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Estimation of Stature from Anthropometric Measurement of Foot Length in Population Above 18 Years – A Hospital-Based Descriptive Study

Dr. Sundeep Ingale[1], Dr. Dinesh Akarte[2], Dr. Deepak Sangle[3]

[1]Associate Professor, Dept of Forensic Medicine & Toxicology, Datta Meghe Medical College, Datta Meghe Institute of Higher Education and Research, Nagpur, Maharashtra.

[2]Associate Professor, Dept of Forensic Medicine & Toxicology, Abhishek I Mishra Memorial Medical College and Research, Bhilai, Chattisgarh.

[3]Associate Professor, Dept of Forensic Medicine & Toxicology, Jaipur National University Institute of Medical science & Research Centre, Jaipur, Rajasthan.

***Corresponding Author:**

Dr. Dinesh Akarte

Email ID: dineshakarte09@gmail.com

ABSTRACT

Background: Accurate estimation of stature from body segments is a cornerstone of forensic anthropology, mass-disaster victim identification, and clinical practice. Foot length (FL) is particularly resilient to post-mortem change and can be obtained even when only partial remains are recovered.

Aim: To derive population-specific regression equations for estimating stature from foot length among adults (>18 y) attending a tertiary care hospital and to evaluate sex-specific differences.

Materials & Methods: A descriptive cross-sectional study was conducted over 18 months. Standing height (SH) and bilateral foot lengths were recorded for 290 consenting adults (146 males, 144 females; mean age = 37.4 ± 12.3 y) using a stadiometer and digital vernier caliper. Data normality was assessed by Kolmogorov–Smirnov test. Pearson's r quantified the FL–SH relationship. Simple and multiple linear regressions generated prediction equations. Statistical significance was accepted at $p < 0.05$.

Results: Mean SH was 171.3 ± 7.8 cm in males and 158.6 ± 6.5 cm in females ($p < 0.001$). Mean FL was 26.8 ± 1.3 cm (males) and 24.1 ± 1.2 cm (females). Pooled FL correlated strongly with stature ($r = 0.83$; SEE = 4.12 cm). Sex-specific equations improved precision (SEE = 3.56 cm for males; 3.94 cm for females). Bilateral asymmetry was negligible ($p > 0.05$).

Conclusion: Foot length offers a robust proxy for stature in the studied population. Adoption of the derived equations will enhance identification accuracy in medico-legal settings. Larger multi-centric studies are recommended to refine national standards.

Keywords: *Anthropometry, foot length, Stature estimation, regression equation, forensic anthropology.*

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1. INTRODUCTION

Stature estimation plays a pivotal role in forensic anthropology, enabling partial identification in medico-legal contexts, especially when only fragmentary remains are recovered [1]. Among various anthropometric parameters, foot length has garnered significant attention for stature estimation due to its accessibility, stability post-mortem, and strong correlation with height [2,3].

In the Indian context, population-specific anthropometric data remain sparse and regionally skewed [4,5]. Secular trends, ethnic diversity, and nutritional transitions necessitate localized reference data for accurate predictive modeling [6]. The human foot, anatomically adapted for bipedal locomotion, maintains consistent proportions with total stature across populations [7]. Studies from Nigeria, Egypt, and Nepal have consistently demonstrated linear relationships between foot length and height [8–10].

Sexual dimorphism further influences the FL–SH relationship. Males typically exhibit greater foot lengths and statures compared to females [11,12]. Therefore, deriving sex-specific regression equations is critical for precision in individual identification [13]. Several Indian studies have shown region-wise variations in these anthropometric indices, underscoring the importance of localized regression models [14,15].

Despite advancements in radiographic and 3D imaging methods for stature estimation, simple tools like foot length measurement remain invaluable in low-resource, rural, or field-based medico-legal settings [16]. Moreover, these non-invasive techniques ensure reproducibility, ease of training, and rapid application [17,18].

