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Research Article

# Determination of stature and sex from anthropometry of the foot among south Indians

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**ABSTRACT**

Forensic podiatry deals with human identification from the foot which is of great value during calamities, terror strikes and in crime scenes. This study evaluates the significance of the foot in determining the sex and stature of the person. It presents linear and logistic regression equations for doing the same. The study was conducted on a sample of 300 South Indian medical students over two months. With their consent, stature, foot length, foot breadth at the ball and foot breadth at the heel were measured. Correlation of these measurements with stature and sex was evaluated and linear regression equations to predict the same were derived. It was found that the stature and foot measurements were larger in males compared to those in females. Foot length correlated best with stature ($r^2$=0.657 females, 0.563 males). Foot breadth at heel correlated best with sex of a person ($r^2$=0.915). Multiple regression analysis had better accuracy than simple linear regressions. Stature and sex of a person can be reliably predicted from the measurements of the feet among south Indians using linear and logistic regression analysis.

**Keywords:** Anthropometry; human identification; podiatry; sex; stature.

## INTRODUCTION

Identification of a person plays a vital role during natural calamities, terror strikes, in crime scene and also in our day to day life. The scientific basis for human identification probably dates back to 19$^{th}$ century when Alphonse Bertillon introduced the use of a number of anthropomorphic measurements to identify habitual criminals. Since then there has been a steady change in techniques to the current age of advanced biometrics for human identification (Jain A and Kumar A, 2010). Still no single technique can be universally applicable in all situations. All alternative, flawless, less utilized techniques need to be equally studied. This brings us to forensic podiatry which deals with the application of sound, researched podiatric knowledge and experience in forensic investigations, to show the association of an individual with a scene of crime, or to answer any other legal question concerned with the feet or footwear that requires knowledge of the functioning foot. It is a branch of anthropometry which contributes to the establishment of personal identity in forensic investigation (Krishan K *et al.,* 2011)

Age, sex, stature and race are popularly referred to as the four pillars of identity of a person. Extensive research has been carried out throughout the world to establish these from various parameters of the body and so also the feet. Different parameters of the feet studied by various researchers have successfully shown to correlate with the sex and stature of a person. However the strength of correlation differed significantly in all these studies.

For a given stature the dimensions of the foot are proven to be relatively smaller in females, when compared to those in males (Mukta R *et al.*, 2011; Reena S *et al.,* 2012; Balasuriya P, 1988; Krishan K *et al.,* 2012; Olasunkanmi S, 2009). Female feet are not simply scaled down isometric versions of male feet but rather differ in a number of shape characteristics. A woman's foot has a higher arch, a shallower first toe, a smaller ball of foot circumference, a shorter ankle length, a shorter length of the outside ball of foot, and a smaller instep circumference (Wunderlich RE and Cavanagh PR, 1999). This structural variation can be used to reliably identify the sex of the person. Foot length and foot breadth have been found to be larger in males compared to the females of the same age by an average of 2 cms (Krishan K *et al.,* 2012). Foot breadth has been proved to be a better indicator of sex of a person among all the other measurements studied (Krishan K *et al.,* 2011). Logistic regression models have been previously studied to predict the sex of a person.

Similar studies have been conducted by many researchers to establish the correlation of various dimensions of the feet with stature. Foot length has shown to have the best correlation with height of a person, both

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in males and females. However the strength of correlation varied from $r^2$= 0.849 to $r^2$= 0.496 in various population groups studied (Chikhalkar *et al.,* 2009; Khanapurkar S and Ashish R, 2012; Mukta R *et al.,* 2011; Ozaslan *et al.,* 2012; Ozden *et al.,* 2005). Correlation was found to be better in males compared to females of the study group (Ozaslan A *et al.,* 2012). Linear regression and multiple regression models have been calculated with a variable accuracy in different groups to estimate the stature. Multiple regression analysis was found to estimate stature more reliably than linear regression models (Krishan K *et al.,* 2012).

Anthropometric data have been shown to be highly population specific. Mathematical models created to predict a variable in one population group failed to be accurate in other populations. Indians can widely be divided to constitute at least three groups namely people of north India, eastern India and south India. Most of the data reported till date has dealt primarily with the north Indians.

In this study we have generated anthropometric data from south Indian population groups involving the people of Tamilnadu, Karnataka, Andhra Pradesh and Kerala. The study aimed at determining the correlation of various measurements of the feet with stature and sex. Prediction of sex of a person from logistic regression analysis of the dimensions of the feet has been attempted in our study. Linear regressions for estimation of stature have been derived to suit the south Indian population. The data presented in this study will be of extreme benefit for fellow researchers in forensic science, investigators and legal experts to aid in sex and stature determination of a person from the dimensions of the feet.

