, estimation of stature from extremities or parts of the extremity become vital in identifying the dead body for personal identification.

Literature review revealed that in comparison to long bones, ossification and maturation in the foot occurs earlier and thus, stature could be more precisely predicted from foot measurements, compared to that of long bones (Mansur et al., 2012; Babu et al., 2013). There are a number of studies that attempted to derive regression equations for the estimation of stature using different foot measurements (Agnihotri et al, 2007; Sen and Ghosh, 2008; Krishan et al., 2012; Khairulmazidah et al., 2013). However, these equations are not universal and only applicable to the population they studied, due to the ethnic variations in foot measurements and stature as well as in their relationships (Tharmar et al., 2011; Babu et al., 2013). This envisages the need to conduct more studies among people of different ethnic groups, so that the stature estimation becomes more accurate and reliable. In view of the above, the objectives of the present study were to understand the correlations of foot measurements with stature and to derive regression equations to estimate the stature from different foot measurements in adult Bengali females.

Materials and methods

The present cross-sectional study in the Birbhum district of West Bengal was conducted on one hundred adult Bengali females. The individuals were identified as Bengali by their language and surnames. The study participants were homogeneous in terms of ethnic composition, language and religious affiliation. All the subjects included in the present study were free from any deformity of the foot and vertebral column. The age range of the subjects was between 18 to 26 years.

Anthropometric measurements includes stature (ST), five foot length measurements [i.e. length of foot from each toe namely, from first toe (T_1), second toe (T_2), third toe (T_3), fourth toe (T_4), and fifth toe (T_5)], foot breadth at the ball (FBB) and foot breadth at the heel (FBH). All foot measurements were taken on both left and right foot. Both stature and foot measurements were taken following standard techniques (Lohman et al, 1988; Krishan et al., 2011). In brief, stature was the straight distance between floor of standing and vertex. During stature measurements, the subject was requested to stand without shoe on a flat surface and the weight was distributed evenly on both feet with the head in Frankfurt Horizontal plane (Eye-Ear plane). The arms hang freely by the sides of the trunk, with the palm facing thigh. For measurements on foot, the subject was also requested to stand without shoe on a flat surface with equal pressure on both feet. T_1 Length is the distance between pternion and the most distal part of the first toe. T_2 Length is the distance between pternion and the most distal part of the second toe. T_3 Length is the distance between pternion and the most distal part of the third toe. T_4 Length is the distance between pternion and the most distal part of the fourth toe. T_5 Length is the distance between pternion and the most distal part of the fifth toe. FBB is the distance between the joint of the anterior epiphyses of the first metatarsal and the joint of the anterior epiphyses of the fifth metatarsal. FBH is the distance between the lateral sides of the heel to the medial side of the heel. Stature and foot measurements were measured to the nearest 0.1 cm using a moveable anthropometer and sliding caliper, respectively.

Descriptive statistics were performed by mean, standard deviation (SD) and range. Bilateral asymmetry in foot measurements were assessed by paired *t*-test. Pearson's correlation coefficient was undertaken to understand the relationship of stature with foot length and breadth measurements. Linear and multiple regression equations were derived to estimate stature by foot measurements, using stature as the dependent and foot measurements as an independent variable. All statistical analysis was performed by using SPSS, version 9 (SPSS Inc., Chicago, IL, USA). A *p*-value of less than 0.05 was considered as significant.

Results

The mean age of the studied population was 22.35 (SD, 1.55) years. The mean stature was153.47 (SD, 4.77) cm. Mean, SD and range of different foot measurements on both left and right side are presented in table 1. Table 2 shows the bilateral asymmetry in foot measurements. The result of the paired *t* test revealed that there were significant ($p<0.05$) differences or bilateral asymmetry in T_3, T_4, T_5 length and FBB in between left and right foot. However, the results were also revealed no significant ($p>0.05$) bilateral asymmetry in T_1, T_2 length and FBH between left and right foot, and thus, the means of right and left foot T_1, T_2 length and FBH were used for further analysis. Results of the Pearson's correlation coefficient of stature with different foot measurements are presented in table 3. It revealed that all foot measurements were significantly ($p<0.05$) and positively correlated with stature. Linear regression models derived for reconstruction of stature from each foot measurements are presented in table 4. Table 5 shows the multiple regression models for the reconstruction of stature from all foot measurements.

