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TECHNICAL NOTE

ANTHROPOLOGY

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Sex Determination from Hand and Foot Dimensions in a North Indian Population

ABSTRACT: Hands and feet are often recovered from the site of natural as well as man-made disasters because of bomb blasts, train accidents, plane crashes, or mass homicides. This study is intended to establish standards for determination of sex from the dimensions of hands and feet in a North Indian population. The data for this study comprise 123 men and 123 women aged between 17 and 20 years from the "Rajput" population of Himachal Pradesh in North India. Four anthropometric measurements viz. hand length, hand breadth, foot length, and foot breadth have been taken on both sides of each subject following international anthropometric standards. The hand index (hand breadth/hand length × 100) and the foot index (foot breadth/foot length × 100) were calculated. Sectioning points and regression models are derived for the hand and foot dimensions and the derived indices. The hand and foot dimensions show a higher accuracy in sex determination by sectioning point analysis when compared to hand and foot index. Of the hand and the foot dimensions, hand breadth and foot breadth showed better accuracy in sex determination. Hand index and foot index remain poor sex discriminators in the study.

KEYWORDS: forensic science, forensic anthropology, sex determination, hand and foot measurements, hand index, foot index, North India

Sex determination from the human body parts and skeletal remains is an essential component of personal identification in forensic investigations when mutilated dead bodies with fragmentary remains are brought for forensic examination. Sex is considered as one of the "big four" parameters in forensic identification besides, race, age, and stature. Accurate sexing of human remains provides valuable clues to a forensic scientist and primarily narrows down the pool of possible victim matches. Anthropometry is a well-established forensic technique, which uses anthropological databanks to calculate computational ratios of specific body parts associated with differences between sexes (1). Various studies in the past have reported a fair possibility of determining sex from skeletal remains and different body parts. The personal identification from extremities becomes more important in cases of mass disasters, where there is a likelihood of recovering feet (often enclosed in shoes) and hands separated from the body (2). With regard to personal identification of dismembered hand and foot, somatometry of the hand and foot, and its osteologic and radiologic examination can help in the determination of primary indicators of identification, such as sex, age, and stature. Studies have been conducted on estimation of stature from hand and foot and their parts in various population groups (2–17).

Sex determination based on osteologic and radiologic examination from hand and foot bones (18–28) and a few studies on determination of sex from morphometric analysis of hand and foot dimensions have been conducted in the past (29–38). The need for population-specific data for methods based on anthropometric measurements has been emphasized time and again as there are vast differences in body size in various populations (39). The principal aim of the present study is to determine sex from dimensions of hands and feet in an endogamous North Indian population using statistical considerations.

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Materials and Methods

Subjects

The sample for this study was taken from 246 subjects (123 men and 123 women) aged between 17 and 20 years. The subjects belong to the Rajput population—a major endogamous caste group in the state of Himachal Pradesh in North India. The study was conducted in Theog tehsil of district Shimla in the state of Himachal Pradesh. Theog is geographically located at latitude 31° 7′ 12″ north of the Equator and longitude 77° 20′ 59″ east of the Prime Meridian on the map of the world (3). The sample was taken from Government Senior Secondary School and Government Degree College, Theog. The subjects included in the study were healthy and free from any apparent symptomatic deformity. This investigation is a part of a larger study conducted on the Rajputs of Himachal Pradesh in India (3,40). For the present study, four anthropometric measurements—hand length, hand breadth, foot length, and foot breadth—were taken independently on the left and right side of each individual. Only right-handed subjects were included in this study. Previous studies have shown that significant differences exist between sides in hand and foot dimensions (3,4,32,36); hence, measurements from both sides were analyzed. All the measurements were taken in a well-lit room using sliding calipers in centimeters to the nearest millimeter according to the techniques described by Vallois (41).