## METHODOLOGY

The study was conducted in Shri Sathya Sai Medical College and Research center, Ammapettai, Chennai over a period of two months during June and July 2012. Institutional Ethical committee clearance was obtained in March 2012 prior to the collection of data. A cross sectional sample of 300 Subjects (150 male and 150 female) was randomly selected for the study. Subjects of south Indian origin were selected based on their mother tongue (Tamil, Telugu, Malayalam and Kannada). The participants were informed of the procedure and purpose of the study and informed consent was obtained in writing from all the participants. Participants who refused to give consent were omitted from the study. After collecting the subject particulars in a proforma the following measurements were collected:

### Stature

Stature is the vertical distance between the point vertex (highest point on the head when the head is held in the Frankfurt's Horizontal plane) and the floor. Using the Stadiometer, the subject was made to stand barefoot in the standing position on its baseboard with both feet in close contact with each other and head oriented in Frankfurt's plane. The height was then recorded in centimeters.

### Foot length

Foot length was taken as a straight distance between the most posterior projecting points of the heel (Pternion) to the most anterior projecting point (Acropodion) of the first or second toe, whichever is bigger when the foot is fully stretched.

### Foot breadth at ball

Distance between the joint of the anterior epiphyses of the first metatarsal, the most prominent part of the inner side of the ball of the foot, and the joint of the anterior epiphyses of the fifth metatarsal, the most prominent part of the outer side of the ball of the foot.

### Foot breadth at heel

Distance taken from the lateral side of the heel to the medial side of the heel. Foot length, foot breadth at the ball and foot breadth at the heal were measured on both sides using the sliding calipers. All the measurements were recorded to the nearest millimeter in standing position using standard instruments by a single individual so as to reduce observer error in taking the measurements.

### Inclusion criteria

1. Medical students above 18 years of age studying in Sathya Sai Medical College and Research Center.
2. Subjects of south Indian origin using mother tongue (Tamil, Telugu, Malayalam, and Kannada) as a criteria for origin.

### Exclusion criteria

1. Subjects having any orthopedic deformity, metabolic or developmental disorders which could have affected the general or bony growth.
2. Subjects refusing to give consent for collection of data.

### Statistical Analysis

The data obtained were computed and analyzed using Statistical Package for Social Sciences (SPSS, version 16.0) computer software (SPSS, Inc., Chicago, IL). Descriptive statistics were generated using the software. Pearson's correlation coefficients were calculated to find the correlation between stature and various measurements of the foot. Similar correlation between the sex and various measurements of the foot were evaluated. Linear regression equations for stature and logistic regressions for sex determination from feet measurements were derived.

## RESULTS AND DISCUSSION

Average adult length of the foot is thought to be attained at about 16 years in males and 14 years in

**Table 1: Descriptive statistics of stature and foot dimensions in male and female subjects**

| S No. | Measurement | Males subjects(n=150) | | | | Female subjects(n=150) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Min | Max | Mean | Std. Dev. | Min | Max | Mean | Std. Dev. |
| 1 | Height(cms) | 158.00 | 186.50 | 172.1 | 5.54732 | 146.00 | 174.00 | 159.4 | 5.40915 |
| 2 | RFL (mm) | 225.00 | 290.00 | 254.2 | 13.0070 | 200.00 | 252.00 | 225.7 | 10.5387 |
| 3 | LFL (mm) | 226.00 | 292.00 | 256.7 | 28.3383 | 201.00 | 252.00 | 225.6 | 11.0285 |
| 4 | BBR (mm) | 76.00 | 110.00 | 92.3985 | 6.27133 | 60.00 | 107.00 | 87.5400 | 6.74027 |
| 5 | BBL (mm) | 79.50 | 116.00 | 92.7139 | 8.79845 | 60.00 | 107.00 | 87.5667 | 6.74703 |
| 6 | BHR (mm) | 51.00 | 86.00 | 64.1230 | 6.19440 | 49.00 | 59.00 | 47.6533 | 4.95617 |
| 7 | BHL (mm) | 47.20 | 88.00 | 63.7780 | 6.56763 | 49.00 | 59.00 | 47.7733 | 5.01828 |

**Note: -** RFL- Right foot Length, LFL- Left foot Length, BBR- Breadth at Ball (right), BBL- Breadth at Ball (Left), BHR- Breadth at Heel (right), BHL- Breadth at Heel (Left), Cms- centimeters, mm- Millimeters

