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TECHNICAL NOTE
ANTHROPOLOGY

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Stature Estimation from Foot Length Using Universal Regression Formula in a North Indian Population

ABSTRACT: Stature is a significant parameter in establishing identity of an unknown. Conventionally, researchers derive regression formula separately for males and females. Sex, however, may not always be determined accurately, particularly in dismembered remains and thus the need for a universal regression formula for stature estimation irrespective of sex of an individual. The study was carried out in an endogamous group of North India to compare the accuracy of sex-specific regression models for stature estimation from foot length with the models derived when the sex was presumed as unknown. The study reveals that regression equation derived for the latter can estimate stature with reasonable accuracy. Thus, stature can be estimated accurately from foot length by regression analysis even when sex remains unknown.

KEYWORDS: forensic science, forensic anthropology, identification, foot length, stature estimation, regression formula

Identification of unknown human remains is one of the essential elements of medicolegal investigation. Determination of race, sex, age, and stature is the primary challenge before a forensic scientist in establishing identity. Stature of an individual is proportionate to various body parts (1). Researchers have tried to estimate stature from long bones for decades, classic studies in this regard being those by Trotter and Gleser (2,3). Racial and ethnic variations arise in different regions. Therefore, each racial group needs a different formula, and the region wise study of the subjects is very much required (4). It has been customary in studies on stature estimation to derive regression formula separately for males and females owing to statistically significant differences in stature and dimensions of various body parts between males and females. Determination of sex, hence, becomes a critical requirement in applicability of sex-specific regression models in stature estimation.

In cases, of mass disasters and criminal mutilation, it is not unlikely to find peripheral parts of the body such as hand and foot. Stature has been estimated from foot prints, foot measurements, and shoe size based on statistical equations and formulae (5–13). Studies on sex determination from foot dimensions and foot index are, however, inconclusive (14–16), thus limiting the applicability of sex-specific regression equations from foot measurements in medicolegal investigations. Moreover, reservations are made on quantification of qualitative data in regression analysis for stature estimation (17). The study aims at finding and comparing the accuracy of regression analysis in stature estimation from foot length among males and females with that of randomized pooled data when sex remains unknown among an endogamous community of North India.

Materials and Methods

The present study was conducted on Gujjars residing in the Badholi village of Patiala district in Punjab, North India (Fig. 1). Gujjars are one of the main endogamous caste groups of North India. This group is homogeneous in terms of ethnic composition, language, and religious affiliation. Stature and foot length in 100 individuals (50 males and 50 females) aged between 18 and 32 years were measured in centimeters to the nearest millimeter using anthropometer and anthropometric rod compass. Stature (Height-vertex) was measured as the vertical distance between the vertex and the floor when the head is held in Frankfurt Horizontal (F.H.) plane. The foot length of each individual was measured as a straight distance between the most backward and prominent part of the heel (pternion) and the most distal part of the longest toe of the foot (acropodian).

Analysis was performed using Statistical Package for Social Sciences (SPSS, Inc., Chicago, IL) version 11.0 to calculate linear regression equation. Paired sample test was performed to find the right and left side differences in foot lengths among males and females. The significance of results was tested and p-value of <0.05 was considered as significant. Sex-specific linear regression models were derived for males and females and for the pooled data where sex was presumed as unknown. Pooled data ($n = 100$) was randomly split into two groups of 50 subjects each (25 males and 25 females) based on random number table and designated as pooled random groups 1 and 2 (PRG 1 and PRG 2). The accuracy