In any forensic study based on anthropometry, the accuracy in measurements is considered as an imperative element. Care was

TABLE 1—*Technical error variance (S^2) of hand and foot measurements within and between sides.*

Measurement (in cm)	S^2 Within Side	S^2 Between Sides	F-Ratio
HL	0.0588	0.4832	8.2176*
HB	0.0487	0.2988	6.1104*
FL	0.0391	0.3251	8.3145*
FB	0.0613	0.4100	6.6884*

*$p < 0.01$.

taken to ensure the precision and reproducibility of the hands and feet measurements in this study. During data collection, all the subjects were measured by one of the authors (AS), a trained biologic anthropologist. All the instruments were regularly checked for their accuracy. Before starting the data collection for the study, the hands and feet measurements were taken on 20 subjects twice at different times and the measurement error was calculated. The measurement error is defined as the square root of the sum of the squared deviations divided by twice the sample size ($S^2 = \sqrt{\sum d^2/2n}$). The same formula was applied to the left-right differences. The value of "F" statistics (F-ratio) was calculated. For judging the statistical significance of the F-score, the value of 0.01 was taken as the level of significance. Table 1 presents the sizes of the technical error variances of the hand and foot measurements. The technical error within side and between sides is described as the "S^2 within side" and "S^2 between side" and the ratio of the two errors is distributed as an F-statistics. F-ratio, for all the measurements is statistically significant at the α-level of $p < 0.01$. Hence, the variation attributed to sides is several times larger than the measurement error, indicating that measurement error contributes but little to the difference between sides. Findings indicate that the technical error contributes negligible to the measurements and the measurements are reproducible without significant technical error.

TABLE 2—*Various landmarks on hand and foot as described by Vallois (41).*

Landmark	Description
Inter-stylion	The middle point of the line connecting the point stylion radiale (the most distal point on the styloid process of the radius) and stylion ulnare (the most distal point on the styloid process of ulna)
Dactylion	The most distal point on the tip of the third finger of the hand
Metacarpal radiale	The point projecting most laterally on the head of the 2nd metacarpal when the hand is stretched
Metacarpal ulnare	The point projecting most medially from the head of the 5th metacarpal
Acropodian	The most forwarding projected point on the head of the 1st or 2nd toe whichever is larger when the subject stands erect
Pternion	The most backwardly projecting point on the heel when the subject is standing upright with equal pressure on both the feet
Metatarsal-tibiale	The most medially projecting point on the head of the 1st metatarsal bone when the subject stands erect
Metatarsal-fibulare	The point most laterally projecting on the head of the 5th metatarsal bone when the subject stands erect

Techniques for Taking Anthropometric Measurements

Landmarks on hand and foot as described by Vallois (41) are shown in Table 2. The measurements that were taken on hand and foot are depicted in Figs 1 and 2. The measurements are taken with the subject standing erect.

Hand Length

Projected distance between interstylion and dactylion. The hand is held by the anthropometrist in one hand to keep the fingers extended. The measurement is then taken with the sliding calipers along the radial border of the hand parallel to the axis of the hand.

Hand Breadth

Projected distance between the most prominent point, outside of the lower epiphyses of the 2nd metacarpal, i.e., metacarpal radiale to the most prominent inside point of the lower epiphyses of the 5th metacarpal, i.e., metacarpal ulnare. The measurement is taken over the dorsum of the hand in full intension. It is easy to locate the points by palpation of the landmarks corresponding to the heads of the metacarpal that should not be confused with the upper epiphyses of the finger joints. This "breadth" is somewhat oblique with regard to the axis of the hand.

Foot Length

The projected distance from acropodian to pternion. The instrument is horizontally placed along the inner border of the foot and the measurement is taken.