**Table 2: Correlation coefficients & logistic regressions for sex determination from various parameters of the foot**

| S. No. | Parameter used | Logistic regression | Correct Prediction % | $R^2$ |
|---|---|---|---|---|
| 1 | Height | S=73.218- 0.442(H) | 88% | 0.747* |
| 2 | Right foot length | S= 55.626- 0.233(RFL) | 88.3% | 0.790* |
| 3 | Left foot length | S= 34.321- 0.143(LFL) | 89.7% | 0.637* |
| 4 | Average Foot length on both side | S= 57.410- 0.240(AFL) | 89.3% | 0.797* |
| 5 | Average of foot breadth at ball on both sides | S= 11.274- 0.125(ABBL) | 68.3% | 0.171* |
| 6 | Average of foot breadth at heal on both sides | S= 41.439 – 0.748(ABHL) | 96% | 0.915* |
| 7 | Height + right foot length+ left foot length | S= 79.313- 0.251(H)- 0.148(RFL)- 0.009(LFL) | 93% | 0.829* |
| 8 | Avg foot length + Avg Breadth at Heel | S= 64.018- 0.122(AFL)- 0.629(ABHL) | 96.3% | 0.931* |
| 9 | Height + Avg foot length + Avg Breadth at Heel | S= 83.525-0.223(H)- 0.062(AFL)-0.568(ABHL) | 95.7% | 0.938* |

**Note: -** Cut off for all the equation is 0.5, i.e. score(S) of < 0.5 indicates male and score of >0.5 indicates female. S- sex, RFL- right foot length, LFL- left foot length, H- height, AFL- avg foot length, ABBL- avg breadth at Ball, ABHL- avg. breadth at heel * P< 0.001

females. By about 18 years of age, the adult stature and foot size are achieved in every one (Krishan K *et al.,* 2011). All the subjects (n=300) involved in the study were above 18 years of age with the average age of the males and females being 19.06 and 19.3 years respectively. Thus all the subjects involved in the study can be assumed to represent the adult population. Since the study was done in Tamilnadu and the subjects were randomly selected, 77.6% (n=233) of the south Indians in the study were Tamlians and the rest belonged to Telugu, Malayalam and Kannada speaking groups.

Descriptive statistics of the stature and foot measurements are presented in table 1. There was no statistically significant difference in the measurements of the feet bilaterally, thus showing symmetry. Males were found to be significantly taller compared to the females in the study with the mean stature being 172cms in males compared to 159cms in females. This could probably be due to earlier closure of the epiphysis in females due to the effect of estrogen leading to a smaller overall bone structure (Krishan K *et al.,* 2011; Mukta R *et al.,* 2011). Except for two subjects none of the males had a height less than 165cms and none of the female subjects had height more than 170cms except for two cases. Foot length, foot breadth at ball and foot breadth at heal were significantly larger in males compared to females. Males had longer and wide based foot compared to females. Researchers studying in other population groups who found similar difference suggest this could be because of heavier bone structure of the male skeleton causing increased weight bearing on the male foot compared to females (Krishan K *et al.,* 2011; Mukta R *et al.,* 2011; Balasuriya P 1988; Krishan K *et al.,* 2012; Wunderlich RE & Cavanagh PR 1999; Khanapurkar S & Ashish R 2012).

This dimorphism in the foot allows us to derive logistic regressions to reliably predict the sex of a person. Logistic regression equations derived to determine the sex of the person from various foot measurements have been presented in table 2. Foot breath at ball showed the least correlation with the sex of the person at $r^2$= 0.171 and only 68.3% correct prediction rates.

Foot breadth at heel gave the best individual correlation with the sex of a person with $r^2$ = 0.915. Findings published by Krishnan *et al.,* (2011 & 2012) also suggest that foot breadth at the heel correlates better than any other factor to discriminate the sex of a person. This could be because of the heel being primarily a weight bearing area of the foot as suggested before.

In males the stature correlated best with foot length ($r^2$= 0.563). However foot breadth at heel did not show any statistically significant correlation with stature. Even in females, the foot length showed the best correlation with stature ($r^2$= 0.657). Multiple regression equations showed better correlation towards the stature of a person compared to any Individual factor taken separately. This was again similar to the findings of Khanapurkar S & Ashish R 2012 in Maharashtra. Foot length showed the best correlation with stature in all the previous reported studies but the strength of its correlation with stature varied widely. Khanapurkar S & Ashish R 2012 showed very high correlation coefficient of $r^2$=0.849 compared to ($r^2$= 0.808) Mukta, R et al. (2011), ($r^2$= 0.614) Ozden et al. (2005), ($r^2$= 0.652) Chikhalkar *et al.,* 2009 & ($r^2$= 0.496) Ozaslan et al. (2012). Correlation of the foot length with stature was better in female Subjects compared to males involved in our study. This shows that the margin of error in prediction is less in females compared to males. This is a finding which is also reported by Danborno B & Elukpo A, 2008 in their study, but no reliable explanation for this variation was given.

