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Original Articles

Do Foot Dimensions Influence Stature Estimation: A Study among the Bhumij Tribal Population of Northern Odisha, India

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In forensic science, medical examinations, or anthropological investigations, stature is considered as one of the critical characteristics for establishing personal identity. The present study is an attempt to estimate stature from different foot measurements among the Bhumij tribal population of Mayurbhanj, Northern Odisha. This study included 202 adult Bhumij tribal people (males-89; females-113) without foot abnormalities or injuries. All anthropometric measurements were recorded following the standard procedures. The findings reveal that no significant sex difference was found between the right and left foot among both the males and females. A linear and multiple regression equation was developed for the estimation of stature from various foot measurements. The multivariate regression formulas are used to calculate the stature from the foot dimensions in both sexes and give a better prediction of stature than the univariate type. Thus, stature could be estimated with reasonable accuracy from the different foot length measurements.

Key words: Forensic Science, Personal identification, Stature, Foot Dimension, Bhumij

Introduction

Forensic anthropology aims to focus on constructing a biological profile from mutilated remains and also utilizing techniques to estimate fundamental traits for identification [40]. Stature is crucial in medical-legal procedures, identifying individuals and aiding in forensic research, and development of profiles for unidentified victims or suspects [18]. Anthropometric data is crucial for international market product creation, enhancing comfort, safety, health, and well-being in footwear design. Humans develop change in size and form of their feet mostly due to the physical strain associated with walking on both feet [55]. A crucial area of forensic research is estimating stature of the deceased from fragmented and badly decomposed human remains, damaged or severed limbs or sections of limbs, or incomplete skeletal remains. In the event of a crime, accident, or natural disaster, these remains are essential for identifying the person. On the other hand, measurements of stature can be obtained from footprints, handprints, or shoes found at the scene of a crime. Anthropologists, medical experts, and anatomists using anthropometric techniques have estimated the size and length of bones from unknown body parts and skeletal remains for more than a century [26]. Recently due to the increase in the number of man-made and natural disasters, including bomb explosions, wars, terrorism, and airline crashes, as well as cyclones, tsunamis, earthquakes, and floods, this has become increasingly crucial. In these situations, the forensic pathologist frequently expresses an opinion on the deceased's identity. [22, 30, 40]. Personal identification is crucial in mass disaster investigations, as disintegrated body parts are common. Due to genetic diversity in Indian populations, correlations between body parts and stature vary across different geographical locations, necessitating separate studies for each group [44]. Footprint measurements are crucial in developing countries like Bangladesh, India, and Pakistan, as people walk barefoot for socioeconomic reasons. Footprints are found at crime locations, including theft and murder, and can be analyzed during stature estimation for criminal identification [41].

The study on different body segments has been used to illustrate and compare the variations across various ethnic groups and to explain their energy expenditure, lifestyle, and locomotor habits [7]. Stature is a highly significant growth and development indicator that is employed in clinical settings and is indispensable in nutrition and health studies. In addition to body weight, stature is a crucial factor in the computation of body composition, basal metabolic rate, body mass index, and basal energy expenditure [17]. Thus, stature has been estimated using body proportions and the measurements of various body segments, such as the vertebral column, the long bones of the limbs, and the bones of the hand and foot [45, 51]. Numerous studies have been done to determine stature using data from the hand, foot as well as from the trunk, limbs, long and short bones, and hand and foot prints [36, 47]. Several studies have also shown the correlation of stature with foot length [8, 13, 25, 26, 54]. A study conducted by Krishan et al. [31] concluded that foot length was more authentic variable than foot breadth variable. Studies also revealed that female foot measurements are comparatively smaller than those of males [21, 31, 39, 46, 50]. Evidence suggests that a shoe left at a crime site can estimate the victim's stature [12, 1]. In the absence of all evidence, body measurements and proportions can be used to solve crimes, such as using footprints, handprints, or footprints at crime sites [4, 14,15, 49].