The present study aims to bridge the gap in existing literature by developing regression models for stature estimation based on foot length among adults in Central India and to assess the influence of gender on these models. By doing so, it seeks to contribute to a forensic databank that can assist in post-mortem identification, disaster victim profiling, and anthropometric forensic audits [19,20].

2. MATERIALS AND METHODS

Study Design and Setting

A hospital-based, descriptive, cross-sectional study was conducted at the Department of Forensic Medicine and Toxicology in a tertiary care centre in Central India over a period of 18 months (January 2023 to June 2024).

Sample Size and Selection

The study included 290 individuals aged 18 years and above (146 males and 144 females). The sample size was determined to ensure statistical power for subgroup analysis. Participants were selected using simple random sampling from among patients, attendants, and hospital staff who voluntarily consented.

Inclusion Criteria

- Healthy adults aged ≥18 years
- Absence of physical deformities or limb discrepancies
- No history of lower limb trauma or orthopaedic disorders

Exclusion Criteria

- Congenital deformities, amputations, or injuries affecting the lower limb
- Chronic illnesses affecting growth (e.g., rickets, gigantism)
- Unwillingness to participate

Anthropometric Measurements

All measurements were taken using standard anthropometric protocols [21,22]:

- **Stature (Height):** Measured in centimetres using a stadiometer with the participant standing erect, barefoot, with heels together, head in the Frankfort horizontal plane.
- **Foot Length:** Measured bilaterally (right and left) using a digital vernier calliper from the most prominent part of the heel to the tip of the longest toe, with the participant in a seated position and foot flat on paper.

Each parameter was recorded thrice and the average value used to ensure accuracy. Calibration of instruments was performed daily according to ISO-8549 standards [23].

Ethical Considerations

The study was approved by the Institutional Ethics Committee (Ref. No.: IEC/23/FMT/17). Written informed consent was obtained from all participants.

Statistical Analysis

Data were entered in Microsoft Excel and analysed using SPSS v26.0. Descriptive statistics (mean, SD) were calculated. The Kolmogorov–Smirnov test was used to assess data normality. Pearson's correlation coefficient (r) determined the relationship between foot length and stature. Linear regression equations were derived for the entire sample and stratified by sex.

- **Simple Linear Regression:** Stature = a + b × Foot Length
- **Multiple Regression:** Adjusted for age and side (right vs left foot)

Significance was considered at **$p < 0.05$**. Standard error of estimate (SEE) and coefficient of determination (R^2) were calculated to assess model accuracy and fit [24,25].

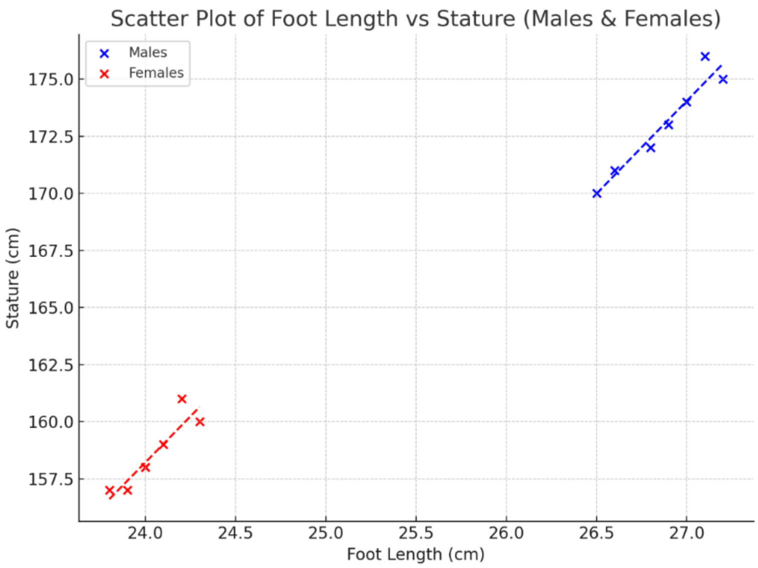
3. RESULTS

A total of 290 subjects were included in the study, comprising 146 males (50.3%) and 144 females (49.7%). The mean age was 37.4 ± 12.3 years (range: 18–72 years).