**Table 3: Correlation coefficients, Linear and multiple regression formula for estimation of stature (H) in males**

| S. no. | Parameter used | Linear & multiple regressions | S.E | $R^2$ |
|---|---|---|---|---|
| 1 | Right foot length (RFL) | H= 111.0005 + 0.242(RFL) | 7.37 | 0.563* |
| 2 | Left foot length (LFL) | H= 113.73+ 0.229(LFL) | 7.29 | 0.550* |
| 3 | Foot Breadth at Ball (right) (FBBR) | H= 155.52 + 0.179(FBBR) | 6.59 | 0.202** |
| 4 | Foot Breadth at Ball (left) (FBBL) | H= 169.089 + 0.118(FBBL) | 4.74 | 0.188** |
| 5 | Foot Breadth at Heel (right) (FBHR) | H= 165.068 + 0.109(FBHR) | 4.70 | $0.122^{ns}$ |
| 6 | Foot Breadth at Heel (left) (FBHL) | H= 163.77 + 0.130(FBHL) | 4.39 | $0.154^{ns}$ |
| 7 | RFL + LFL | H= 110.736 +0.189(RFL)+0.052(LFL) | 7.40 | 0.564* |
| 8 | RFL+FBHR+FBBR | H= 111.026 + 0.280(RFL) +0.27(FBBR) -0.197(FBHR) | 7.66 | 0.591* |
| 9 | LFL+FBHL+FBBL | H= 111.90 + 0.273(LFL) + 0.035(FBBL) – 0.119(FBHL) | 7.31 | 0.579* |

**Note: -** ***Correlation is significant at p < 0.01, ******** Correlation is significant at p< 0.05, **NS**- Not significant

**Table 4: Correlation coefficients, Linear and multiple regression formula for estimation of stature (H) in females**

| S. No. | Parameter used | Linear & multiple regressions | S.E | $R^2$ |
|---|---|---|---|---|
| 1 | Right foot length (RFL) | H= 83.24 +0.337(RFL) | 7.18 | 0.657* |
| 2 | Left foot length (LFL) | H= 88.305 + 0.315(LFL) | 6.98 | 0.643* |
| 3 | Foot Breadth at Ball (right) (FBBR) | H= 145.81 + 0.155(FBBR) | 5.68 | 0.193** |
| 4 | Foot Breadth at Ball (left) (FBBL) | H= 144.38 + 0.171(FBBL) | 5.65 | 0.214* |
| 5 | Foot Breadth at Heel (right) (FBHR) | H= 145.90 + 0.283(FBHR) | 5.14 | 0.254* |
| 6 | Foot Breadth at Heel (left) (FBHL) | H= 146.004+ 0.280(FBHL) | 4.11 | 0.260* |
| 7 | RFL + LFL | H= 83.244 + 0.256(RFL) + 0.081(LFL) | 7.19 | 0.659* |
| 8 | RFL+FBHR+FBBR | H= 84.40 + 0.340(RFL)- 0.063(FBBR)+ 0.080(FBHR) | 7.43 | 0.662* |
| 9 | LFL+FBHL+FBBL | H= 88.299+ 0.315(LFL)- 0.063(FBBL)+0.116(FBHL) | 7.24 | 0.651* |

**Note: -***Correlation is significant at p < 0.01, ** Correlation is significant at p< 0.05, NS- Not significant.

Multiple logistic regression equations predicted sex of the person better compared to logistic regressions equations using individual factors. This is found to be as suggested by Khanapurkar S & Ashish R 2012. Correlation with the sex was best ($r^2$= 0.938) when a combination of height, average foot length and average foot breadth at heel was considered. The findings were statistically significant at P< 0.001.

We can see from the data presented that there is a statistically significant difference among the dimensions of the foot in males and females. Hence for estimation of stature from various parameters of the feet, the data was analyzed separately for males and females. These are presented in tables 3 & 4.

## CONCLUSION

The present study concludes that foot measurements among South Indians correlate well with the stature and sex of a person. Some other reliable conclusions derived from the study are that foot breadth at heel has the best correlation with sex of a person and can be accurately used in predicting the sex of a person. Foot length correlates best with the stature of a person. Correlation of these factors with stature is better in females compared to males. Considering multiple factors together in estimation of stature or determination of sex from the foot yields better accuracy than when these factors are considered separately. This study presents some very important anthropometric data from South Indian population which will be of significant benefit in Forensic human identification.

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