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TECHNICAL NOTE

PHYSICAL ANTHROPOLOGY

Jaydip Sen,[1] *M.Sc., Ph.D.; Tanuj Kanchan,*[2] *M.B.B.S., D.F.M., M.D.; and Shila Ghosh,*[1] *M.Sc.*

Sex Estimation from Foot Dimensions in an Indigenous Indian Population

ABSTRACT: Dismembered/severed human remains are frequently found in cases of mass disasters and criminal mutilation. Sex estimation from foot dimensions, therefore, has a vital role in establishing personal identity. There is a paucity of literature on this issue from various Indian populations. The "Rajbanshi" is one such indigenous population located in the state of West Bengal, India. The present study attempts to estimate sex from foot length, foot breadth, and foot index among 350 living adult Rajbanshi (175 men and 175 women) individuals (age range: 18–50 years). The study concludes that foot dimensions show significant sex differences. Both sectioning point and regression analyses can be used to estimate sex from foot dimensions. However, multiple regression models appear to have the maximum accuracy in sex differentiation. Although statistically significant sex differences are evident for foot index, its practical utility appears to be limited because of considerable overlap.

KEYWORDS: forensic science, forensic anthropology, sex estimation, foot measurements, foot index, Rajbanshi

Personal identification is an important element in forensic investigations, especially in cases of mass disasters and criminal mutilation where dismembered/severed body parts are frequently encountered. The main issues in the determination of the identity of an individual are sex, age, race, and stature (1). Estimation of stature and sex remains one of the most significant stages in establishing personal identity (2). With the recovery of a human foot from the scene of a crime or disaster, anthropometric examinations can provide valuable information about the stature and sex of the individual. Over the last few decades, studies have been largely conducted on the human foot for both ergonomic shoe design (3) and forensic purposes (4–6). There has been extensive published literature on the estimation of stature from foot dimensions (1,7–13). Although earlier researchers have attempted to estimate sex from foot bones (14,15) and foot shape (3), studies on sex estimation from foot dimensions among various populations are limited in number (1,16,17).

The objectives of the present study, therefore, were to study sex differences in foot measurements and to develop relevant statistical formulae for estimation of sex from foot dimensions in the "Rajbanshi," an indigenous Indian population. Contemporary India is composed of a large number of ethnic and indigenous elements having enormous amounts of ethnic and genetic diversity (18–22). This extensive diversity among the Indian population is nurtured to a large extent by the varied topography of the country (23). It is now recognized that the Indian population comprises more than a billion people and consists of 4693 communities with several thousand endogamous groups (24). The northern part of the state of West Bengal, India, popularly known as North Bengal comprises six districts and is home to a number of indigenous populations. The most widely distributed population among them is the Rajbanshi (25).

Published scientific literature on various aspects of forensic science, including estimation of sex from foot dimensions among the indigenous populations of North Bengal, is virtually nonexistent. Only recently has there been an attempt to determine stature from foot dimensions among individuals belonging to the Rajbanshi population (8). However, there are no conclusive and systematic studies on the estimation of sex from foot measurements among the Rajbanshis or related populations. Each racial group needs a separate formula owing to racial and ethnic variations (26), a fact that becomes very pertinent in the case of a diverse country such as India. It has also been shown that the anatomic structure of the foot shows ethnical and regional variations owing to congenital conditions, climatic factors, physical activities, and nutritional conditions (1). Hence, study of one homogenous population such as the Rajbanshi will eliminate the possible variations in foot dimensions owing to climatic, racial, and genetic factors.

Materials and Methods

This study has been performed in accordance with the ethical standards laid down in the Helsinki Declaration of 2000 (27). All the individuals who took part in the study gave their informed consent prior to inclusion in the study. Necessary permissions have also been given by the Gossainpur Gram Panchayet (a local government authority at the village level). The measurements for the present cross-sectional study were recorded from 350 living adult Rajbanshi individuals (175 men and 175 women). These individuals were the residents of two Rajbanshi-dominated villages called

[1]Department of Anthropology, University of North Bengal, P.O. NBU, Dist. Darjeeling, West Bengal, India.
[2]Department of Forensic Medicine and Toxicology, Kasturba Medical College, Mangalore (Affiliated to Manipal University), India.