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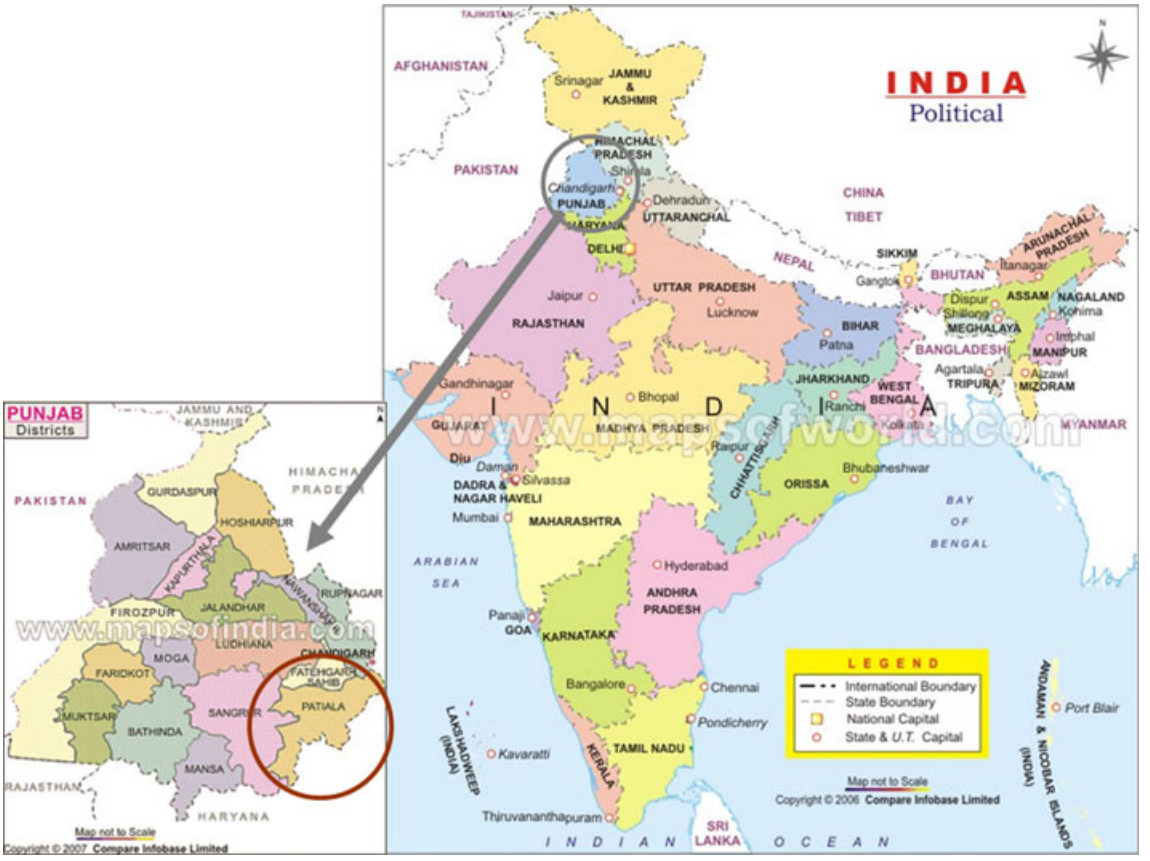

FIG. 1—*Map of India showing the location of Patiala district of Punjab state where the study was conducted (adapted from www.mspsofworld.com and www.mapsofindia.com.) Available at: http://www.mapsofindia.com/maps/india/india-political-map.htm*

of the derived regression model for the randomized pooled data is compared with sex-specific linear regression models. The stature of the study sample is estimated using the derived regression equations and is compared with the actual stature to assess the accuracy of derived regression models.

Results and Discussion

The stature and foot length on both sides were significantly greater ($p < 0.001$) in males when compared with females (Table 1). The findings in our study are in agreement with other

TABLE 1—*Descriptive statistics: foot length and stature (cm) in males and females.*

	Male (n = 50)			Female (n = 50)		
	Range	Mean	SD	Range	Mean	SD
Stature	151.4–176.7	166.39*	5.6	143.1–171.0	159.56*	5.1
RFL	23.1–29.1	26.03*	1.4	21.1–28.1	23.82*	1.3
LFL	23.2–29.3	26.01*	1.4	21.8–28.1	23.78*	1.2

SD, standard deviation; RFL, right foot length; LFL, left foot length; *p-value <0.00.

TABLE 2—*Linear regression equations derived for stature estimation.*

Variable	Sex	Equation	SE (cm)	R	R^2
RFL	Males (n = 50)	88.116 + 3.007 (RFL*)	3.746	0.750	0.563
	Female (n = 50)	106.709 + 2.219 (RFL*)	4.313	0.558	0.311
	PRG 1 (n = 50)	87.014 + 3.007 (RFL*)	3.920	0.820	0.672
	PRG 2 (n = 50)	94.253 + 2.796 (RFL*)	4.000	0.749	0.560
LFL	Males (n = 50)	95.202 + 2.737 (LFL*)	4.024	0.704	0.496
	Female (n = 50)	104.302 + 2.324 (LFL*)	4.387	0.536	0.287
	PRG 1 (n = 50)	88.710 + 2.941 (LFL*)	4.110	0.800	0.640
	PRG 2 (n = 50)	94.719 + 2.782 (LFL*)	4.106	0.733	0.537

SE, standard error of estimate; RFL, right foot length; LFL, left foot length; R, correlation coefficient; PRG, pooled random group; *p-value < 0.001.