While several research papers have been published on various Indian communities, there are surprisingly few studies on the tribal community of Eastern India. Therefore, the purpose of the current study was to estimate stature from foot measurements among the adult Bhumij indigenous tribal community of Northern Odisha and to ascertain the association between stature and all foot dimensions.

Material and Methods

The present cross-sectional study was conducted among the Bhumij tribal population of the Khunta block of the Mayurbhanj district of Northern Odisha. Etymologically, the term ‘Bhumija’ means ‘one who is born out of the soil’. The study participants included 202 (Male-89, Female-113) Bhumij adult population aged above 18 years of age. The information about the age of the participants was taken from Aadhar card or voter card and was crosschecked with the participants. Only healthy participants free from any deformity of the foot were included in the study. The data were collected in May 2023.

Anthropometric measurements were collected using the standard technique and the relevant landmarks [33]. The data for the present study included stature, length of the foot from each toe (T1, T2, T3, T4, and T5 respectively), foot breadth at the ball and foot breadth at the heel. All the foot measurements were taken using the standard protocol [31]. The informed consent was obtained from all subjects. The study was approved by the competent authorities of the Institutional Ethical Committee, MSCB University and has been conducted according to the principles expressed in the Declaration of Helsinki.

Stature: The vertical distance between the floor and the point vertex, or the highest point on the head when held in the Frankfurt Horizontal plane, is known as the stature. Martins anthropometer was used to measure the participant’s stature to the closest 0.1 cm, while they had to stay upright and without any footwear or helmet. For recording foot measurements, the participant was made to stand so that both feet were slightly apart with equal pressure on both. The Martin’s sliding caliper was placed horizontally on the landmarks and the measurement was taken (**Fig. 1**). Different landmarks on the foot are described in **Table 1.** TEM (Technical error of measurement) was calculated for the anthropometric variables [56] and the majority of the values were under the permissible limit (0.08 – 0.61).

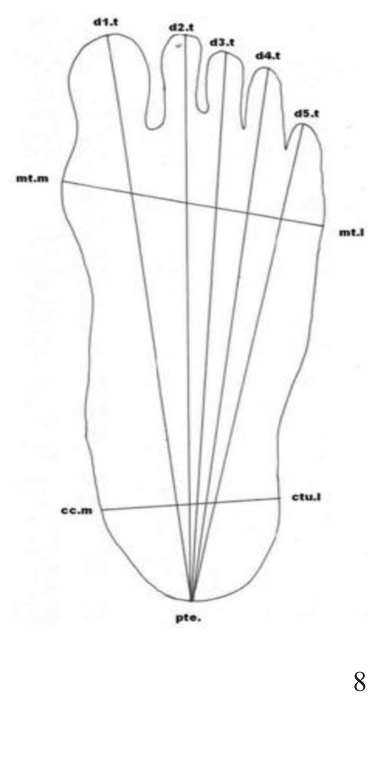

Fig. 1. Landmarks of different foot anthropometric measurements (Source- Krishna et al. 2001)

Table 1. Land marks of different foot measurements

SL. No.	Foot anthropometric measurements	Landmarks
1	Foot length	Distance from the pternion point to the frontal end of the longest toe of the feet
2	Foot breadth at ball	Distance between the anterior epiphyses of the first metatarsal and the fifth metatarsal.
3	Foot breadth at heel	Distance between the medial and lateral sides of the heel.
4	T1	Distance from pternion to the most anterior point of the first toe
5	T2	Distance from pternion to the most anterior point of the second toe
6	T3	Distance from pternion to the most anterior point of the third toe
7	T4	Distance from pternion to the most anterior point of the forth toe
8	T5	Distance from pternion to the most anterior point of the fifth toe

T1 – Foot length at first toe, T2 – Foot length at second toe, T3 – Foot length at third toe , T4 – Foot length at fourth toe , T5 – Foot length at fifth toe

