Forensic and Clinical Utility of Lower Limb Measurements in Stature Estimation and Prosthetic Design: Evidence from an Adult Population in Uttar Pradesh

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Introduction

Stature estimation is a fundamental component of forensic anthropology and clinical practice, providing critical information for identifying individuals when complete skeletal remains are unavailable or in cases of limb loss [1]. The lower limbs—comprising the femur, tibia, fibula, and foot—play a significant role in determining stature due to their proportional contribution to overall body height [2]Anthropometric measurement of these bones involves precise techniques. Linear dimensions such as femoral length, tibial length, and foot length are recorded using standard osteometric tools like measuring tapes, spreading calipers, and osteometric boards. Careful measurement of both right and left sides ensures accuracy and allows for the assessment of bilateral symmetry [3].

Clinically, these measurements have substantial applications. They guide the design and fitting of prosthetic limbs, ensuring optimal comfort, mobility, and load distribution for amputees [4]. Additionally, accurate lower limb data are crucial in reconstructive surgery, orthopedics, and rehabilitation planning, allowing customized interventions tailored to individual morphometry [5].

Forensically, lower limb measurements enable reliable estimation of stature, which is often the first step in constructing a biological profile in medico-legal investigations, mass disasters, or archaeological studies [6]. Population-specific data are especially important because limb proportions vary with ethnicity, region, and environmental factors, affecting both forensic predictions and prosthetic design [7].

The novelty of this study lies in its focus on an adult population from Uttar Pradesh, India, where limited anthropometric data are available. By providing region-specific measurements and assessing their correlation with stature, the study not only enhances forensic stature estimation models but also informs clinical prosthetic design and rehabilitation protocols tailored for the local population [8].

Aim and Objectives

1. To measure right and left foot length, foot breadth, and lower limb length in adults of Uttar Pradesh.
2. To compare male and female differences in these parameters.
3. To determine the correlation between stature and each measurement.
4. To develop regression equations for stature estimation using these parameters.
5. To evaluate bilateral differences and identify the most reliable predictors.

MATERIALS AND METHOD

This was a cross-sectional observational study conducted at the Department of Anatomy, Uttar Pradesh University of Medical Sciences, Saifai. A total of 500 healthy adults (308 males and 192 females) aged 17–50 years, all native to Uttar Pradesh, were included. Ethical clearance was obtained prior to data collection.

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Inclusion Criteria:

1. Age between 17 and 50 years.

2. Native residents of Uttar Pradesh.

3. Asymptomatic and healthy individuals.

4. Individuals willing to participate with informed consent.

Exclusion Criteria:

1. Age below 17 or above 50 years.

2. History of stature or lower limb injuries.

3. Congenital anomalies

4. Severe surgeries.

Sample Size Calculation :

$$n = \left(\frac{Z \times \sigma}{d}\right)^2$$

Where,

n = required sample size

Z = Z-score corresponding to desired confidence level (typically 1.96 for 95% confidence)

σ = estimated standard deviation (from pilot study or previous research)

d = allowable error or precision

Assumptions based on previous research or pilot study:

Z = 1.96 (for 95% confidence)

σ = 6.5 cm (standard deviation of stature) d = 0.6cm (acceptable margin of error

$$n = \left(\frac{1.96 \times 6.5}{0.6}\right)^2 = \left(\frac{12.74}{0.6}\right)^2 = (21.23)^2 = 450.4$$

Based on a standard deviation of 6.5 cm from previous literature, a 95% confidence level, and a precision of 0.6 cm, the minimum required sample size was calculated to be approximately 451. To enhance statistical power the sample size was rounded up to 500 participants.

Materials Used :

1. Stadiometer (precision 0.1 cm) used for accurate measurement of standing height. (Fig 5.1)

2. Flexible measuring tape for assessing lower limb length. (Fig 5.2)

3. Digital camera to document subject posture and methodology.

4. Digital vernier calliper (precision 0.01 mm) to ensure precise measurement of smaller anthropometric landmarks. (Fig 5.3)

5. Logbook to systematically record participant data and measurement

6. Anthropometric proforma for standardized data entry and analysis preparation.

7. DSLR Camera for capturing the photo.

Examination Process :

1. Each participant was examined under standardized conditions to ensure precision in anthropometric measurements.

2. Subjects were instructed to wear normal clothing and remove footwear.

3. They were evaluated in a well-lit environment with a stable, level surface for standing measurements.

4. All measurements were taken on both side of the body to maintain consistency.

5. Participants were guided through each posture required for accurate landmark identification.

6. Each reading was taken three times to ensure reproducibility, and the mean was recorded for final analysis.

Measurements :

1. Foot Length

Measured from the most posterior point of the heel to the tip of the hallux or second toe. (Fig 1)

2. Foot Breadth

Measured as the distance between the medial aspect of the first metatarsal head and the lateral aspect of the fifth. . (Fig 2)

All measurements were performed under standardized anthropometric protocols. Each parameter was measured thrice, and the mean value was recorded to minimize observer error. Measurements were taken bilaterally to assess asymmetry.