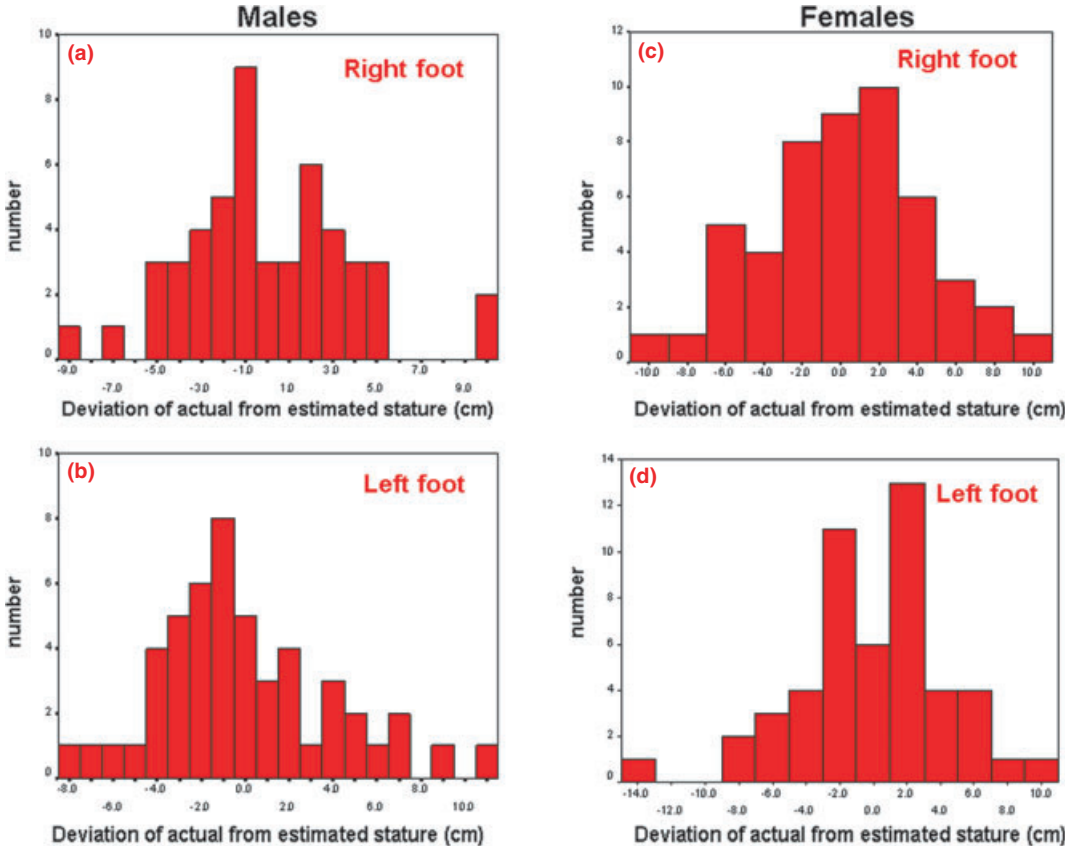

FIG. 2—*Deviation of the actual stature from the stature estimated from the foot length in males (A & B) and females (C & D).*