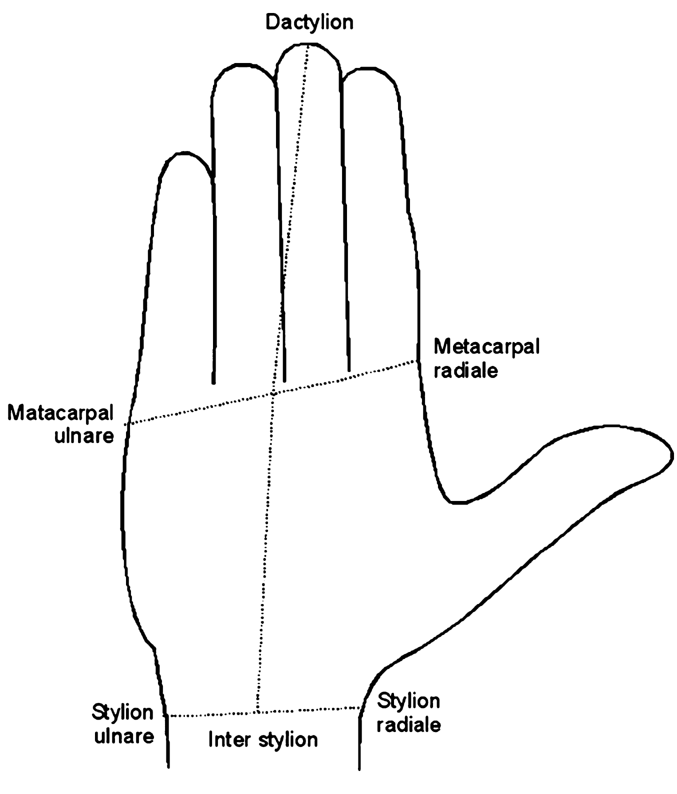

FIG. 1—*Measurements and landmarks on human hand.*

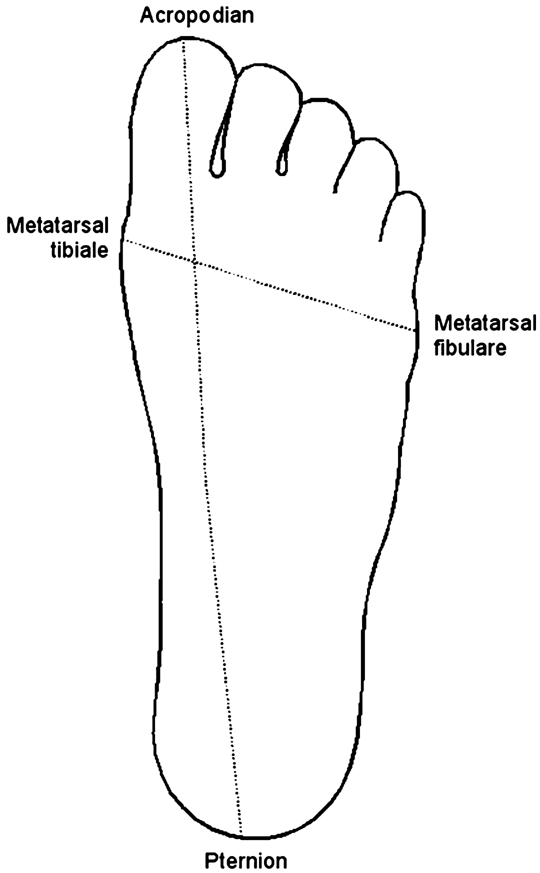

FIG. 2—*Measurements and landmarks on human foot.*

Foot Breadth

The distance between the points of the anterior epiphyses (distal) of the 1st metatarsal, the most prominent of the inner side of the foot (metatarsal-tibiale), and the joint of the anterior epiphyses of the 5th metatarsal, the most prominent of the outer side (metatarsal-fibulare). The measurement that is taken in the dorsal region of the foot "loaded" as in the preceding measurement is oblique with regard to length.

Statistics

From the total sample of 246 subjects (123 men and 123 women), 200 subjects (100 men and 100 women) were randomly selected that comprised the study group on which statistical analysis was performed and the remaining 46 subjects (23 men and 23 women) formed the test group on which the accuracy of sectioning points derived in the study were tested.

The hand index is calculated individually for both hands in men and women by using the formula: hand index = (hand breadth/hand length) × 100, while the foot index is calculated individually for both feet in men and women by using the formula: foot index = (foot breadth/foot length) × 100. The data obtained were computed and analyzed using SPSS, version 11.0, statistical analyses program (SPSS Inc., Chicago, IL). The significance of results was tested using student's *t*-test. A *p*-value of <0.05 was considered as significant. Sectioning point analysis is performed to differentiate sex from hand and foot dimensions and the hand and foot indices that were derived form the hand and foot measurements. For all dimensions and indices, average of mean values in men and women was taken as cut off value for sex determination and termed as the "sectioning point."

$$\text{Sectioning point} = \frac{\text{Mean male value} + \text{Mean female value}}{2}$$

Accuracy of sectioning points derived in the study group was tested on the study as well as the test group. Linear and multiple regression models/equations are derived to differentiate sex from hand and foot dimensions. Men were coded as 1 and women as 2. Values up to 1.50 were considered as men and those above 1.50 as women. Accuracy between the test and study sample was compared.