Ethical standards

This study was conducted in accordance with the ethical principles of the Declaration of Helsinki (2013 revision). Ethical clearance was obtained from the Institutional Ethics Committee (IEC) of Uttar Pradesh University of Medical Sciences (UPUMS), Saifai, Etawah prior to initiation of the study. All participants were informed in detail about the nature, purpose, and procedures of the study in a language they could understand. Written informed consent was obtained from each participant before enrolment. Confidentiality and anonymity of patient information were strictly maintained at all stages of data collection, analysis, and reporting. Patients were assured that their participation was voluntary and that refusal or withdrawal would not affect their medical care.

Data Analysis

Statistical Analysis Data will be entered into a standardized study proforma and analyzed using SPSS (30th Version). Statistical tools to be applied include:

1. Mean and Standard Deviation (SD).

2. Pearson’s correlation coefficient (r).

3. Chi-square test for categorical variables.

4. Significance level set at $p < 0.05$

Figure 1: Measurement of Foot Length Foot length measured from the most posterior point of the heel to the tip of the hallux (big toe) or second toe.

Figure 2: Measurement of Foot Breadth Foot breadth was measured as the linear distance between the medial aspect of the head of the first metatarsal

bone and the lateral aspect of the head of the fifth metatarsal bone using Vernier caliper

Results

Table 1 : Distribution of study participants by gender.

Gender	Number of Participants
Male	**308**
Female	**192**
Total	**500**

Figure 3: Bar diagram showing the number of male and female participants in the study.

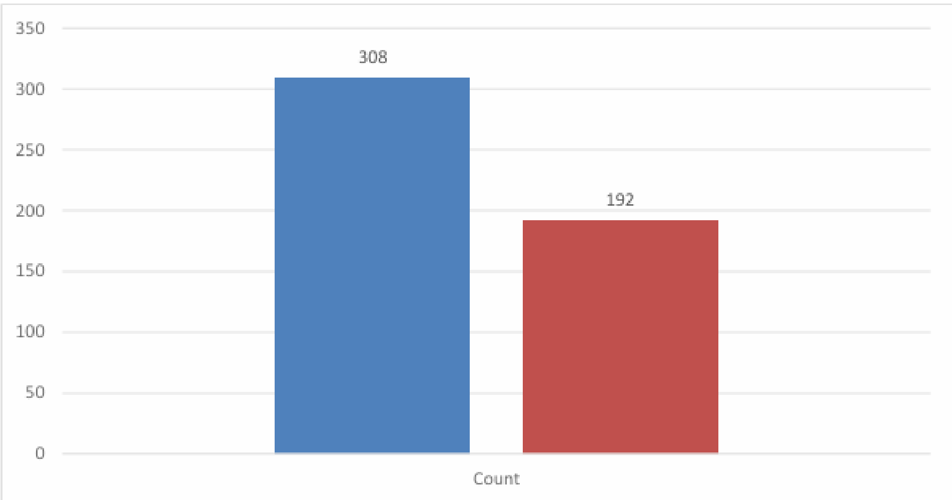

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Table 2 : Table showing mean age and std dev in different age groups in our study

Age Group	Number of Particpants	Mean Age	Standard Deviation
17 - 25	345	21	2.1
26 - 34	94	30	2.7
35 - 43	441	38	2.8
44 - 50	17	47	2.3

Figure 4 : Bar diagram showing mean age and std dev in different age groups in our study