Statistical Analysis

The foot anthropometric data and stature of the participants collected were analysed using Statistical Package for Social Science (SPSS, version 18) computer software. Foot measurements were compared for bilateral asymmetry and sexual dimorphism using paired and unpaired t-tests respectively. Subsequently no significant differences is observed between the measures of both the feet (right and left), therefore, further analysis is done from the mean values of both the feet. [23]. Pearson's correlation coefficient was obtained to find correlation between stature and various foot measurements. A *p* value of <0.05 was considered to be statistically significant. Stature was estimated from the foot measurements by using linear and multiple regression analysis. The linear regression model for stature estimation is derived as S (stature) = a + b x ± SEE, where, 'a' is constant, 'b' is the regression coefficient of the independent variable (individual foot measurement), 'x' is an individual foot measurement and SEE is Standard Error of Estimate. Multiple regression models were considered for reconstruction of stature from foot length (T1 to T5) and foot breadth measurements.

Results

Descriptive statistics for the foot measurements of left and right feet of both males and females are presented in **Table 2**. An independent t-test was performed but no significant difference ($p>0.05$) was observed between the measures of the left foot and right foot.

Thus, bilateral asymmetry is absent and subsequent analyses were done with the mean values of both the feet (males and females).

Table 2. Mean and standard deviations of foot measurements stratified by sex

variable	Male		t	p-value	Female		t	p- value
	right (mean±sd)	left (mean±sd)			right (mean±sd)	left (mean±sd)		
Foot Length	23.90±1.15	23.93±1.15	0.137	0.892	22.01±1.01	22.05±1.15	0.263	0.793
Ball Breadth	9.43±0.69	9.47±0.68	0.422	0.673	8.48±0.54	8.57±0.55	1.223	0.223
Heel Breadth	5.97±0.42	5.89±0.46	-1.241	0.216	5.48±0.47	5.40±0.49	-1.254	0.211
T1	23.63±1.20	23.69±1.23	0.356	0.722	21.78±1.04	21.80±1.17	0.150	0.881
T2	23.41±1.21	23.42±1.17	0.050	0.960	21.46±1.09	21.40±1.12	-0.401	0.689
T3	22.48±1.15	22.50±1.16	-0.149	0.822	20.57±1.12	20.56±1.10	-0.083	0.934
T4	21.49±1.13	21.46±1.09	-0.209	0.835	19.53±1.09	19.51±1.06	-0.197	0.844
T5	20.13±1.02	20.05±1.10	0.480	0.632	18.26±1.01	18.23±0.94	-0.237	0.813

Table 3. Sexual differences in different foot measurements

Variables	male (mean±sd)	female (mean±sd)	t	p-value
Stature	159.44±5.85	148.47±7.26	11.89	.000*
Weight	52.71±9.54	45.03±7.40	6.25	.032*
Foot Length	23.91±1.13	22.02±1.06	12.04	.000*
Ball Breadth	9.45±0.65	8.52±0.51	11	.000*
Heel Breadth	5.93±0.38	5.44±0.40	8.84	.000*
T1	23.66±1.19	21.79±1.07	11.52	.000*
T2	23.42±1.16	21.43±1.08	12.35	.000*
T3	22.49±1.11	20.56±1.08	12.35	.000*
T4	21.47±1.06	19.52±1.03	13.09	.000*
T5	20.09±1.02	18.24±0.92	13.25	.000*

* Highly significant

All foot measurements except stature showed statistically significant difference ($p<0.05$) between the male and female participants (**Table 3**). **Table 4** shows the results of the correlation between stature and all foot measurements. In males, statistically significant positive correlation ($p<0.05$) was observed between all foot measures and stature. Similar results were also observed among the female participants except ball breadth and heel breadth. It is also evident that foot length and toe length 5 (T5) of males can give better prediction of stature when compared with foot length and toe length 5 (T5) of females. The correlation of stature with foot length for males is 0.642, which shows strong correlation but the correlation of stature with ball breadth and heel breadth are 0.351 and 0.438, which shows a moderate correlation. Among females, correlation of stature with foot length is 0.434 which shows moderate correlation but correlation of stature with ball breadth and heel breadth are 0.193 and 0.063, which shows low correlation.