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Dhansara and Dhanujote, both located in Gossainpur Gram Panchayet, Naxalbari Block, Darjeeling district, West Bengal, India. The Rajbanshi individuals were identified by their physical features, cultural features, and surnames. The records of the Gram Panchayet were also utilized for this purpose. All the individuals were adults in the age range of 18 years to 50 years and were free from any apparent symptomatic deformity of the foot and vertebral column. Test subjects were interviewed regarding any previous history of deformity, injury, or operation. The modified version of the scale of Kuppuswamy, as proposed by Mishra and Singh (28), was utilized to ascertain the socioeconomic status of the individuals. Relevant data on family income, education, and nature of occupation were recorded using prestructured and pretested schedules. Based on the above-mentioned scale, all the individuals in this study belonged to the lower socioeconomic class. Moreover, all the individuals included in this study were engaged in agriculture, thereby controlling the twin factors of physical activity and nutritional condition to a large extent.

All the subjects were barefoot at the time of recording the measurements. Owing to the diurnal variation in stature (29), all the subjects were measured during the morning hours prior to leaving for their work. Foot length (FL) was recorded using a rod compass, while foot breadth (FB) was recorded with the help of a spreading caliper. All the measurements were recorded to the nearest millimeter following the method outlined by Singh and Bhasin (30). The

TABLE 1—*Descriptive statistics: foot dimensions (cm) and foot index among Rajbanshi men and women.*

Sex	Male (n = 175)		Female (n = 175)	
Variable	Mean (S.D.)	Range	Mean (S.D.)	Range
RFL	23.95 (1.1)	21.10–27.30	22.23 (1.1)	19.70–24.90
LFL	24.01 (1.1)	21.20–27.40	22.26 (1.1)	19.80–25.10
RFB	9.89 (0.5)	08.60–12.10	08.99 (0.5)	07.60–10.50
LFB	9.90 (0.5)	08.80–11.90	09.01 (0.5)	07.50–10.50
RFI	41.32 (1.8)	36.20–46.90	40.48 (2.1)	35.20–46.80
LFI	41.30 (1.8)	36.30–45.40	40.50 (2.1)	35.10–46.80

S.D., standard deviation; RFL, right foot length; LFL, left foot length; RFB, right foot breadth; LFB, left foot breadth; RFI, right foot index; LFI, left foot index.

