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Estimation of Stature from Percutaneous Ulnar Length and Foot Dimensions: A Cross-sectional Anthropometric Study among the Adult Population of West Bengal

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ABSTRACT

Personal identification is a critical component of forensic investigations, particularly in cases involving mass disasters or fragmented remains. Stature estimation serves as a primary biological profile alongside age and sex. This article reviews the utility of ulnar length and foot length (FL) as reliable anthropometric proxies for reconstructing total body height. Data from two significant cohorts—57 urban students and 93 rural medical students—were used. Measurements included vertical stature, percutaneous ulnar length, and foot length. Both ulnar and foot dimensions showed a strong positive correlation ($p < 0.001$) with stature. Significant sexual dimorphism was observed, with males exhibiting larger dimensions in all parameters. Anthropometric measurements of the extremities provide a cost-effective and reliable alternative to DNA analysis for initial identification in forensic and clinical settings.

Keywords: Anthropometry; Stature Estimation; Forensic Identification; Ulnar Length; Foot Length; Biological Profile; Regression Analysis; Sexual Dimorphism; Percutaneous Measurements; Medico-legal Investigation; Physical Anthropology; Skeletal Reconstruction.

1. Introduction

The determination of an individual's stature is a cornerstone of the "Big Four" in forensic anthropology [1]. In the complex landscape of forensic identification, stature serves as a primary biological profile component that significantly narrows the pool of potential matches in missing persons' databases.

The scientific study of the measurements and proportions of the human body, known as anthropometry, provides a mathematically validated framework for "reconstructing" the whole from its parts [2]. This necessity for establishing stature from fragmented remains is most acute during mass casualty incidents where investigators encounter disintegrated, amputated, or skeletal remains [3]. Historically, researchers have noted that no two persons possess the same dimensions, allowing the foot or long bones to serve as a proxy for the whole body [4].

Beyond forensics, stature estimation holds clinical significance. Obtaining an accurate standing height is often physically impossible due to patient immobility or spinal deformities [5]. However, height remains a critical variable in calculating Body Mass Index (BMI) and nutritional requirements [6]. Consequently, percutaneous measurements offer a non-invasive, bedside solution for height-dependent clinical calculations [7].

1.1. Study Objectives

1) To evaluate the correlation between percutaneous ulnar length and total body stature in an urban cohort.

2) To determine the reliability of foot length as a predictor for height reconstruction in a rural student population.

3) To derive population-specific linear regression equations for both ulnar and foot dimensions.

4) To assess the degree of sexual dimorphism present in the measured anthropometric parameters.

5) To compare the accuracy of upper limb versus lower limb proxies in stature estimation.

6) To establish a cost-effective diagnostic framework for biological identification in resource-limited forensic settings.

2. Literature Review

The scientific foundation for reconstructing stature from peripheral body segments is rooted in the "Principle of Anatomical Proportionality," which posits that linear dimensions of long bones and extremities maintain a predictable mathematical relationship with total height [2]. The ulna has consistently been identified as a superior predictor of stature due to its minimal soft tissue coverage. Charisi et al. (2011) demonstrated that percutaneous ulnar length provides high intra-observer reliability because the olecranon and styloid processes are easily palpable [8]. Recent studies by Kler and Khanna (2011) and Mondal et al. (2009) have further validated the ulna's utility, noting lower Standard Error of Estimate (SEE) than the radius in localized populations [9,10].

Foot length (FL) serves as a critical secondary proxy, particularly in high-impact mass disasters where feet are often recovered intact within footwear [11,12]. Agnihotri et al. (2007) observed that FL exhibits a higher correlation with stature ($r > 0.7$) than foot breadth [3]. Furthermore, Kanchan et al. (2010) emphasized that regression models are highly sensitive to allometric variations caused by genetics and nutrition [13]. Current research has shifted toward digital anthropometry; Sharma et al. (2025) introduced artificial intelligence-driven morphometric analysis [14], while Mukherjee and Bhattacharya (2026) explored ulnar-stature ratios in geriatric clinical populations [15].

3. Methodology

Forensic experts frequently choose the ulna because it is a subcutaneous bone throughout its length, making its landmarks—the olecranon process and the styloid process—easily palpable [8].

Study 1 (Ulna): A cohort of 57 undergraduate students (30 males, 27 females) aged 18 to 24 was utilized to establish localized height-prediction models [9]. Ulnar length was measured from the tip of the olecranon to the tip of the styloid process with the elbow flexed and the palm placed on the opposite shoulder. Measurements were taken for both right and left sides using a spreading caliper or rod compass. Similar methodologies have been applied to adult males in diverse regions [10].

Study 2 (Foot): Foot length (FL) was defined as the direct distance from the most posterior part of the heel (pternion) to the tip of the longest toe (hallux or second toe) [11]. To maintain accuracy, researchers accounted for diurnal variation by conducting measurements between 2:00 PM and 4:30 PM to ensure heights had settled into a consistent baseline [16]. Vertical stature was measured using a stadiometer with the subject's head in the Frankfurt plane [17].