Table 4. Pearson Correlation (r) between stature and different foot dimensions

variables	male		female	
	r	p-value	*r*	p-value
Foot Length	0.642***	.000Ψ	0.434**	.000Ψ
Ball Breadth	0.351**	.001Ψ	0.123*	.193
Heel Breadth	0.438**	.000Ψ	0.175*	.063
T1	0.625***	.000Ψ	0.408**	.000Ψ
T2	0.640***	.000Ψ	0.404**	.000Ψ
T3	0.610***	.000Ψ	0.368**	.000Ψ
T4	0.629***	.000Ψ	0.334**	.000Ψ
T5	0.678***	.000Ψ	0.332**	.000Ψ

Ψ – Highly significant
***Strong degree Correlation- Coefficient value lies between ± 0.50 and ± 1
**Moderate degree Correlation: Coefficient value lies between ± 0.30 and ± 0.49
*Low degree Correlation: Coefficient value lies below ±0.29

The simple linear regression equations for the estimation of stature from all explanatory variables are presented in **Table 5**. All the foot measurements did not show any significant differences between the left and right feet; hence the mean of right and left feet together was used to derive linear regression models from individual foot measurements. The determination coefficient (R^2) and standard error of estimate (SEE) are also shown in the table. All the correlation coefficients were found to be statistically significant ($p < 0.05$) except ball breadth and heel breadth in female. Thus, stature is positively and significantly related to various foot measurements. However, measurements of the length of the foot have greater correlation values than those of the breadth (**Figs. 2, 3, 4**).

These regression models can be used for stature estimation from the different foot measurements. The present study showed that foot length measurements are more accurate indicators of stature than foot breadth measurements. Among the foot length measurements, T5 gives the most accurate estimation of stature by linear regression analyses. It was observed that the SEE (0.759) value is minimal and the predictive accuracy (R^2) is maximum (0.4602) for T5 but the accuracy of all other measurements in stature estimation were comparable among the foot length measurements. Similarly, among females, of all the foot length measurements, T5 gives the most accurate estimation of stature by linear regression analyses. It was observed that the SEE value is minimal and the predictive accuracy (R^2) is maximum for T5 but the accuracy of all other measurements in stature estimation were comparable among the foot length measurements.

Table 5. Linear regression equation for reconstruction of stature from different foot measurements

Variable	male					female				
	Equation	SEE	r	R^2	Sig.	Equation	SEE	R	R^2	Sig.
Foot Length	y=4.094+.124(FL)	.873	.642	.412	.000*	y=12.567+.064(FL)	.966	.434	.188	.000*
Ball Breadth	y=3.228+.039(BB)	.613	.351	.123	.001*	y=7.230+.009(BB)	.512	.123	.015	.193
Heel Breadth	y=1.364+.029(HB)	.346	.438	.192	.000*	y=3.974+.010(HB)	.404	.175	.031	.063
T1	y=3.250+.128(T1)	.941	.625	.390	.000*	y=12.800+.061(T1)	.988	.408	.167	.000*
T2	y=3.090+.128(T2)	.901	.640	.409	.000*	y=12.463+.060(T2)	1.000	.404	.163	.000*
T3	y=4.022+.116(T3)	.886	.610	.372	.000*	y=12.443+.055(T3)	1.01	.368	.135	.000*
T4	y=3.162+.115(T4)	.834	.629	.396	.000*	y=12.470+.048(T4)	.977	.334	.112	.000*
T5	y=1.108+.119(T5)	.759	.678	.460	.000*	y=11.949+.042(T5)	.879	.332	.110	.000*

* Highly significant

The multiple linear regression equations are derived for stature estimation from different foot length (Foot length, T1, T2, T3, T4, T5) and foot breadth (Ball breadth and Heel breadth) measurements. The values of coefficient of determination of foot length and foot breadth measurements of both males and females are presented in **Table 6.**