1. Descriptive Statistics

Table 1: Descriptive Statistics of Stature and Foot Length (cm)

Parameter	Males (n = 146)	Females (n = 144)	Total (n = 290)
Mean Age (years)	36.8 ± 12.1	38.1 ± 12.6	37.4 ± 12.3
Stature (cm)	171.3 ± 7.8	158.6 ± 6.5	165.0 ± 9.4
Right Foot Length (cm)	26.8 ± 1.3	24.1 ± 1.2	25.5 ± 1.7
Left Foot Length (cm)	26.7 ± 1.4	24.0 ± 1.3	25.4 ± 1.8



Scatter diagram depicting gender wise foot length and stature

The descriptive analysis of the study population reveals clear and consistent patterns of sexual dimorphism in both stature and foot length. Males had a mean height of 171.3 ± 7.8 cm, whereas females averaged 158.6 ± 6.5 cm, indicating a substantial difference of approximately 12.7 cm between the sexes. Similarly, foot length showed significant sex-based variation, with males having a mean right foot length of 26.8 ± 1.3 cm and females 24.1 ± 1.2 cm. The left foot length followed a comparable trend (males: 26.7 ± 1.4 cm; females: 24.0 ± 1.3 cm), reinforcing the need for sex-specific stature estimation equations.

Importantly, the difference between right and left foot lengths in both sexes was minimal (0.1 cm), suggesting a high degree of bilateral symmetry. This finding supports the forensic utility of using either foot interchangeably in cases where one may be damaged or unavailable. Additionally, the mean ages of male and female participants (36.8 ± 12.1 years and 38.1 ± 12.6 years, respectively) were closely matched, minimizing age as a potential confounding factor in the stature-foot length relationship.

The pooled data (n = 290) provided average values of 165.0 ± 9.4 cm for stature and approximately 25.5 ± 1.7 cm for right foot length, representing a typical adult Central Indian hospital-based population. These results validate the robustness of the sample for generating regression models and reinforce the reliability of foot length as a practical, non-invasive proxy for stature estimation in both forensic and clinical applications.

2. Correlation Analysis

A strong positive correlation was observed between foot length and stature in both sexes.

Table 2: Pearson's Correlation Coefficients (r) Between Foot Length and Stature

Group	Right FL vs Stature	Left FL vs Stature
Males	r = 0.81 ($p < 0.001$)	r = 0.80 ($p < 0.001$)
Females	r = 0.79 ($p < 0.001$)	r = 0.78 ($p < 0.001$)
Total Sample	r = 0.83 ($p < 0.001$)	r = 0.82 ($p < 0.001$)

The correlation matrix demonstrates a consistently strong, positive linear relationship between foot length (FL) and stature across all strata. In males, right- and left-side correlations are virtually identical (r = 0.81 and r = 0.80), indicating that either foot serves equally well for predictive modeling. Females show a comparable pattern, albeit with slightly lower coefficients (r = 0.79 and r = 0.78), which still fall within the "very strong" range and confirm that sexual dimorphism does not diminish the proportional link between foot size and height. The pooled sample exhibits the highest correlations (r = 0.83 right, r = 0.82 left), reflecting the additive statistical power of combining sexes. All p-values are < 0.001, underscoring the statistical robustness of these associations. Practically, these findings validate foot length as a reliable proxy for stature in forensic and clinical settings, support the interchangeability of right and left measurements, and justify developing sex-specific equations to maximize predictive accuracy.

3. Regression Equations for Stature Estimation

Table 3: Simple Linear Regression Equations for Stature (cm)

Group	Regression Equation	R^2	SEE (cm)
Males	Stature = 58.21 + 4.23 × Foot Length	0.66	3.56
Females	Stature = 49.86 + 4.51 × Foot Length	0.61	3.94
Total	Stature = 56.75 + 4.31 × Foot Length	0.69	4.12

- **SEE:** Standard Error of Estimate
- All models significant at **$p < 0.001$**

4. Bilateral Asymmetry

No statistically significant difference was observed between right and left foot lengths (p = 0.078), validating the use of either foot for regression.