Results

Descriptive statistics for hand and foot dimensions and the derived indices (hand index and foot index) in men and women is shown in Table 3. Hand and foot dimensions are found to be significantly higher ($p < 0.001$) in men in both right and left sides. With reference to right- and left-side differences, hand breadth was found to be significantly larger on the right side in both men ($t = 5.606$, $p < 0.001$) and women ($t = 5.493$, $p < 0.001$), while

TABLE 3—*Descriptive statistics for hand and foot dimensions (cm) and index.*

	Men (n = 100)		Women (n = 100)			
	Range	Mean (SD)	Range	Mean (SD)	t-Value	p-Value
Right						
HL	16.0–21.1	18.27 (0.9)	15.2–19.0	16.81 (0.8)	11.886	<0.001
HB	07.3–09.6	08.25 (0.4)	06.4–08.8	07.41 (0.4)	14.173	<0.001
FL	22.0–28.0	24.75 (1.1)	20.4–25.1	22.60 (1.1)	13.851	<0.001
FB	08.3–10.9	09.61 (0.5)	07.5–09.8	08.62 (0.5)	14.136	<0.001
HI	40.8–53.1	45.23 (2.2)	39.0–50.3	44.13 (2.2)	3.598	0.001
FI	32.9–38.5	38.89 (2.2)	33.6–43.5	38.17 (2.1)	2.321	0.021
Left						
HL	15.9–20.8	18.21 (0.9)	15.1–19.2	16.77 (0.8)	11.507	<0.001
HB	07.1–09.8	08.12 (0.4)	06.1–08.5	07.30 (0.4)	13.173	<0.001
FL	21.7–28.6	24.73 (1.2)	20.4–24.9	22.57 (1.1)	09.217	<0.001
FB	08.2–10.9	09.55 (0.5)	07.3–09.8	08.55 (0.5)	14.040	<0.001
HI	39.7–51.6	44.63 (2.3)	37.6–49.1	43.59 (2.5)	3.054	0.003
FI	33.9–38.3	38.65 (2.1)	33.3–43.4	37.93 (1.9)	2.544	0.012

SD, standard deviation; HL, hand length; HB, hand breadth; FL, foot length; FB, foot breadth; HI, hand index; FI, foot index.

hand length was found to be significantly larger on the right side in men only (t = 2.455, p = 0.01). Among foot dimensions, significant side differences were observed only for foot breadth that was found to be significantly larger on the right side in men (t = 2.539, p = 0.01) and women (t = 2.312, p = 0.02). Frequency distribution of the hand and foot measurements (cm) among men and women for right and left sides is shown in Figs 3–6. Hand index and foot index are found to be significantly higher in men on both right and left sides ($p < 0.05$). With regard to side differences, hand index was significantly higher on the right side in men (t = 4.085, $p < 0.001$) and women (t = 3.891, $p < 0.001$). However, no significant differences were observed in the foot index between sides in men (t = 2.370, p = 0.20) and women (t = 1.804, p = 0.074).

Linear regression models derived from hand and foot dimensions are shown in Table 4 (men are coded as 1 and women as 2). Hand breadth and foot breadth show a better prediction in sex estimation when compared to hand length and foot length. Multiple regression models derived from hand and foot dimensions are shown in Table 5. Multiple regression models for foot dimensions are found to be better predictor of stature than hand dimensions.

The sectioning points are derived from hand and foot dimensions and the derived indices, and its percentage accuracy was tested on the study group itself (Table 6). Sectioning points derived for hand and foot dimensions determine sex with a reasonable accuracy, whereas hand index and foot index remained a poor and unreliable sex indicator especially considering the fact that 50% chances of correct sex determination always exists. With regard to hand and foot index, a considerable overlapping in the male and female values is observed in the study. The accuracy of sectioning point analysis in sex determination from hand and foot dimensions is further tested in the test group comprising of 46 subjects (Table 7). Sectioning points derived in the study group determine sex in the test group with a reasonable accuracy that is comparable to the accuracy of the sectioning point in the study group itself.