Table 6. Multiple regression equations for estimation of stature by using different foot measurement

Measurements	**Sex**	**Models**	**R^2**	**S.E.E.**
Foot length, T1, T2, T3, T4, T5	Male	73.04+3.27(FL)-1.57(T1)-0.10(T2)-1.32(T3)+0.44(T4)+3.26(T5)	0.455	4.32
	Female	83.55+4.22(FL)-1.83(T1)+0.14(T2)+0.98(T3)-0.42(T4)-0.17(T5)	0.193	6.71
FBB, FBH	Male	108.48+1.96(BB)+5.46(HB)	0.233	5.18
	Female	125.44+0.99(BB)+2.67(FB)	0.035	7.20

FL – Foot length T1 – Foot length at first toe, T2 – Foot length at second toe, T3 – Foot length at third toe , T4 – Foot length at fourth toe , T5 – Foot length at fifth toe , FBB – Foot breadth at ball, FBH – Foot breadth at heel.

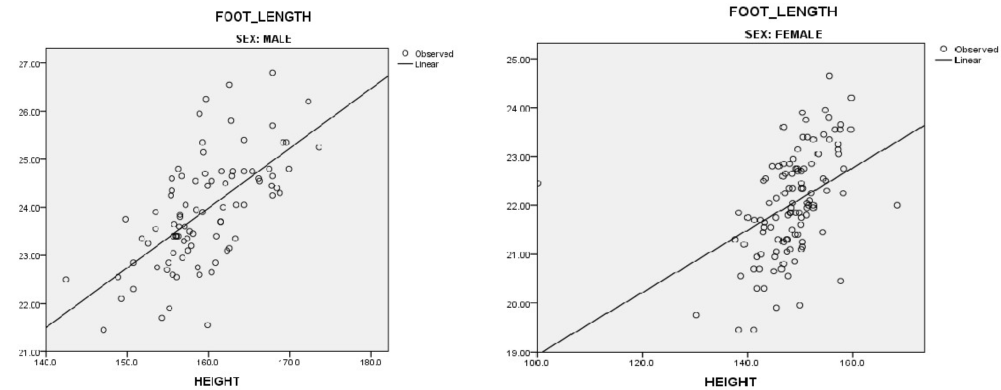

Fig. 2A **Fig. 2B**

Fig. 2. Scatter diagram of stature and foot length for males and females

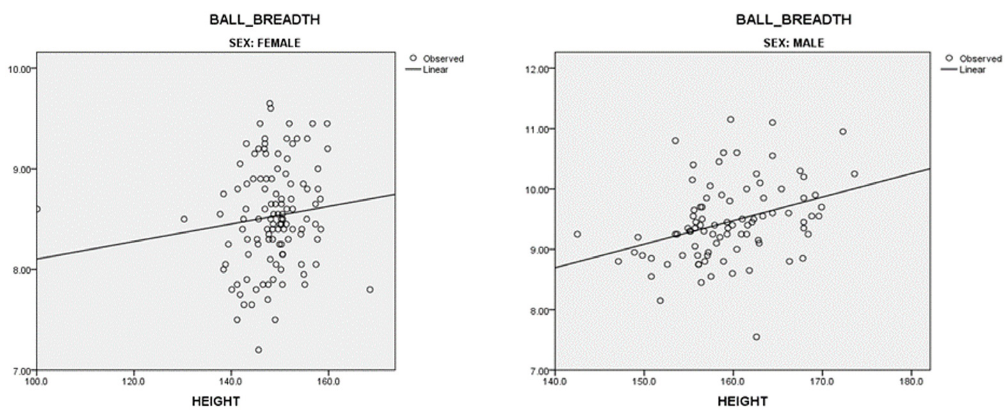

Fig. 3A **Fig. 3B**

Fig. 3. Scatter diagram of stature and ball breadth for males and females

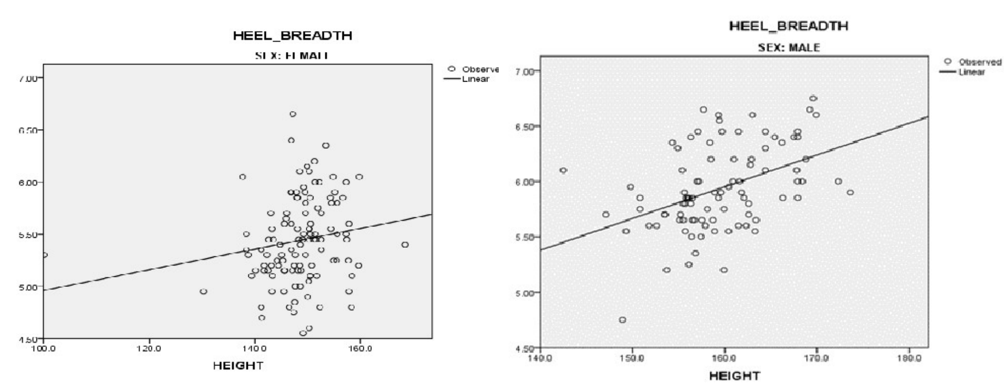

Fig. 4A **Fig. 4B**

Fig. 4. Scatter diagram of stature and heel breadth for males and females

Table 7. Regression equation for estimation of stature among different populations of India

S. No.	Area and population	Age Groups	Sex	Regression equation	r	Year	Author
1	Karnataka	18-60	M	H = 69.346 + 3.66 FL	0.636	2013	Dayananda
2	Gujrat	18 and above	M	H=75.45+3.64 FL	0.65	2007	Patel M Shah
			F	H=75.41+3.43 FL	0.80		
3	Sri Lanka	18-32	M	H=79.042+3.590 FL	0.72	2008	I. Ilayperuma
			F	H=65.549+3.944 FL	0.71		