Table 1: Mean, standard deviation and range of foot measurements on left and right side

Variables	Mean (cm)	SD	Range (cm)	Mean (cm)	SD	Range (cm)
	Left foot			Right foot		
T_1	22.68	0.97	20.00-25.10	22.63	1.01	20.00-25.10
T_2	22.15	0.98	19.30-25.00	22.10	0.97	19.40-24.70
T_3	21.33	0.97	19.00-24.40	21.22	0.95	19.20-23.90
T_4	20.19	0.89	18.10-22.50	20.10	0.88	18.20-22.70
T_5	18.81	0.93	16.60-21.50	18.75	0.89	16.70-21.50
FBB	08.86	0.49	07.60-09.80	08.77	0.47	07.60-09.70
FBH	05.43	0.43	04.40-06.50	05.40	0.40	04.40-06.50

SD-standard deviation; T_1-T_1 length; T_2-T_2 length; T_3-T_3 length; T_4-T_4 length; T_5-T_5 length; FBB-foot breadth at ball; FBH-foot breadth at heel

Table 2: Bilateral asymmetry in foot measurements

Variables	Mean differences (cm)	SD	*t*	*p*
LFT_1-RFT_1	0.048	0.260	1.849	0.067
LFT_2-RFT_2	0.055	0.281	1.959	0.053
LFT_3-RFT_3	0.111	0.414	2.682	0.009
LFT_4-RFT_4	0.087	0.286	3.047	0.003
LFT_5-RFT_5	0.055	0.265	2.076	0.040
LFBB-RFBB	0.089	0.219	4.060	0.000
LFBH-RFBH	0.032	0.262	1.221	0.225

SD-standard deviation;LFT_1-left foot T_1 length;LFT_2-left foot T_2 length;LFT_3-left foot T_3 length;LFT_4- left foot T_4 length;LFT_5- left foot T_5 length; LFBB-left foot breadth at ball; LFBH-left foot breadth at heel; RFT_1-right foot T_1 Length;RFT_2-right foot T_2 length;RFT_3-right foot T_3 length;RFT_4- right foot T_4 length;RFT_5- right foot T_5 length; RFBB-right foot breadth at ball; RFBH-right foot breadth at heel.

Table 3: Pearson correlations of stature with foot measurements

Variables	r	*p*
T_1	0.681	0.001
T_2	0.664	0.001
LFT_3	0.689	0.001
RFT_3	0.622	0.001
LFT_4	0.720	0.001
RFT_4	0.645	0.001
LFT_5	0.711	0.001
RFT_5	0.680	0.001
LFBB	0.239	0.017
RFBB	0.245	0.014
FBH	0.233	0.020

T_1-T_1 length;T_2-T_2 length; LFT_3-left foot T_3 length; LFT_4- left foot T_4 length;LFT_5- left foot T_5 length; LFBB-left foot breadth at ball; FBH-foot breadth at heel; RFT_3-right foot T_3 length;RFT_4- right foot T_4 length;RFT_5- right foot T_5 length; RFBB-right foot breadth at ball

Table 4: Linear regression models for reconstruction of stature from each foot measurements

Variables	Regression models	SEE (cm)	R^2	p
T_1	78.377+3.311 (T_1)	3.509	0.464	0.01
T_2	80.422+3.297 (T_2)	3.583	0.441	0.01
LFT_3	81.219+3.386 (LT_3)	3.470	0.475	0.01
RFT_3	87.485+3.109 (RT_3)	3.750	0.387	0.01
LFT_4	76.160+3.830 (LT_4)	3.327	0.518	0.01
RFT_4	83.380+3.487 (RT_4)	3.661	0.416	0.01
LFT_5	84.929+3.645 (LT_5)	3.370	0.505	0.01
RFT_5	85.162+3.643 (RT_5)	3.515	0.462	0.01
LFBB	132.721+2.341 (LFBB)	4.652	0.057	0.02
RFBB	131.767+2.474 (RFBB)	4.646	0.060	0.01
FBH	138.195+2.807 (FBH)	4.660	0.054	0.02

T_1-T_1 length;T_2-T_2 length; LFT_3-left foot T_3 length; LFT_4- left foot T_4 length; LFT_5- left foot T_5 length; LFBB-left foot breadth at ball; FBH-foot breadth at heel; RFT_3-right foot T_3 length; RFT_4- right foot T_4 length;RFT_5-right foot T_5 length; RFBB-right foot breadth at ball; SEE-standard error of estimate

Table 5: Multiple regression model for reconstruction of stature from foot measurements