Discussion

In this investigation into an endogamous North Indian Rajput population, hand and foot dimensions are found to be significantly larger ($p < 0.001$) in men than women in both right and left sides. Our findings are similar to earlier studies conducted on different population groups by Fessler et al. (17) on Americans, Danborno and Elukpo (38) on African populations, Ozden et al. (31), Sanli et al. (9), and Zeybek et al. (16) on Turkish populations, Agnihotri et al. (4,5) on Mauritian populations, Kanchan and Rastogi (36) on North and South Indian students, Kanchan et al. (14) on Gujjars of North India, and Sen and Ghosh (15) on Rajbanshis of North Bengal region in India. The hand and foot dimensions however vary between populations and can be attributed to, albeit not exclusively, factors such as genetics, environment, and social conditions. For this reason, investigations into the development of population-specific standards are warranted (42).

With regard to bilateral differences in the present study, hand breadth was found to be significantly larger on the right side in men and women, while hand length was significantly larger on the right side in men only. Among foot dimensions, significant side differences were observed only for foot breadth that was found to be significantly larger on the right side in men and women. Thus,

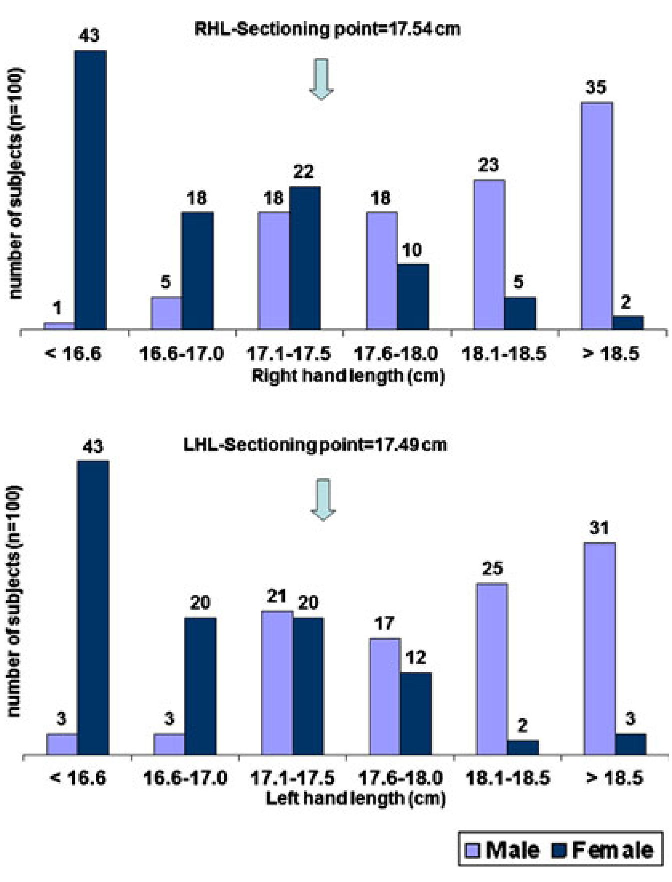

FIG. 3—*Frequency distribution of the hand length (cm) among men and women.*

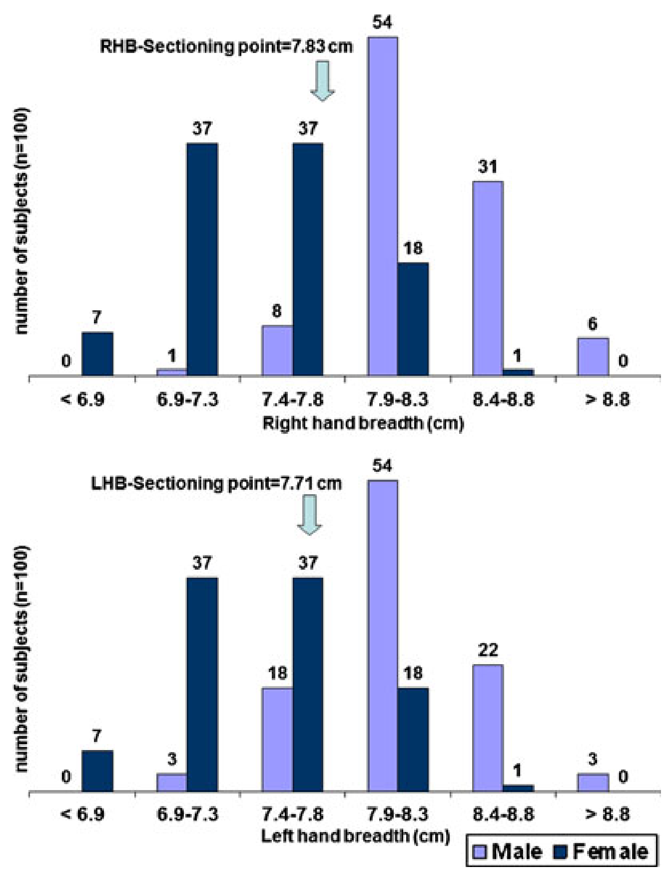

FIG. 4—*Frequency distribution of the hand breadth (cm) among men and women.*

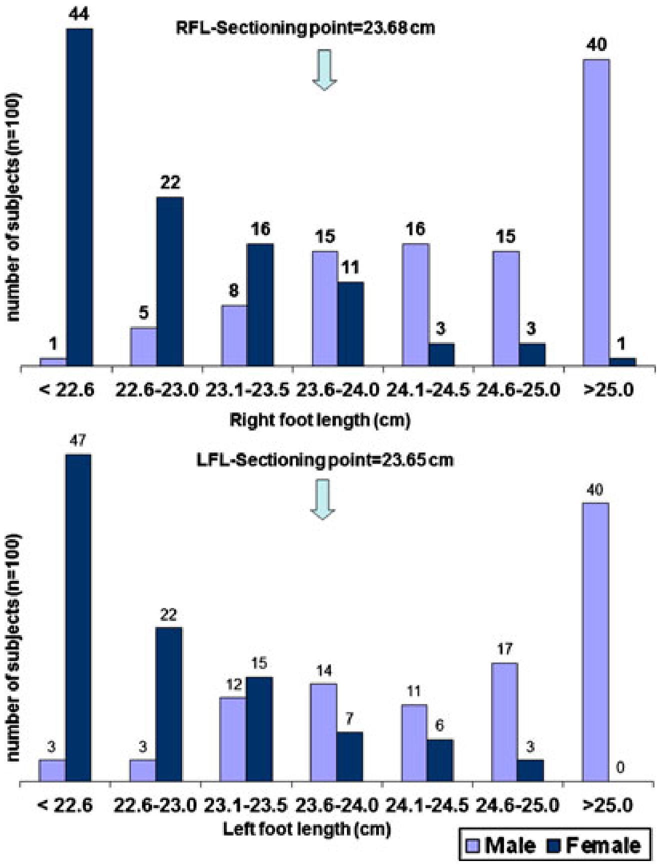

FIG. 5—*Frequency distribution of the foot length (cm) among men and women.*

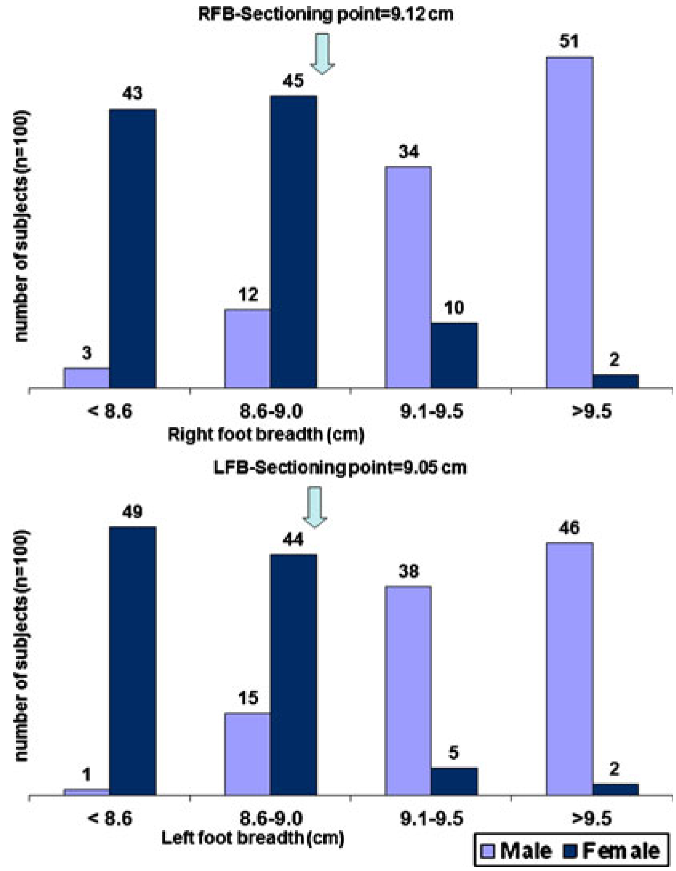

FIG. 6—*Frequency distribution of the foot breadth (cm) among men and women.*