4	Haryana, India	18-42	F	H=65.194+4.068 LFL	0.719	2008	Jakhar
			M	H=80.671+3.648 LFL	0.725		
5	Pune, India	18-30	M	H=90.0+3.2 FL	0.645	2012	Sanli
			F	H=72.8+3.7 FL	0.702		
6	Delhi	18 and above	M	H = 98.32 + 3.05 FL	0.808	2011	Mukta Rani
7	Pakistan	18-30	M	H = 104.455 + 2.591 FL	0.581	2015	Malik AR
8	North India	18-60	M	H = 90.27 + 2.93 FL	0.764	2008	Krishnan K
9	Gulbarga	18-25	M	H= 86.9 + 3.40 FL	0.82	2016	Karaddi *et al.*
10	Maharashtra	18 and above	M	H=72.8 + 3.7 FL	0.70	2011	Khanapurkar *et al.*
11	Gujarat	18 and above	M	H= 77.35 + 3.605 RFL	0.73	2015	Upadhyay MC *et al.*
12	India	18-50	M	H = 68.58 + 4.036 FL	0.72	2007	Agnihotri
13	West Bengal	18-50	M	H= 83.518 + 3.282 FL	0.62	2008	Sen and Ghosh
			F	H= 67.009 + 3.707 FL	0.69		
14	Aurangabad	18-25	M	H= 58.46+4.29 RFL	0.79	2016	Pandey and Kulkarni
			F	H=113.45+1.69 RFL	0.46		
15	Cuttack	18-25	M	H=-27.77 + 7.695 FL	0.224	2012	Mohanty *et al.*
			F	H=77.85 + 3.58 FL	0.259		
16	Mayurbhanj	18 and above	M	H=4.094+0.124 FL	0.642	2024	Present study
			F	H=12.567+0.064 FL	0.434		

The foot length measurements showed greater estimation accuracy than foot breadth measurements. It is further observed that the multiple regression models with higher values of coefficient of determination R^2 tend to estimate stature more accurately than the respective linear regression models for length and breadth measurements. In **Table 7**, comparison of the coefficient of correlation (r) from different studies has been presented.