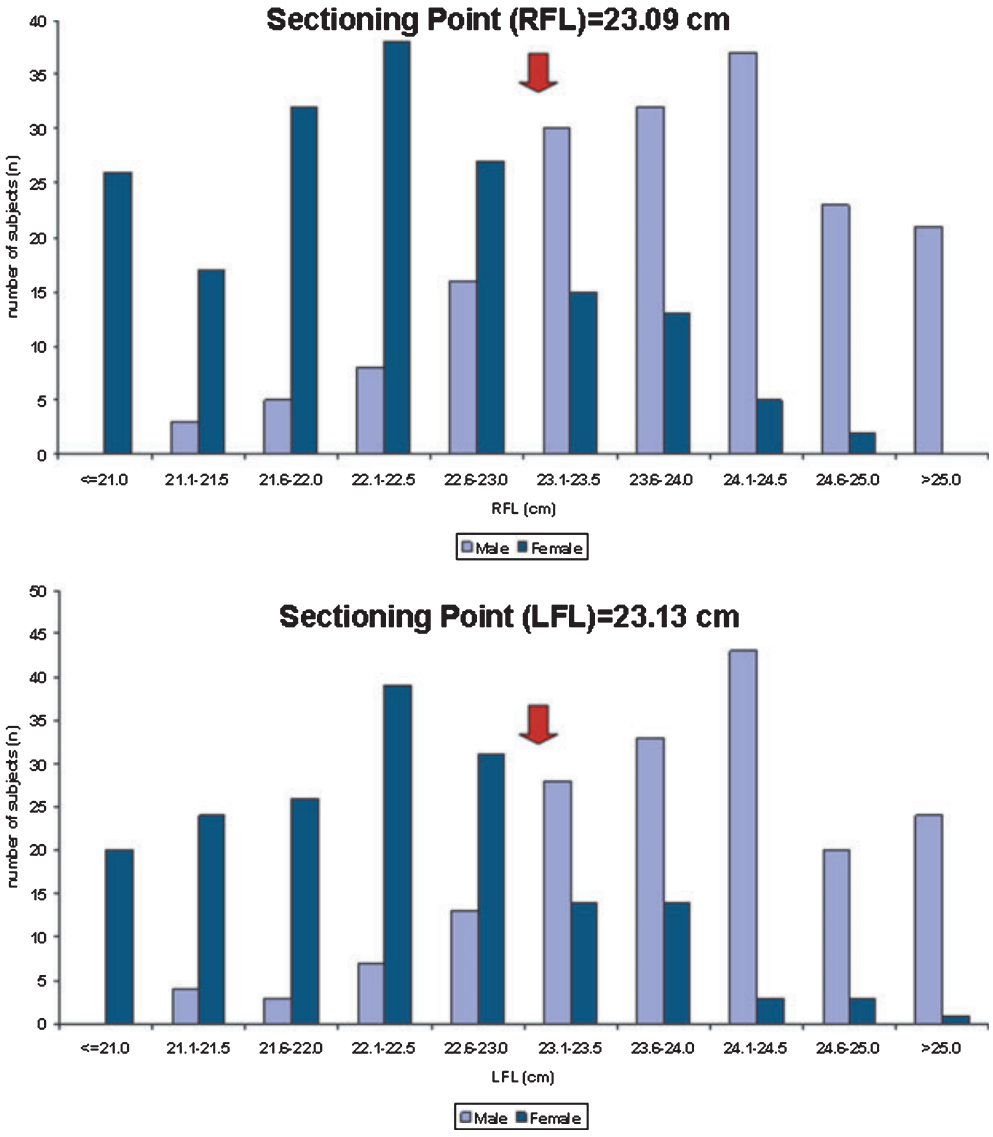

FIG. 1—*Frequency distribution of foot length (cm) among Rajbanshi men and women in right (RFL) and left foot length (LFL).*

foot index (FI) was calculated individually for each foot in men and women using the formula: Foot index = (FB/FL) × 100.

The technical errors of measurement (TEM) that is an accuracy index and measures the standard deviation between repeated measures (31) has been determined to check the consistency of the data. Even though a number of methods of measuring inconsistency are available, the preferred method involves calculation of relative TEM and subsequently determination of the coefficient of reliability (*R*) (32). The value of *R* ranges from 0 (not reliable) to 1 (complete reliability). A value of above 0.950 is indicative of good quality control and reliability (32). In this study, measurements of FL and FB were recorded from 30 Rajbanshi individuals by two of the authors (JS and SG) to calculate inter-observer TEM. The inter-observer TEM for the right foot length (RFL) was 0.053, 0.071 for the left foot length (LFL), 0.050 for the right foot breadth (RFB), and 0.039 for the left foot breadth (LFB). Very high values for *R* were subsequently obtained for RFL (0.997), LFL (0.999), RFB (0.995), and LFB (0.996). Two repeated measurements were taken on 30 individuals by one of the authors (SG) to calculate intra-observer TEM. The intra-observer TEM for the RFL was 0.077, 0.065 for the LFL, 0.052 for the RFB, and 0.052 for the LFB. Very high values for *R* were subsequently obtained for RFL (0.998), LFL (0.999), RFB (0.999), and LFB (0.999). All the values of *R* were appreciably higher than the cut-off value of 0.950, and hence, the measurements were considered reliable. Subsequently, all the measurements were recorded by one of the authors (SG).