a right-sided dominance was evident for hand and foot breadth in men and women. This right-sided dominance in hand dimensions has often been attributed to the handedness of the subjects. Repeated high levels of mechanical loading and more stress and strain on the dominant side are responsible for the significant asymmetry in upper limb (43). Earlier studies on the right- and left-sided dominance in foot dimensions are inconclusive (33). The hand index was significantly higher on the right side in men and women similar to that reported by Kanchan and Rastogi (36). No significant differences were observed in the foot index between sides in men and women in our study. Moudgil et al. (33) observed statistically significant differences in foot index between the two sides only in men.

The sectioning points derived for the hand length in this are lower, while the same is higher for the hand breadth when compared to a similar study by Kanchan and Rastogi (36) on North and South Indian medical students. With regard to foot dimensions, sectioning points derived in our study for the foot length are higher, while the same is lower for the foot breadth when compared to a recent study by Sen et al. (37) on Rajbanshis of West Bengal region in the eastern part of India. An earlier research by Moudgil et al. (33) studies the sexual dimorphism of foot index in Gujjars of North India. They, however, have not estimated the sectioning points for foot dimensions in their study. Sectioning point for the foot length and foot breadth when calculated from the available data in their study is found to be higher when compared to the findings of our study. Sectioning point derived for the hand index in our study is higher to that observed by Kanchan and Rastogi (36), while that for the foot index was lower in our study when compared to the observations of Sen et al. (37).