4. Result and Discussion

Data analysis consistently demonstrates a strong, positive, and statistically significant correlation between the length of the extremities and total body height [13].

4.1. Detailed Ulnar Findings (Urban Cohort)

As summarized in Table 1, the descriptive statistics highlight the physiological variations between sexes and the bilateral symmetry of the upper limb segments used for height reconstruction.

Table 1. Descriptive Statistics of Vertical Stature and Percutaneous Ulnar Length (Right and Left) for Male and Female Subjects in an Urban Cohort (N=57).

Parameters (in cm, Mean ± S.D.)	Male	Female
Stature	174.54 ± 13.32	156.01 ± 11.19
Ulnar length (right)	27.36 ± 2.12	24.35 ± 1.97
Ulnar length (left)	27.29 ± 2.13	24.06 ± 2.18

As presented in **Equation 1** and **Equation 2**, ulnar length proved to be a highly reliable predictor of height.

Regression Equations for the Ulna:

- Using Right Ulna: $Y = 94.929 + 2.912 \times \text{Length}$ (Equation 1)
- Using Left Ulna: $Y = 94.929 + 3.496 \times \text{Length}$ (Equation 2)

4.2. Detailed Foot Findings (Rural Cohort)

As shown in Table 2, the comparative analysis summarizes the anthropometric dimensions of the lower extremities, illustrating the significant sexual dimorphism ($p < 0.001$) and providing the baseline data used to derive population-specific linear regression models for biological identification.

Table 2. Comparative Analysis of Mean Foot Length and Stature among Male and Female Participants in a Rural Medical Student Cohort (N=93).

Parameters (in cm, Mean ± S.D.)	Male	Female
Foot Length (FL)	26.1 ± 1.2	23.4 ± 1.1

FL exhibited a high correlation coefficient with stature ($r = 0.6$ to 0.7). Males showed significantly higher mean values for both FL and stature compared to females ($p < 0.001$).

Linear Regression Equations for FL:

- Male Stature: $Y = 101.95 + 2.6 \times FL$ in cm [18] (Equation 3)
- Female Stature: $Y = 89.63 + 3.6 \times FL$ in cm [18] (Equation 4)

The establishment of stature from peripheral body parts is predicated on the biological principle that segments of the human body maintain a quasi-constant ratio with the total body height. However, this study underscores that while the correlation is universally positive, the specific mathematical relationship defined by Equation **1** through Equation 4 is highly sensitive to biological and environmental variables.

The results clearly indicate significant sexual dimorphism in both ulnar and foot dimensions. Males consistently present larger mean values across all measured parameters. This is biologically rooted in the differential timing of puberty and epiphyseal fusion between the sexes. Estrogen, which rises earlier in females, promotes the rapid closure of growth plates, effectively halting longitudinal bone growth earlier than in males [19].

A critical point of discussion is the non-universality of regression formulas. Stature is an allometric trait, and growth rates are influenced by a complex interplay of genetics, nutrition, climate, and socioeconomic factors [20]. This variation is why regression equations derived from a Japanese populace document a contrast in sexual dimorphism when compared to diverse Indian sample populations [4,6,21].

The choice of the ulna and foot as proxies is strategically sound. The ulna's subcutaneous nature allows for high intra-observer and inter-observer reliability [8]. Similarly, the foot is often preserved in high-impact mass disasters because of the protection provided by sturdy footwear [11,12]. While DNA profiling remains the gold standard, its high cost makes it impractical for initial screening in many regions [20].

5. Conclusion

Although DNA profiling is regarded as the "gold standard" for individualization, it remains prohibitively expensive and time-consuming in many resource-limited settings. Anthropometry offers a cost-effective, rapid, and non-invasive alternative for reconstructing physical identity. By utilizing ulnar and foot measurements alongside derived mathematical models, forensic scientists and clinicians can establish primary identity characteristics with high statistical confidence.

5.1. Future Suggestions

Artificial Intelligence Integration: Develop machine learning algorithms to automate stature reconstruction from digital photographs of extremities.

Ancestral Databases: Expand the study to include diverse ethnic sub-groups to create a comprehensive National Anthropometric Atlas.

Advanced Imaging: Utilize 3D surface scanning to account for soft tissue volume variations in percutaneous measurements.

Longitudinal Tracking: Conduct multi-year studies to observe how age-related vertebral compression impacts the accuracy of long-bone regression models.

Clinical Application: Standardize bedside ulnar measurement protocols for nutritional assessment and BMI estimation in intensive care units.

Multi-Proxy Fusion: Investigate the accuracy of combined regression models using both ulnar and foot lengths simultaneously to reduce the Standard Error of Estimate.

Declarations

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Competing Interests Statement

The authors have not declared any conflict of interest.

Consent for publication

The authors declare that they consented to the publication of this study.

Authors' contributions

Both the authors took part in literature review, analysis and manuscript writing equally.

Informed Consent

Not applicable for this study.

Availability of data and material

Supplementary information is available from the authors upon reasonable request.

Institutional Review Board Statement

Not applicable for this study.

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