The results were evaluated using SPSS for Windows (version 15.0). Descriptive statistics of FL, FB, and FI were obtained for right and left sides. Homogeneity of variance was tested using Levene's test of equality of variance. For all variables, the *p* value was observed to be statistically not significant ($p > 0.05$) thus showing that the variance is the same for both the groups for all the variables. Normality was tested using the Shapiro–Wilk test for each of the variables groupwise, and *p* values observed were not statistically significant ($p > 0.05$). Male and female sex differences were evaluated using the paired *t*-test. Differences between the right and left sides were also evaluated by the paired *t*-test. Sex determination from FL, FB, and FI was made by sectioning point and multiple regression analyses. The sectioning point was determined by the formula: sectioning point = (mean male value + mean female

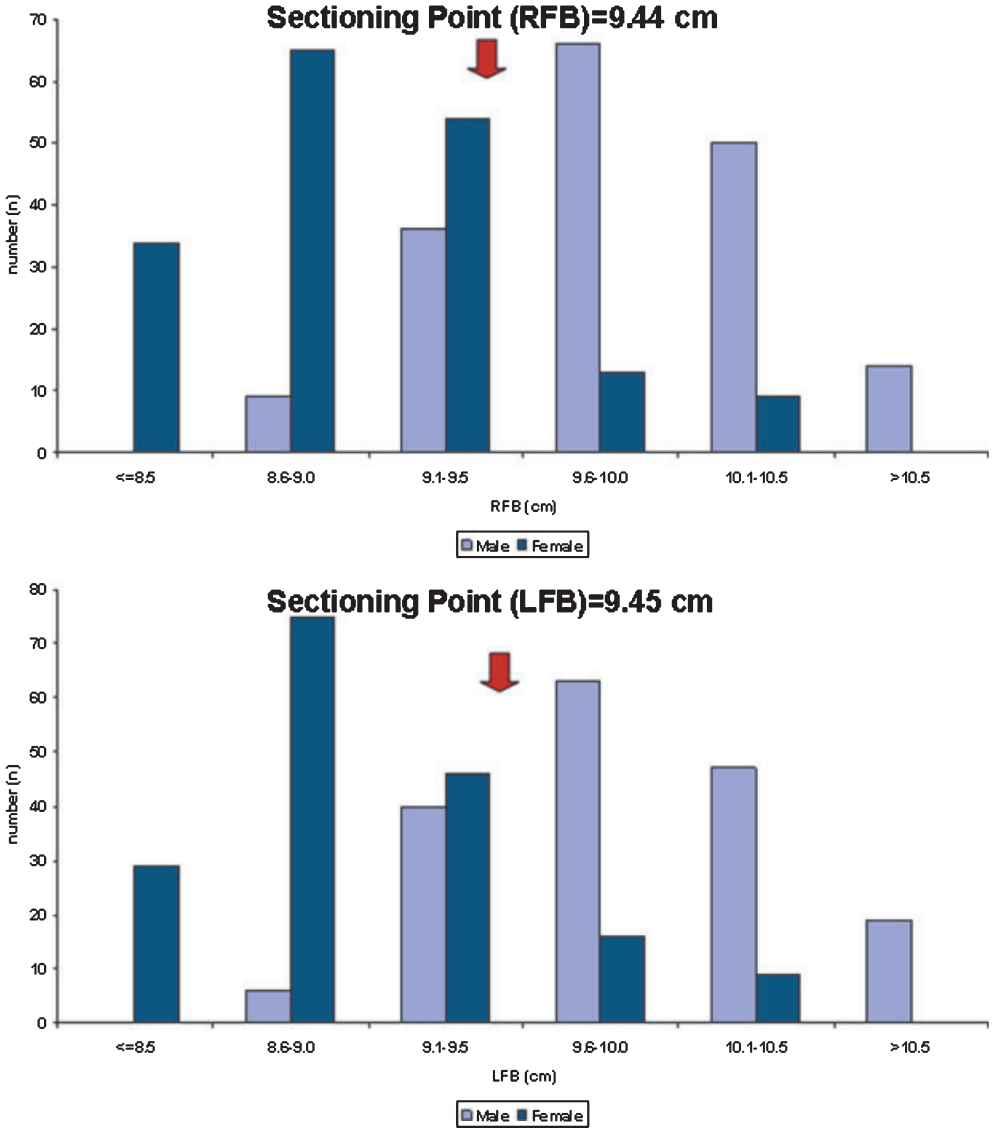

FIG. 2—*Frequency distribution of foot breadth (cm) among Rajbanshi men and women in right (RFB) and left foot breadth (LFB).*

