Estimation of Stature and Sex by Foot Length Measurements using Linear Regression and Discriminant Function Analysis, Respectively: A Study in Central India Population

Rekha Lalwani1  Himank Gupta2  Sunita A. Athavale1  Sheetal Kotgirwar1

1Department of Anatomy, All India Institute of Medical Sciences, Bhopal, Madhya Pradesh, India  
2All India Institute of Medical Sciences, Bhopal, Madhya Pradesh, India

Address for correspondence Sunita A. Athavale, MD (Anat), Department of Anatomy, All India Institute of Medical Sciences, Bhopal, Madhya Pradesh, India (e-mail: sunita.anatomy@aiimsbhopal.edu.in).

Abstract

Background and Aim  In forensic investigations establishing the identity of a person is a vital step. Stature and sex are important attributes of personal identity. In cases of mass disasters, generally isolated body parts and extremities are recovered as remains and are utilized to ascertain identity of an individual with personal attributes like gender, stature. The present study was conducted to ascertain if the foot length can be reliably used in estimation of stature and gender, and to establish population-specific regression equation and discriminant function analysis in population of Central India.

Methods  One hundred subjects (50 males and 50 females) between the age group of 20 and 40 years, who are residents of Central India for two generations, were studied. Foot length, of both right and left sides, was recorded for each individual and stature was measured with the help of a stadiometer. Data were subjected to statistical analysis.

Results  Statistical analysis of the data of the study population showed statistically highly significant differences ($p < 0.001$) between males and females. Statistically highly significant positive correlation was observed between stature and foot length in males and females. Linear regression equations for stature estimation were derived separately for males and females. The discriminant function analysis, utilizing foot length correctly, classified 78 to 85.1% of cases for respective gender.

Conclusion  The statistically significant positive correlation between the foot length and stature and accuracy of sex classification by discriminant function analysis indicate the reliability of foot length in predicting stature and gender of an individual.

Introduction

An important role of forensic anthropologists is their contribution for identification of individuals.1 Stature and gender are primary attributes of biological profiling utilized for identification in medicolegal cases from pool of potential matches.

In mass disaster cases such as warfare, aircraft crashes, and explosions, body parts and extremities are the only remnants recovered.2–4 Feet dimensions have been often utilized for prediction of stature and gender and their relationships have been established in various studies.4–12 Studies have shown that the foot can be reliably utilized to predict the stature and sex of an individual with reasonable accuracy. Among the various dimensions of foot, foot length is considered to be a better predictor of stature and sex.5,6 However, the regression equations for estimating stature and sectional points for identifying sex are considered to...
be population specific. Due to strong influence of genetic and environmental factors on the height of the individual, homogeneity of the study population is vital in formulating the regression equations.

Although stature and sex studies have been conducted in various populations including Central India, but most of these studies are on ethnically mixed groups. Hence, the present study was planned to create a baseline data for ethnically identical group of residents of Central India for two generations.

Materials and Methods

Sample Size Calculation

The sample size was calculated using the formula for continuous variable

\[ n = N^2X/(1 + X - 1) \]

where \( X = Z_{\alpha/2} \times \sigma / \text{MOE} \), and \( Z_{\alpha/2} \) is the critical value of the normal distribution at \( \alpha/2 \). MOE is the margin of error, \( \sigma \) is the population variance (obtained from previous studies), and \( N \) is the population size.

At confidence level 95% and confidence interval of 5, the minimum recommended sample size is 33 males and 33 females.

Source of Data

Data were collected from 50 males and 50 females between the age group of 20 and 40 years from individuals who are residents of Central India for two generations. The range for age was selected because foot length and height shows growth and increment before 20 years of age and resorption of bone results in reduction of height after 40 years. A resident for two generations means that the individual himself/herself and his/her parents are born and have stayed in Central India.

Method of Data Collection

The study was conducted on the residents of Central India. The objectives and the methods of the study were explained to the participants and informed consent was obtained. All the measurements were taken in a reasonably well-lit room, at a fixed time between 10 a.m. and 2 p.m. to eliminate diurnal variation. It was measured and recorded only by one person, to avoid interobserver variation.

Stature, sex, and anthropometric dimension of foot length of the left and right sides were recorded separately for each subject.

Land marks and technique involved in taking anthropometric measurements are as follows:

**Stature:** It is the vertical distance between point vertex and the floor. The subject stood erect, barefoot on a level floor against the wall with his back and hips touching the wall. The feet ran parallel to each other and the heels touched the wall. Arms hanging by the side. The head of the subject rested without any strain in the eye–ear plane or Frankfurt plane, that is, the tragion and the lower margin of the right orbit must lie in the same plane.