TABLE 4—*Linear regression models for the hand and foot dimensions.*

Regression Equation	R	R^2	p-Value
Hand dimensions			
Sex = 6.495−0.285 (RHL)	0.645	0.416	<0.001
Sex = 6.195−0.600 (RHB)	0.710	0.504	<0.001
Sex = 6.363−0.278 (LHL)	0.633	0.401	<0.001
Sex = 5.929−0.575 (LHB)	0.683	0.467	<0.001
Foot dimensions			
Sex = 6.922−0.229 (RFL)	0.702	0.416	<0.001
Sex = 6.097−0.504 (RFB)	0.709	0.502	<0.001
Sex = 6.704−0.220 (LFL)	0.689	0.475	<0.001
Sex = 6.034−0.501 (LFB)	0.706	0.499	<0.001

RHL, right hand length; RHB, right hand breadth; LHL, left hand length; LHB, left hand breadth; RFL, right foot length; RFB, right foot breadth; LFL, left foot length; LFB, left foot breadth.

Sex was determined from hand and foot dimensions with reasonable accuracy using sectioning point and regression analysis. Similar findings are reported in earlier studies (36,37). Multiple regression models appear to have a better accuracy in sex differentiation than linear regression models. Ozden et al. (31) devised regression formulae for the estimation of sex in a Turkish population and concluded that the foot and shoe lengths can estimate the sex better than foot and shoe breadth. In our study, however, the foot breadth showed better accuracy than foot length in sex determination. Zeybek et al. (16) found a high accuracy of foot

TABLE 5—*Multiple regression models for the hand and foot dimensions.*

Regression Equation	*R*	R^2	*p*-Value
Hand dimensions			
Sex = 6.845−0.108 (RHL)−0.441 (RHB)	0.727	0.528	RHL = 0.002 RHB < 0.001
Sex = 6.835−0.130 (LHL)−0.397 (LHB)	0.714	0.510	LHL < 0.001 LHB < 0.001
Foot dimensions			
Sex = 7.403−0.132 (RFL)−0.305 (RFB)	0.766	0.587	RFL < 0.001 RFB < 0.001
Sex = 7.062−0.117 (LFL)−0.308 (LFB)	0.748	0.560	LFL < 0.001 LFB < 0.001