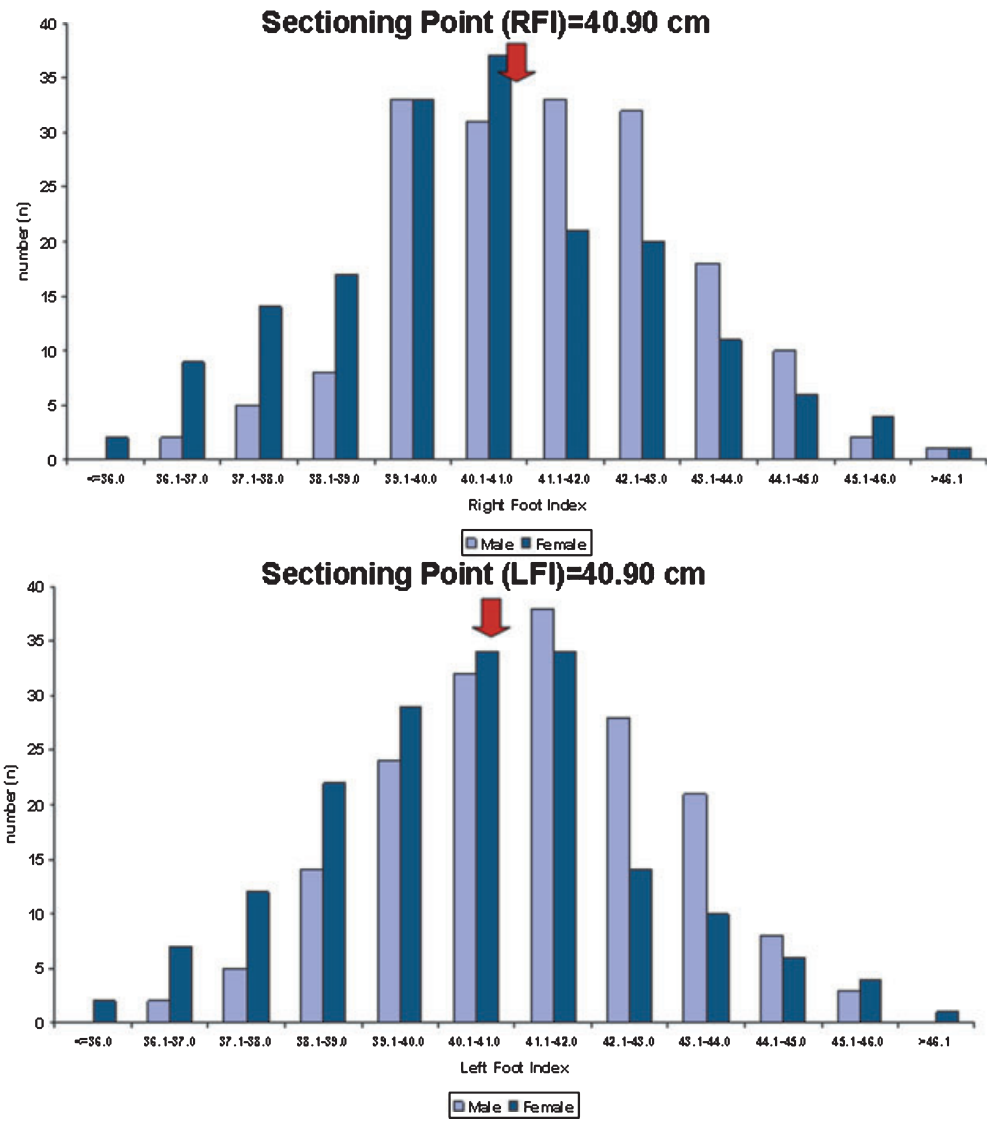

FIG. 3—*Frequency distribution of foot index among Rajbanshi men and women in right (RFI) and left foot index (LFI).*

value)/2. Accuracy of sectioning point analysis and regression analysis was tested using the study sample itself. While deriving regression models men were coded as "1" and women as "2." For testing the accuracy of multiple regression models in the study sample, values up to 1.50 were considered as male and those above 1.50 as females.

Results and Discussion

The detailed descriptive statistics of the foot dimensions among the Rajbanshi men and women are depicted in Table 1. The foot dimensions are found to be significantly larger in men than in women ($p < 0.001$). Frequency distributions of the foot dimensions (FL and FB) among Rajbanshi men and women on right and left sides are depicted in Figs. 1 and 2. The results of the present study add credence to the earlier observations that female foot dimensions are consistently smaller than those of the men in different human populations (5,7,16). FL on the left side is significantly longer among both men ($t = -3.942$, $p < 0.001$) and women ($t = -2.318$, $p < 0.05$). With regards to FB, no significant differences were observed between the two sides in men ($t = 1.314$, $p > 0.05$) and women ($t = 1.441$, $p > 0.05$). Existing studies on the right- and left-sided dominance in foot dimensions are inconclusive. In literature, right-sided dominance in foot dimensions (9,10) and dominant left-sided foot dimensions (17,33) have been reported among men and women in past.

The descriptive statistics of FI for men and women in the present study are shown in Table 1. Statistically significant sex differences