**Foot Length:** It was measured at the direct maximum distance from the most posterior projecting point of the heel (pternion) to the anterior tip of whichever toe yields the longest measurement. The subject was asked to stand on an A4 size blank paper with both the feet at the same level for accuracy in measurement of foot length and in relaxed manner so as to avoid undue pressure. The point of maximum convexity (pternion) of the curve of the heel and tip of the longest toe (irrespective of which toe it is) was marked by a sharp-tip pencil at right angle. Then, the distance between the two above marked points was measured by the ruler in millimeters. Three readings were recorded and the mean of three readings was taken. The same ruler was used for all 100 subjects.

The instruments used in the measurement are:

1. A 12-inch size scale was used for foot length measurements.
2. A stadiometer for stature estimation.

Inclusion Criteria

Apparently healthy, asymptomatic males and females of age group 20 to 40 years.

Exclusion Criteria

Individuals with physical deformities and history of systemic diseases affecting stature (e.g., endocrine and genetic disease) and foot dimensions were excluded from the study.

Age group below 20 years and above 40 years was also excluded.

Statistical Analysis

Data were analyzed by the Statistical Package for Social Sciences 21. Descriptive statistics was performed for the study sample. Comparison of data was done for the right and left sides and for two genders by paired t-test. Subsequently, correlation coefficient was obtained by Pearson’s correlation coefficient between stature and foot length.

Regression equations were formulated for prediction of stature (dependent variable) of an individual from foot length (independent variable) by univariate technique.

Subsequent to ascertaining sexual dimorphism measurements were subjected to discriminant function analyses. The discriminant function \( D \) for the determination of gender from measurement of foot length is given as:

\[ D = b_0 + \sum b_iX_i \]

where \( b_0 \) and \( b_i \) are the coefficients of the discriminant function and \( X_i \) is the foot length dimension. The sex discrimination is done on the basis of sectioning points \( S \) resultant for the discriminant function. An individual is classified as male if the value of the discriminant function \( D \) is greater than \( S \) and as female if the value of \( D \) was lesser than \( S \). Sectional points were derived to predict sexual dimorphism from foot length.

Observations

Following observations were tabulated after statistical analysis of the data recorded in the study. The mean age
of study population was 27.04 years ± 5.42 in males and 25.84 years ± 5.09 in females.

Table 1 shows the descriptive statistics of study parameters in the study population.

The comparison of data of various parameters studied shows that all parameters have higher values in males than in females. Statistical differences between male and female readings were assessed by paired sample t-test. The results of t-test (Table 2) indicate that the differences between males and females were statistically highly significant (p < 0.001). However, the differences between the right and left side were statistically not significant.

Statistically highly significant positive correlation was observed between stature and foot length in males and females (Table 3).

Regression analysis of the study parameters was performed separately for each sex, as statistically significant differences were observed between these two groups. Linear regression equations for estimation of stature using foot length in males and females were derived as follows:

Male: \( \text{STATURE} = 73.155 + 3.732 \times \text{FOOT LENGTH} \pm 4.846 \)
Female: \( \text{STATURE} = 73.991 + 3.494 \times \text{FOOT LENGTH} \pm 4.237 \)

The equations also exhibit standard error of estimate (SEE). The SEE predicts the deviations of estimated stature from the actual stature. A low value of SEE indicates greater reliability in the estimated stature. SEE was found to be 4.846 in males and 4.237 in females for the study population.

Table 4 presents the results of discriminant function analysis for foot length in males and females. When eigenvalue is > 1, the groups are distinct, and hence the model has good discriminating power. Values of Wilk’s lambda range from 0 to 1. Values close to 0 indicate that the groups are distinctly different. Lambda of < 0.5 indicates the solution is statistically significant and acceptable.

Univariate discriminant functional analysis shows that 85.1% of cases in males and 78% of cases in females were correctly classified in their group.

Discussion

Findings of the present study indicate that the foot length was sexually dimorphic. This is consistent with the findings of previous researchers.\textsuperscript{4,5,13,14} This can be ascribed to obvious difference in genetic makeup of male and female and early maturity of girls than boys. This fact necessitates formulation of different regression equations for the two genders and it also opens up an opportunity to utilize these differences for ascertaining sex of an individual.