Variables	Regression model	SEE (cm)	R	R^2	*P*
T_1, T_2, LT_3, RT_3, LT_4, RT_4,LT_5, RT_5, LFBB, RFBB, FBH	81.205+1.367(T1)-.720(T2) +0.878(LT3)0.594(RT3)+3.715(LT4)1.876(RT4) +1.978(LT5)-0.637(RT5) -1.941(LFBB)+0.746 (RFBB)-0.150(FBH)	3.260	0.764	0.584	0.01

Discussion

Estimation of stature from body parts is crucial in identification of disfigurement human remains in forensic investigation. This can be done by mathematical methods like regression equations that utilize the measurements of available samples, which may be body parts or parts of skeleton to estimate the living stature. However, in the present study an attempt has been made to understand the correlation of foot measurements with stature and to derive regression equations to estimate the stature from different foot measurements in adult Bengali females. The result revealed that the mean of all left foot measurements (T_1, T_2, T_3, T_4, T_5, FBB and FBH) were comparatively higher than the right foot. However, statistically significant bilateral asymmetries were observed only in T_3, T_4, T_5 and FBB. A previous study (Krishan et al., 2011) in sub-adult females of North India also demonstrated significant bilateral asymmetry in FBB, but in contrary to the present study they also observed significant bilateral asymmetry in FBH. When we compared this result with some other studies the results were inconclusive, because, some studies demonstrated significant bilateral asymmetry, others were not (Jasuja et al., 1999; Zeybek et al., 2008; Sen and Ghosh, 2008). However, comparatively higher mean left foot measurements were also observed in adult Rajbanshi females (Sen and Ghosh, 2008) of North Bengal, adult females of South India (Rajesh et al., 2015) and adult females of Malaysia (Khairulmazidah et al., 2013).The results of the correlation analysis revealed that all foot measurements were significantly ($p<0.05$) and positively correlated with stature, thus indicating that the stature could be estimated from footmeasurements. Similar significant positive association was also observed in other studies (Kanchan et al., 2008; Krishan et al., 2011; Mansur et al., 2012; Khairulmazidah et al., 2013). Furthermore, the correlations were much stronger for foot length measurements than the breadth measurements and the strongest correlation was observed between stature and left foot T_4 length ($r=0.720$; $p<0.001$). In accordance with the present study, a previous study by Zeybek et al., (2008) also observed highest correlation of foot length with stature. Contrary to that Kanchan et al., (2008) demonstrated maximum correlation of stature with foot breath.

It was observed from the simple linear regression models that the predictive value or the coefficient of determinant was best for left foot T_4 length, followed by left foot T_5 length. Moreover, the standard error of estimate was also less for left foot T_4 length. Thus, indicating that the error in estimating stature will be lower by left foot T_4 length, compared to other foot measurements. In a similar study in sub-adult female Krishan et al., (2011) observed different result. In that (Krishan et al., 2011) study T1 length was the most accurate predictor of stature by linear regression analysis. This difference might be due to the variation in age and ethnic group. However, the overall lower standard error of estimate for foot length measurements indicated that foot lengths provide comparatively higher reliability and accuracy in estimating stature. Several recent studies (Sen and Ghosh, 2008; Rani et al., 2011; Krishan et al., 2011; Rajesh et al., 2015) also observed that the stature can be estimated more accurately from foot length measurements than the foot breadth measurements. The standard error of estimate of multiple regression analysis indicated that the use of multiple regression model will further lower the standard error in estimating the stature when compared with linear regression models. Thus, multiple regression model could be a batter option for the prediction of stature with lower standard error. Kanchan et al., (2008) also demonstrated lower standard error of estimate for multiple regression equation in comparison with linear regression equations. This is also in agreement with other studies (Krishan et al., 2011; Singh et al., 2013), that the multiple regression models tend to estimate stature more accurately than the simple linear regression models for length and breadth measurements. However, an addition of age as a variable in multiple regression model, along with other foot measurements did not significantly affect the predictive value (R^2=+0.002) in stature estimation, a finding that agrees with the studies of Kanchan et al., (2008) and Sen and Ghosh et al., (2008).

Conclusion

In conclusion, significant positive correlation of foot measurements with stature revealed that the stature could be estimated from foot measurements. However, the stronger correlation and lower standard error of estimate for foot length measurements indicated that foot lengths provide comparatively higher reliability and accuracy in estimating stature. The present study also demonstrated that though, in adult Bengali females stature can be predicted by both simple and multiple linear regression models, preference should be given to multiple regression equation for the estimation of stature more accurately with lower standard error.

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