TABLE 2—*Percentage accuracy of sectioning points derived in the study sample.*

Variable	S.P.	Male (n = 175)	Female (n = 175)
RFL	23.09	80.6%	82.9%
LFL	23.13	82.9%	81.7%
RFB	09.44	80.6%	84.0%
LFB	09.45	81.1%	81.7%
RFI	40.90	56.6%	58.9%
LFI	40.90	58.3%	58.9%

RFL, right foot length; LFL, left foot length; RFB, right foot breadth; LFB, left foot breadth; RFI, right foot index; LFI, left foot index; S.P., sectioning point; FL, foot length; FB, foot breadth; FI, foot index.

TABLE 3—*Multiple regression models in sex estimation from foot length and foot breadth.*

Regression Equation	R	R^2	p value
Sex = 7.177 – 0.127 (RFL) – 0.291 (RFB)	0.693	0.480	RFL<0.001 RFB<0.001
Sex = 7.145 – 0.130 (LFL) – 0.279 (LFB)	0.691	0.477	LFL<0.001 LFB<0.001

RFL, right foot length; RFB, right foot breadth; LFL, left foot length; LFB, left foot breadth.

were observed for FI on the right ($t = 3.831$, $p < 0.001$) and the left side ($t = 3.723$, $p < 0.001$). The FI is found to be larger in men. A higher mean value of FI among men than women has also been reported in a recent study among the Gujjars of North India (16). However, this study by Moudgil et al. (16) did not find the differences to be statistically significant ($p > 0.05$). The FI in the present study has been observed to be marginally higher for the right side among men and for the left side among women. The differences between right and left sides within sexes are, however, not statistically significant ($p > 0.05$). A statistically significant bilateral difference in FI has, however, been reported in the study by Moudgil et al. (16). Frequency distribution of the FI in men and women on right and left sides is depicted in Fig. 3.