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**Table 1** Descriptive statistics of parameters studied in males and females

<table>
<thead>
<tr>
<th>Gender</th>
<th>Males</th>
<th></th>
<th></th>
<th>Females</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Height (mm)</td>
<td>Right foot length (mm)</td>
<td>Left foot length (mm)</td>
<td>Height (mm)</td>
<td>Right foot length (mm)</td>
<td>Left foot length (mm)</td>
</tr>
<tr>
<td>Mean</td>
<td>169.52 (155.4–188.7)</td>
<td>25.82 (23.228.4)</td>
<td>25.99 (23.1–28.4)</td>
<td>154.75 (144–169)</td>
<td>23.11 (21–26)</td>
<td>23.23 (21–27)</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>7.02</td>
<td>1.37</td>
<td>1.41</td>
<td>5.76</td>
<td>1.13</td>
<td>1.14</td>
</tr>
</tbody>
</table>

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**Table 2** Paired samples t-test showing statistical difference between males and females

<table>
<thead>
<tr>
<th>Pair</th>
<th>Male right foot length–Female right foot length</th>
<th>Male left foot length–Female left foot length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pair 1</td>
<td>11.032</td>
<td>49</td>
</tr>
<tr>
<td>Pair 2</td>
<td>10.742</td>
<td>49</td>
</tr>
</tbody>
</table>

Abbreviation: df, degrees of freedom.

*Statistically highly significant (p < 0.001).

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**Table 3** Correlation between the stature and foot length in males and females

<table>
<thead>
<tr>
<th>Sex</th>
<th>Foot length</th>
<th>N</th>
<th>Pearson's correlation</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>Foot length</td>
<td>50</td>
<td>0.731</td>
<td>0.000*</td>
</tr>
<tr>
<td>Female</td>
<td>Foot length</td>
<td>50</td>
<td>0.686</td>
<td>0.000*</td>
</tr>
</tbody>
</table>

*Correlation is significant at the 0.01 level (two-tailed) (p < 0.001).

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**Table 4** Canonical discriminant function coefficient for the foot length of males and females

<table>
<thead>
<tr>
<th>Sex</th>
<th>Foot length</th>
<th>Unstandardized coefficient</th>
<th>Constant</th>
<th>Wilk’s lambda</th>
<th>Eigenvalue</th>
<th>Group centroid</th>
<th>Sectioning point</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>Foot length</td>
<td>0.784</td>
<td>~19.193</td>
<td>0.460</td>
<td>1.175</td>
<td>M = 1.040</td>
<td>–0.066</td>
</tr>
<tr>
<td>Female</td>
<td>Foot length</td>
<td>–0.066</td>
<td>–1.106</td>
<td>0.492</td>
<td>1.175</td>
<td>F = –1.106</td>
<td>–0.066</td>
</tr>
</tbody>
</table>

Abbreviations: F, female; M, male.

*Discriminant score less than sectioning point is female.
Highly significant positive correlation was observed between foot length and stature of the individual, indicating the reliability of foot length as a parameter for stature estimation. Several studies have formulated gender-specific regression equation using foot length in different populations.\textsuperscript{6-8,10}

Krishan and Sharma found that the correlation coefficients between stature and all the measurements of hands and feet were positive and statistically significant. They stated that highest correlation coefficient between stature and foot length and lowest SEE indicate that the foot length provides highest reliability and accuracy in estimating stature of an unknown individual.\textsuperscript{8}

A correlation coefficient between height and foot length in Gujarati population was shown to be +0.69 for males and +0.70 for females.\textsuperscript{15} In Sri Lankan population between the same variables, a correlation coefficient of +0.724 for males and +0.719 for females was found which is said to be most significant.\textsuperscript{16}

The present study shows a correlation coefficient of 0.731 for males and 0.686 for females between stature and foot length. SEE was found to be 4.846 in males and 4.237 in females for the study population. A low value of SEE indicates greater reliability in the estimated stature.

Utilization of foot length in determining sex of an individual has also shown reasonably good accuracy. Wunderlich and Cavanagh in a study of 491 females and 293 males of the U.S. Army stated that the dimensions of foot are sexually dimorphic.\textsuperscript{17} The study also pointed that the foot length is a determinant factor in differentiating between the sexes and it has a higher accuracy rate than any other parameter of foot measurement (85.0%). Atamturk in a study on 506 Turks (253 males and 253 females) has reported similar higher accuracy for foot length (84.6%).\textsuperscript{5} The above findings are similar to the present study which has predicted the gender of a person by foot length with accuracy of 78 to 85.1% by discriminant functional analysis.

Findings of many previous studies have indicated that even when all foot and/or shoe dimensions are jointly used the discriminant function varied from 69 to 80.3% among Ghanaians, 79.5 to 89.5% in Western Australians, and 66.7 to 82.4%.\textsuperscript{5,15,11}

Though supremacy of pelvis, clavicle, and scapula for estimation of gender\textsuperscript{2} and that of long bones for estimation of stature\textsuperscript{18} cannot be ignored, it is more likely to come across footprints/isolated body parts during forensic investigation, thus justifying the exploration of foot length as a determinant of stature and sex.

Conflict of Interest
The authors have no conflicts of interest to disclose.

References