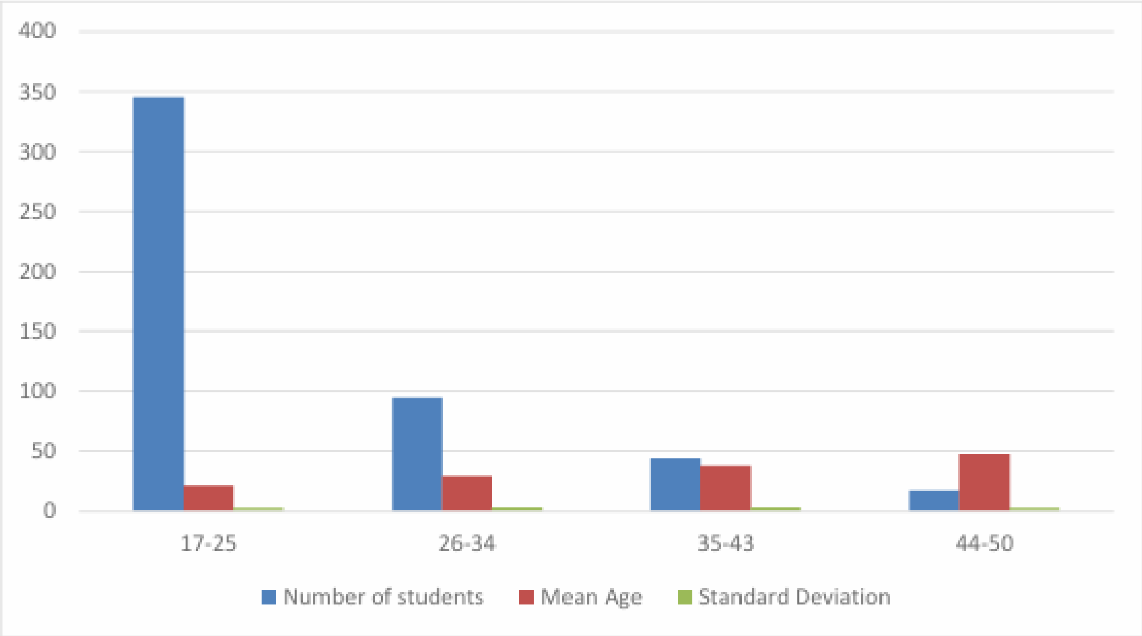

Table 3 : Mean and standard deviation (in cm) of stature and lower limb parameters measured on both sides in 500 individuals.

Parameter	Mean	Standard Deviation (cm)
Foot Length Right	24	21
Foot Length Left	24	5
Foot Breadth Right	9	1
Foot Breadth Left	10	35

Fig 5 : Bar Representation of Mean and standard deviation (in cm) of stature and lower limb parameters measured on both sides in 500 individuals

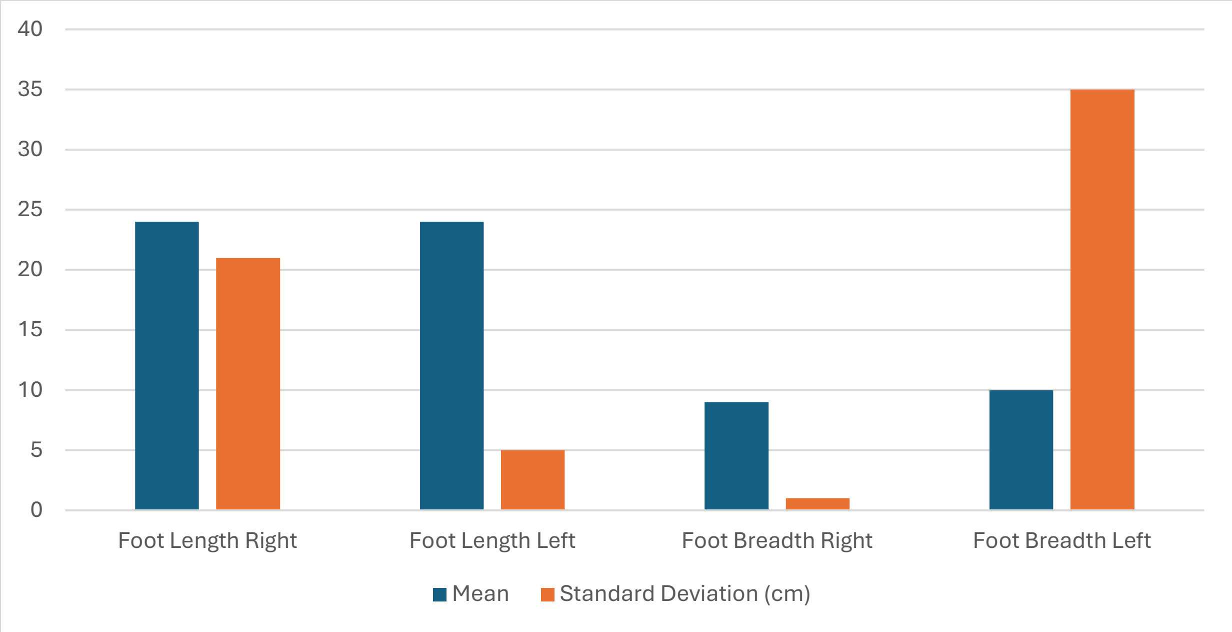

Table 4 : Table showing Pearson correlation coefficients between height and various lower limb parameters. All parameters demonstrate a positive correlation with height. This suggests that as height increases, all the parameters mentioned also increases.