Sectioning point analysis was utilized for the estimation of sex from the foot dimensions, and FI subsequently derived from the foot dimensions. The sectioning points derived for the foot dimensions and FI are shown in Table 2 along with the percentage accuracy of sectioning points in the study sample from which they are derived. It is evident that the sectioning points derived for foot dimensions can estimate sex of an individual with reasonable accuracy. FL and FB thus appear to be strong predictors of sex. Although statistically significant sex differences are observed for FI in the present study ($p \leq 0.001$), the FI is a poor and unreliable sex indicator in the study sample owing to considerable overlapping of the values and recognizing the fact that sex can be estimated by pure chance with 50% accuracy. Hence, the derived indices do not demonstrate any diagnostic value. Our findings confirm the findings of Moudgil et al. (16) that FI cannot be used to estimate sex, even though statistically significant sex differences exist in foot measurements.

Multiple regression models derived for the estimation of sex from FL and FB among Rajbanshi men and women in the present study are shown in Table 3. The regression coefficients are found to be statistically significant ($p \leq 0.001$). Among men, regression models could estimate sex correctly in 84% of individuals from the right foot and 83.4% of individuals from the left foot. Sex was estimated correctly in 84.6% of women from right foot and 84% of women from the left foot using multiple regression models. The percentage accuracy of multiple regression models in estimating the sex of an individual in the present study is higher when compared to sectioning point analysis. Findings of our study are similar to observations of Zeybek et al. (1); their research, however, reports a higher accuracy in sex estimation from foot measurements using logistic regression analysis.

Conclusion

The present study has focused on the estimation of sex from foot dimensions in the Rajbanshi population of North Bengal. It provides the necessary methodology for the estimation of sex from foot dimensions that is of immense value in forensic identifications especially in cases of mass disasters and criminal mutilation. It can be concluded that foot dimensions show significant sex differences and that sex can be estimated from foot dimensions with reasonable accuracy. The sex of an individual can be successfully estimated using both sectioning point analysis and regression analysis. The accuracy of sex estimation from foot dimensions, however, is higher with multiple regression analysis than sectioning point analysis. Even though significant sex differences exist in the FI, the practical utility of using this index in sex estimation remains limited.

Conflict of interest: The authors have no relevant conflicts of interest to declare.