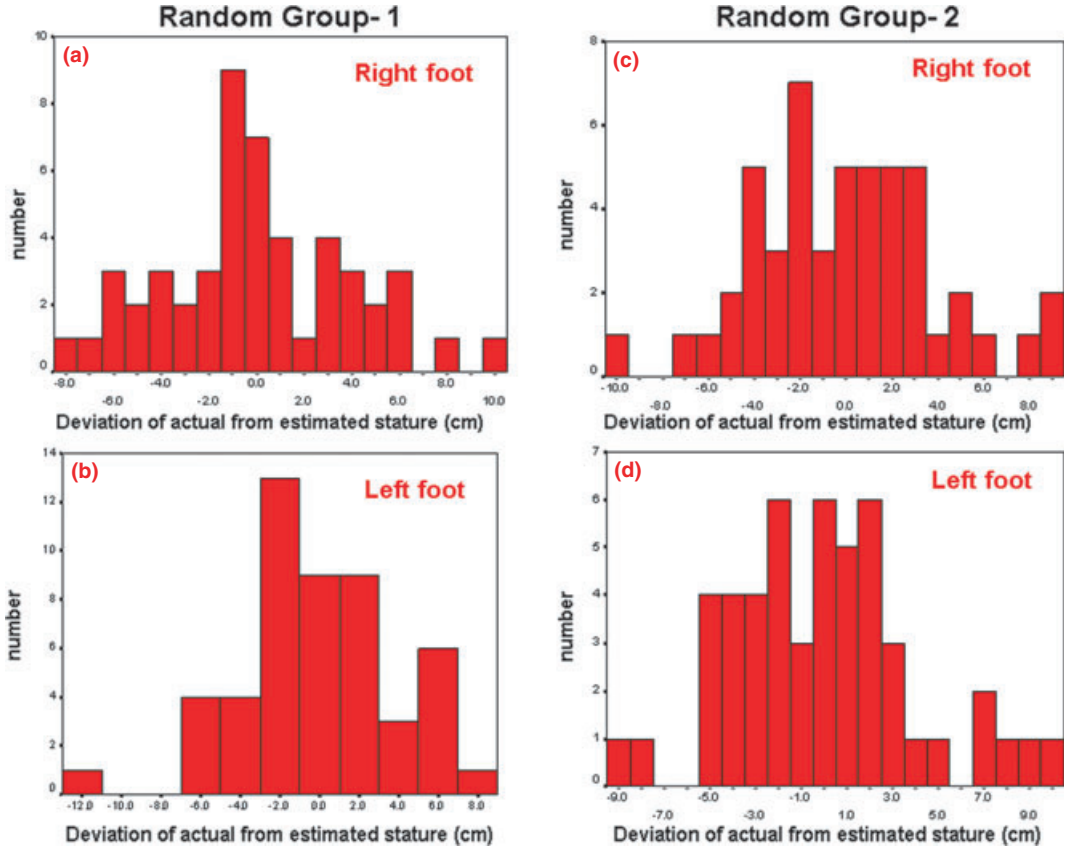

FIG. 3—*Deviation of the actual stature from the stature estimated from the foot length in random group 1 (A & B) and random group 2 (C & D).*

TABLE 3—*Sex-specific regression models—comparison of the two North Indian groups.*

		North Indian Gujjars*		North Indian Rajputs†	
Sex	Variable	SE (cm)	*R*	SE (cm)	*R*
Male	RFL	3.75	0.750	4.44	0.732
	LFL	4.02	0.704	4.38	0.741
Female	RFL	4.31	0.558	3.50	0.739
	LFL	4.39	0.536	3.53	0.734

SE, standard error of estimate; RFL, right foot length; LFL, left foot length; *R*, correlation coefficient.

*Present study.

†Other study by Krishan and Sharma (8).

researchers (1,7–12). The right and left foot length shows no systematic differences between sides ($p = 0.77$ in males, $p = 0.60$ in females).

Stature of an individual is found to be significantly correlated to foot length among males and females similar to that reported in earlier studies (1,7–12). Gordon and Buikstra (18) explored linear regression models with and without sex and race indicators and found slight difference between the two models. The sex-specific regression models for the study sample along with those for the pooled randomized groups are shown in Table 2. Earlier studies have reported the regression models for both sexes together to be an effective model in stature estimation (11,12). However, the increased sample size because of pooling of data might have been potentially responsible for the reported higher *R* values. The accuracy of linear regression models derived for the estimation of stature from foot length among males and females in the present study is comparable with regression models derived for the pooled randomized groups that were uninfluenced by the pooling effect.

The mean estimated stature using different regression models including those derived for the randomized groups was close to the actual stature in different groups. Minimum and maximum estimated stature, however, shows a larger variation with respect to the actual minimum and maximum stature. Our observations are similar to those of Krishan and Sharma on Rajputs of North India (8). The estimated minimum stature overestimated the actual minimum stature while the estimated maximum stature underestimated the actual maximum stature. Deviation of the actual stature from the estimated stature in different models is shown in Figs. 2 and 3. The accuracy of sex-specific regression models derived in our study is compared with the study of Krishan and Sharma (8) on another endogamous North Indian Rajput population of Himachal Pradesh (Table 3). Among Rajputs stature estimation is more accurate in females, whereas the contrary was observed among Gujjars in the present study. Variations in the two studies are attributed to the differences in the two population groups of North India.

Conclusion

It may not always be possible to determine sex of dismembered remains with reasonable accuracy, and hence, there is a need to derive universal regression formula for stature estimation from dismembered remains. Foot length is found to be well correlated to stature in the Gujjar community of North India. It is apparent that accuracy of regression analysis in stature estimation from foot length in the pooled randomized sample when sex is presumed as unknown is comparable with the sex-specific regression models in the study sample. Thus, stature can be estimated accurately by regression analysis even when sex remains unknown. However, as these formulae should be restricted and applied to the population group from which they are derived, similar studies to derive universal regression formula on larger samples in different population groups and from other body parts are proposed.

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