Parameter	Correlation with Height (r)
Right Foot Length	0.4589
Left Foot Length	0.6289
Right Foot Breadth	0.4955
Left Foot Breadth	0.5158

The right foot length demonstrated a correlation of 0.4589 with height. This moderate association supports previous findings that longer feet often accompany taller stature, although the strength of correlation is less than that observed with long bones. (Table 4)

Interestingly, left foot length had the strongest correlation with height among all parameters (r = 0.6289), indicating that it may be a particularly useful measurement for predicting stature in this study population. (Table 4)

Right foot breadth had a lower but still positive correlation of 0.4955, suggesting a modest relationship with stature. Although not as strong as linear bone measurements, foot breadth still reflects some proportional association with height. (Table 4)

Lastly, the left foot breadth had a slightly higher correlation (r = 0.5158), again demonstrating moderate association. Its positive correlation suggests that foot breadth measurements may add value when combined with other parameters for stature estimation (Table 4)

Discussion

In the present study, left foot length showed the highest correlation with stature (r = 0.6289), followed by foot breadth and right foot length. This emphasizes the superiority of length over breadth in stature estimation. Similar findings have been reported across Indian populations. **Dhaneria et al. (2016)**[9] in Rajasthan observed that foot length (r = 0.756) correlated more strongly with stature than foot breadth (r = 0.624), supporting our observation that length is a more reliable predictor of height in anthropometric analysis.

Mild asymmetry was noted in our study, with left foot length (r = 0.6289) correlating more strongly with stature than right foot length (r = 0.4589). This is consistent with the findings of **Kamboj et al. (2018)** [10] in Barabanki, Uttar Pradesh, where left foot length demonstrated slightly better predictive accuracy for height than the right. Such asymmetry, though subtle, highlights the practical utility of bilateral assessment in forensic and clinical contexts.

A high correlation between foot length and stature has also been demonstrated in other Indian studies. **Agnihotri (2007)** [11] reported a strong relationship ($r = 0.877$) in North Indian subjects, confirming the robustness of foot length as a predictor of height. Similarly, **Kanchan et al. (2008)** [12], working on a Gujjar population in North India, found foot length to be the most reliable indicator in males, whereas foot breadth was more predictive in females. These regional variations underline the importance of population-specific regression models.

Our findings are further supported by **Krishan et al. (2011)** [13], who demonstrated that foot length provided more accurate stature estimates than breadth among sub-adult females in North India. More recently, **Jain et al. (2020)** [14] in Central India developed regression equations based on foot anthropometry and confirmed the positive and significant correlation between stature and foot length, consistent with our results.

Beyond Indian populations, international studies have consistently validated the reliability of foot length in stature estimation. For example, Egyptian [Abdel-Malek et al., 1990][15], Nigerian [Igbigbi et al., 2018][16], and Turkish populations [Sanli et al., 2005] [17] all demonstrated stronger correlations between foot length and stature compared to breadth, highlighting its universal applicability in forensic anthropology and prosthetic design.

Taken together, the current study corroborates existing literature by establishing that foot length particularly left foot length is a reliable predictor of stature. The consistency of these findings across diverse populations underscores the forensic and clinical utility of foot measurements in reconstructing biological profiles and in designing region-specific prosthetic devices

Conclusion

The present study demonstrates that lower limb measurements, particularly foot length, show a significant positive correlation with stature, with the left foot length emerging as the most reliable predictor in the adult population of Uttar Pradesh. These findings highlight the forensic utility of foot measurements in biological profiling, especially in situations where long bones are unavailable for analysis. In addition, the results underscore the clinical relevance of foot dimensions in designing ergonomically appropriate prosthetics, orthotics, and footwear tailored to regional anthropometric profiles. The consistency of our results with both national and international studies strengthens the evidence base for applying foot-based parameters in stature estimation, medico-legal investigations, and prosthetic design. Future research with larger multi-ethnic cohorts and advanced predictive models may further refine these applications and enhance their accuracy.

Limitations

It was restricted to adults aged 17–50 years, and the results may not be generalizable to children, adolescents, or elderly individuals with age-related stature changes. Nutritional and occupational influences on body proportions were not controlled, and the sample was confined to a single geographic region (Uttar Pradesh), limiting wider applicability. Future studies with larger, multi-regional samples and integration of digital imaging techniques could provide more generalizable and precise models.

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