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

TABLE 6—*SP analysis and its accuracy in sex determination in the study group.*

Variable	SP	Total (*n* = 200)	Men (*n* = 100)	Women (*n* = 100)
RHL	17.54	159 (79.5)	76 (76.0)	83 (83.0)
LHL	17.49	159 (79.5)	78 (78.0)	81 (81.0)
RHB	07.83	172 (86.0)	91 (91.0)	81 (81.0)
LHB	07.71	168 (84.0)	79 (79.0)	89 (89.0)
RHI	44.68	113 (56.5)	59 (59.0)	54 (54.0)
LHI	44.11	112 (56.0)	56 (56.0)	56 (56.0)
RFL	23.68	164 (82.0)	82 (82.0)	82 (82.0)
LFL	23.65	167 (83.5)	81 (81.0)	86 (86.0)
RFB	09.12	172 (86.0)	83 (83.0)	89 (89.0)
LFB	09.05	177 (88.5)	84 (84.0)	93 (93.0)
RFI	38.53	111 (55.5)	55 (55.0)	56 (56.0)
LFI	38.29	112 (56.0)	58 (58.0)	54 (54.0)

SP, sectioning point; HL, hand length; HB, hand breadth; HI, hand index; FL, foot length; FB, foot breadth; FI, foot index.
The values in parentheses are expressed in percentage.

TABLE 7—*Accuracy of SP* in sex determination in the test group.*

Variable	SP	Total (*n* = 46)	Men (*n* = 23)	Women (*n* = 23)
RHL	17.54	35 (76.1)	16 (69.6)	19 (82.6)
LHL	17.49	37 (80.4)	19 (82.6)	18 (78.3)
RHB	07.83	42 (91.3)	20 (87.0)	22 (95.7)
LHB	07.71	37 (80.4)	16 (69.6)	21 (91.3)
RFL	23.68	36 (78.3)	18 (78.3)	18 (78.3)
LFL	23.65	36 (78.3)	18 (78.3)	18 (78.3)
RFB	09.12	38 (82.6)	17 (73.9)	21 (91.3)
LFB	09.05	40 (86.9)	17 (73.9)	23 (100.0)

SP, sectioning point; HL, hand length; HB, hand breadth; HI, hand index; FL, foot length; FB, foot breadth; FI, foot index.
*Derived from the study group.
The values in parentheses are expressed in percentage.

measurements in sex determination using logistic regression analysis. To the best of our knowledge, no published literature is available on the determination of sex from hand dimensions using regression models; hence, the findings of our study could not be compared in this respect. Although the hand and foot index show statistically significant sex differences in our study, they are found to be poor indicators of sex because of considerable overlapping of male and female values. Similar findings are reported in earlier studies by Kanchan and Rastogi (36), Moudgil et al. (33), and Sen et al. (37).

The study is intended to make standards for North Indian populations, which may be used for the determination of sex from isolated hands and feet in a forensic investigation. With regard to feet, the measurements were taken on standing subjects. Although all the anthropometric measurements used in the study are based on fixed bony landmarks, yet the feet in standing posture expand in anterior-posterior and medio-lateral direction. The measurements taken in the standing position (weight-bearing foot) thus may slightly differ from those taken from the isolated (nonweight-bearing) foot often recovered from the disaster site and brought for medicolegal investigation. This can be considered as a limitation of this study. Study of variation between the measurements of a weight-bearing and a nonweight-bearing foot is an issue of interest in future studies.

Conclusion

Although the DNA analysis in forensic identification provides the most reliable results, it is yet to be used routinely in forensic investigations in the developing countries owing to its cost-effectiveness especially in cases of mass disasters. Hence, techniques in forensic anthropology continue to play a major role in identification of human remains using statistical considerations. The results of this study show that dimensions of hands and feet show significant sex differences. Hence, sex can be determined from the dimensions of hands and feet with reasonable accuracy using sectioning point and regression analysis. Hand breadth and foot breadth showed better accuracy in sex determination than hand length and foot length. Hand index and foot index remain poor sex discriminators in the study. The results of the study can directly be utilized in forensic examinations pertaining to human identification. These formulae are population specific; while applying the formulae to other populations, one must consider the component of population variation because of different morphological features existing among humans worldwide.

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