Discussion

In biological anthropological studies along with medico-legal investigations, body stature evaluation is important [20]. In addition, anthropologists with forensic expertise assist in personal identification by determining a person's age, sex, and ethnicity. The relative completeness of the skeleton determines the gender from the unknown skeletal remains. Estimating an individual's stature is an essential initial step in identifying remains that have been severely damaged [16]. Foot length and stature have a biological connection and using foot length stature can be determined [11].

In the present study, utmost care was taken to ensure the precision of anthropometric measurements. The measurement errors have a substantial effect on the accuracy and reliability of the standards in forensic science which ultimately affect the forensic anthropology case work involving anthropometry [27]. Our study reveals no significant variation and errors associated with the technique in anthropometric measurements (**Table 2**). Therefore, a set of standards in the estimation of stature from foot and its parts produced by the present study are reliable.

India is a multi-racial, multi-ethnic and multicultural land of great diversity. The stature estimation is considered as important parameters in the identification of a person by measuring various long bones [33]. Patel et al., 2007 [42] estimated height from measurements of foot length in the Gujrat region.

The present study is unique in its sample selection. The study populations were selected from the Bhumij tribal population of Mayurbhanj district of Odisha. Tribals are known to be socially, environmentally, culturally and even genetically secluded communities. While literature abounds with forensic anthropological studies of estimating stature with hand and foot dimensions, very few studies have selected a homogenous group as study population [27, 30]. Due to strong influence of genetic and environmental factors on the height of the individual, homogenecity of the study population is vital in formulating the regression equations.

The present study shows that there is no bilateral asymmetry between the left and right feet of both males and females. Such finding was also observed in the study conducted by Kautilya et al. (2013) [28] among the urban population of Chennai. Hemy et al. (2013) [19] and Jimenez-Ormeno et al. (2013) [23] have also reported the same findings.

In the present study, males showed higher mean values in all the parameters studied than among females and the difference being highly statistically significant. This finding is in accordance with several studies where significant gender difference was observed [5, 10, 25]. Similarly, stature estimation studies by Giles and Vallandigham 1991 [14], and Krishan et al. 2012 [31], and have reported statistically significantly higher values for males. In the present study, all the foot measurements in both the males and females exhibited a statistically significant correlation with stature, which advocates their use for stature estimation. However, the extent of correlation is lower than other two reported studies from North India [24]. The values of correlation co-efficient of males and females for estimation of stature from foot length was remarkable in the present study (0.64 in males and 0.43 in females). Foot length is more positively related than foot breadth.

There is paucity of workers who have considered foot length and foot breadth for stature estimation. The observations of the present study suggest that these parameters can be utilized to formulate equations to predict stature. Present study has established that though regression formula and multiplication factor, both are useful to determine stature from foot dimensions, regression formula measures stature more precisely than multiplication factor. Krishan et al. (2012) [31] also observed such finding for Rajput (India) population. The present study may be helpful in the estimation of stature where other possible means of identification are not useful.

Conclusion

It is found that there exists a significant sexual dimorphism in male and female population. Males have higher values than the females in dimensions of foot. This study discovered a strong positive association between foot length and stature. A linear and multiple regression equation was developed for the estimation of stature from various foot measurements. The multivariate regression formulas used to calculate the stature from the foot dimensions in both the sexes and give a better prediction of stature than the univariate type. Thus, it was observed that both linear and multiple regression equation are equally sensitive for prediction of stature. The strength of the correlation tends to be enhanced when more than one associative factor was introduced in the derivation of regression equations. Thus, it can be concluded that stature could be estimated with reasonable accuracy from the different foot length measurements.

The data obtained in the present study can be used to obtain certain population specific anthropometric indices amongst the tribal population. The data and subsequently the results obtained in the present study, to the best of the knowledge of the author, is the first ever documented anthropological work on the Bhumij tribe.

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