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References

1. Zeybek G, Ergur I, Demiroglu Z. Stature and gender estimation using foot measurements. Forensic Sci Int 2008;181:54. doi:10.1016/j.forsciint.2008.08.003.
2. Krogman WR, Iscan MY. The human skeleton in forensic medicine. Springfield, IL: Charles C. Thomas, 1986.
3. Wunderlich RE, Cavanagh PR. Gender differences in adult foot shape: implications for shoe design. Med Sci Sports Exerc 2001;33:605–11.
4. Krishan K. Individualizing characteristics of footprints in Gujjars of North India—forensic aspects. Forensic Sci Int 2007;169:137–44.
5. Ozden H, Balci Y, Demirustu C, Turgut A, Ertugrul M. Stature and sex estimate using foot and shoe dimensions. Forensic Sci Int 2005;147:181–4. doi:10.1016/j.forsciint.2004.09.072.
6. Jasuja OP, Singh J, Jain M. Estimation of stature from foot and shoe measurements by multiplication factors: a revised attempt. Forensic Sci Int 1999;50:203–15.
7. Kanchan T, Menezes RG, Moudgil R, Kaur R, Kotian MS, Garg RK. Stature estimation from foot dimensions. Forensic Sci Int 2008;179:241. doi:10.1016/j.forsciint.2008.04.029.
8. Sen J, Ghosh S. Estimation of stature from foot length and foot breadth among the Rajbanshi: an indigenous population of North Bengal. Forensic Sci Int 2008;181:55. doi:10.1016/j.forsciint.2008.08.009.
9. Agnihotri AK, Purwar B, Googoolybe K, Agnihotri S, Jeebun N. Estimation of stature by foot length. J Forensic Leg Med 2007;14:279–83.
10. Krishan K, Sharma A. Estimation of stature from dimensions of hands and feet in North Indian population. J Forensic Leg Med 2007;14:327–32.
11. Sanli SG, Kizilkanat ED, Boyan N, Ozsahin ET, Bozkir MG, Soames R, et al. Stature estimation based on hand length and foot length. Clin Anat 2005;18:589–96.
12. Sharma VK, Garg RK, Chattopadhyay PK. Calculation of stature from foot measurements: a study of Gaur Brahmins. Coll Antropol 1978;2:194–5.
13. Baba K. Foot measurement for shoe construction with reference to the relationship between foot length, foot breadth, and ball girth. J Hum Ergol (Tokyo) 1974;3:149–56.
14. Bidmos MA, Dayal MR. Sex determination from the talus of South African Whites by discriminant function analysis. Am J Forensic Med Pathol 2003;24:322–8.
15. Robling AG, Ubelaker DH. Sex estimation from the metatarsals. J Forensic Sci 1997;42:1062–9.
16. Moudgil R, Kaur R, Menezes RG, Kanchan T, Garg RK. Foot index: is it a tool for sex determination? J Forensic Leg Med 2008;15:223–6.
17. Rao NG, Kotian MS. Foot print ratio (FPR)—a clue for establishing sex identity. J Indian Acad Forensic Med 1990;12:51–6.
18. Indian Genome Variation Consortium. Genetic landscape of the people of India: a canvas for disease gene exploration. J Genet 2008;87:3–20.
19. Beiteille A. The Indian heritage—a sociological perspective. In: Balasubramanian D, Rao NR, editors. The Indian human heritage. Hyderabad: University Press, 1998:27–94.
20. Majumder PP. People of India: biological diversity and affinities. Evol Anthropol 1998;6:100–10.
21. Kalla AK. The ethnology of India: antecedents and ethnic affinities of peoples of India. New Delhi: Munshiram Manoharlal Publishers, 1994.

22. Risley HH. Tribes and castes of Bengal. Calcutta: The Bengal Secretariat Press, 1891.
23. Gadgil M, Guha R. The fissure land: an ecological history of India. New Delhi: Oxford University Press, 1992.
24. Singh KS. People of India: introduction national series. New Delhi: Anthropological Survey of India-Oxford University Press, 2002.
25. Sen J, Kanchan T, Mondal N. A comparison of palmar dermatoglyphics in two ethnic Indian populations of North Bengal, India. J Forensic Sci 2011;56(1) doi: 10.1111/j.1556-4029.2010.01554.x
26. Telkka A. On the prediction of human stature from the long bones. Acta Anat (Basel) 1950;9:103–17.
27. Touitou Y, Portaluppi F, Smolensky MH, Rensing L. Ethical principles and standards for the conduct of human and animal biological rhythm research. Chronobiol Int 2004;21:161–70.
28. Mishra D, Singh HP. Kuppuswami's socio-economic status scale—a revision. Indian J Pediatr 2003;70:273–4.
29. Krishan K, Vij K. Diurnal variation of stature in three adults and one child. Anthropologist 2007;9:113–7.
30. Singh IP, Bhasin MK. Anthropometry. Delhi: Kamla-Raj Enterprise, 1989.
31. Goto R, Mascie-Taylor CGN. Precision of measurement as a component of human variation. J Physiol Anthropol 2007;26:253–6.
32. Ulijaszek SA, Kerr DA. Anthropometric measurement error and the assessment of nutritional status. Br J Nutr 1999;82:165–77.
33. Tyagi AK, Rani M, Kohli A. Sexing by foot index. J Forensic Med Toxicol 2004;21:10–1.

Additional information and reprint requests:
Jaydip Sen, M.Sc., Ph.D.
Department of Anthropology
University of North Bengal
P.O. NBU
Raja Rammohunpur
Darjeeling
West Bengal
India 734013
E-mail: jaydipsen@rediffmail.com