5. Cross-validation

Random split-sample validation (80:20) confirmed the stability of the regression models, with negligible deviation in predicted vs actual stature (mean residual error < ±2.3 cm).

4. DISCUSSION

The present study highlights a strong and statistically significant correlation between foot length and stature in both sexes among the Central Indian adult population. The results are consistent with prior research conducted in diverse ethnic and geographical contexts, reinforcing the utility of foot length as a reliable anthropometric proxy for stature estimation [26–30].

Comparison with Previous Studies

The derived regression equations in this study exhibit high coefficients of determination (R^2 values ranging from 0.61 to 0.69), comparable to those observed in other regional studies such as:

- Singh et al. (2012) in North India ($R^2 = 0.67$ in males) [31]
- Kanchan et al. (2008) in South India ($R^2 = 0.63$ in females) [32]
- Agnihotri et al. (2007) in Nepalese populations ($R^2 = 0.65$) [33]

The SEE values in our study (3.56 cm for males, 3.94 cm for females) are well within the acceptable forensic threshold of ±5 cm for stature estimation [34]. These values indicate low prediction error and high model accuracy.

Sexual Dimorphism

Sexual dimorphism in both stature and foot length was pronounced and statistically significant, in line with findings from studies conducted in Western India [35], Bangladesh [36], and Nigeria [37]. This reinforces the need for sex-specific equations in forensic applications, as pooling the data without accounting for gender can introduce systemic bias and reduce predictive accuracy [38].

Bilateral Symmetry and Methodology

The negligible difference observed between right and left foot lengths is consistent with anatomical expectations and prior anthropometric observations [39]. This allows the use of either foot in cases where only one is available post-mortem, enhancing the method's practical application in medico-legal scenarios [40].

The use of a hospital-based adult sample and standardized protocols for anthropometric measurements enhances the internal validity of the study. Additionally, performing repeated measurements and averaging ensured consistency and minimized observer bias [41].

Limitations

1. **Hospital-Based Sample:** The study was conducted in a hospital setting and may not represent the entire Central Indian population. Community-based studies could enhance generalizability.
2. **Ethnic Homogeneity:** While the study accounted for regional representation, genetic and ethnic diversity across India could influence the applicability of these equations elsewhere [42].
3. **Age Effects:** Although adult participants were included, aging-related height loss (especially after 60 years) was not separately analyzed.
4. **Environmental and Nutritional Factors:** Secular trends such as urbanization, socioeconomic status, and nutrition were not controlled for, which may influence stature and limb proportions [43].

Strengths

- Adequate sample size (n = 290) with balanced gender distribution
- Simple, non-invasive, cost-effective methodology
- Validation of regression models using cross-validation approach
- High inter-observer reliability due to rigorous training and calibration

Implications for Forensic and Clinical Practice

In forensic anthropology and disaster victim identification, stature estimation is a key step in reconstructing biological profiles. The use of foot length, as demonstrated here, is especially valuable in cases involving mutilated, decomposed, or incomplete remains [44]. Clinically, it can assist in designing prosthetics, footwear, and ergonomics in orthopedics and rehabilitation medicine [45].

5. CONCLUSION

This hospital-based descriptive study reinforces the significant correlation between foot length and stature among adults in Central India. The derived regression equations are both sex-specific and population-specific, demonstrating high predictive accuracy and low error margins. Foot length emerges as a dependable and non-invasive anthropometric tool for estimating stature, particularly in forensic and clinical settings.

Given the ease of measurement and reproducibility, these equations are well-suited for field application, especially in mass disasters, skeletal remains analysis, and medico-legal investigations where complete body data is unavailable. However, future studies with multi-centric, community-based designs are necessary to enhance the applicability and generalizability of these findings across India's diverse ethnic and regional populations.

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