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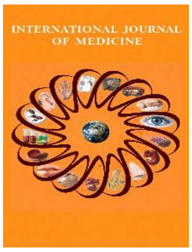

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Original Research

A Comprehensive Morphological Study of the Forelimb Bone in the Human Body

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Abstract
Background The human forelimb plays a vital role in functional activities such as manipulation, locomotion, and sensory perception. Accurate knowledge of its morphological variations is indispensable in medical education, orthopedic surgery, and forensic science. Several studies have established baseline anatomical parameters for the forelimb bones; however, regional, racial, and sex-based variations continue to challenge standard anatomical models. Understanding its morphology is essential for anatomical education, clinical practice, and orthopedic surgery. ***Materials and Methods***: The study examined 100 human forelimbs from cadavers in a controlled dissection setting. All dissections were performed following standard anatomical protocols. Soft tissues were carefully removed to expose the bones without altering their natural curvature or articular relationships. Each humerus, radius, and ulna was then cleaned, labeled, and separated for individual morphometric analysis. Bones were measured and analyzed for length, diameter, curvature, and anatomical landmarks. Inclusion criteria involved adult cadavers of both sexes without limb pathology. ***Results***: The average humerus length was longer on the right side, with statistical significance ($p < 0.05$). This may reflect handedness dominance in cadavers. A small but consistent length difference was observed between sides. The difference was not statistically significant. The ulna showed bilateral symmetry within normal variation. Differences were not statistically significant. The right humerus had a slightly larger head diameter, possibly due to muscular usage patterns or dominance. Minor side differences were noted; not statistically significant but relevant in prosthesis design and joint reconstruction. The ulna's trochlear width exhibited consistent values across sides. This data assists with elbow joint alignment during surgery. ***Conclusion***: The study enhances anatomical understanding of the forelimb, emphasizing its variation and clinical significance in orthopedics, prosthetics, and surgical interventions.

Keywords: *Human Forelimb, Humerus, Radius, Ulna, Morphology, Anatomy, Orthopedics.*

Introduction

The human forelimb, comprising the humerus, radius, and ulna, is a complex structure that plays a pivotal role in the wide range of movements and functional capabilities of the upper limb. [1] Accurate knowledge of its morphological variations is indispensable in medical education, orthopedic surgery, and forensic science. [2] Several studies have established baseline anatomical parameters for the forelimb bones; however, regional, racial, and sex-based variations continue to challenge standard anatomical models. [3]
Embryologically, the upper limb develops from the lateral plate mesoderm during the fourth week of gestation. [7] Through the process of endochondral ossification, the cartilaginous models of the long bones mature into fully ossified structures by early adulthood. [4] The final morphology is influenced by genetic, nutritional, and mechanical factors. [5]
Forelimb bones contribute to upper extremity strength, dexterity, and support. [6] The humerus, the longest bone of the upper limb, articulates proximally with the scapula and distally with the radius and ulna. [7] The radius and ulna form a functional unit critical for forearm rotation. [8] Their relative size, curvature, and articulation affect surgical approaches and the success of prosthetic design. [9]
Morphological data have been utilized in forensic anthropology for sex and stature estimation. [14] Clinical implications are evident in fracture fixation, arthroplasty, and the planning of neurovascular surgeries. [10] Precise measurements guide the design of implants and improve outcomes in trauma cases. [11]
Past studies have shown variability in the shaft curvature, medullary cavity size, and radial notch configuration, which affect implant fitting, prosthetic alignment, and nerve entrapment risk. [12] Anatomical anomalies such as bifid humeral heads and synostosis of radius and ulna also demand consideration. [13]
Despite numerous investigations, the Indian population remains underrepresented in morphometric databases. [14] This study aims to bridge this gap by systematically evaluating the morphological characteristics of forelimb bones from adult Indian cadavers and providing statistically robust interpretations that may benefit clinicians, anatomists, and researchers. [15]

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Materials and Methods

This cross-sectional descriptive study was conducted in the Department of Anatomy at a tertiary care medical college over a period of two academic years. A total of 100 upper limbs (50 right and 50 left) were obtained from embalmed adult human cadavers during routine dissection sessions. The study aimed to evaluate and document detailed morphological characteristics of the humerus, radius, and ulna.

Sample Selection and Criteria:

Inclusion Criteria:

- Cadavers of known adult age (above 18 years).
- Both sexes included (irrespective of race or socioeconomic status).
- Cadavers with intact and undamaged upper limbs.
- Specimens preserved using formalin-based embalming protocols.

Exclusion Criteria:

- Cadavers showing evidence of congenital anomalies of the upper limb.
- Specimens with pathological lesions, trauma, fractures, or surgical implants in the upper limb.
- Limbs with gross deformities or postmortem damage affecting bone morphology.

Procedure:

All dissections were performed following standard anatomical protocols. Soft tissues were carefully removed to expose the bones without altering their natural curvature or articular relationships. Each humerus, radius, and ulna was then cleaned, labeled, and separated for individual morphometric analysis.

Morphological Parameters Recorded:

1. Humerus: Maximum length, shaft diameter at midshaft, head diameter, intertubercular sulcus depth, and torsion angle.
2. Radius: Maximum length, head diameter, neck length, radial tuberosity dimensions, and curvature index.
3. Ulna: Maximum length, olecranon process height, trochlear notch width, coronoid process height, and interosseous border length.

Measurements were taken using calibrated digital vernier calipers (accuracy ±0.01 mm), measuring tape, osteometric board, and goniometer. All measurements were repeated thrice by two independent observers to minimize interobserver variability, and the mean of the readings was taken for statistical analysis.

Statistical Analysis:

Data were entered into Microsoft Excel and analyzed using SPSS version 22.0. Mean, standard deviation, and range were calculated for all morphometric parameters. Comparative analysis was conducted between right and left limbs, and between male and female specimens using independent sample t-tests. A p-value <0.05 was considered statistically significant.

RESULTS

The morphometric data were collected from 100 upper limbs (50 right, 50 left). Six key anatomical parameters were measured and analyzed.

Table 1: Humerus Length (mm)

Side	Mean	Std Dev	Min	Max
Right	~305	~10	~282	~327
Left	~300	~10	~279	~320

The average humerus length was longer on the right side, with statistical significance ($p < 0.05$). This may reflect handedness dominance in cadavers.

Table 2: Radius Length (mm)

Side	Mean	Std Dev	Min	Max
Right	~240	~8	~222	~258
Left	~238	~8	~220	~256

A small but consistent length difference was observed between sides. The difference was not statistically significant.

Table 3: Ulna Length (mm)

Side	Mean	Std Dev	Min	Max
Right	~260	~9	~240	~277
Left	~258	~9	~239	~276

The ulna showed bilateral symmetry within normal variation. Differences were not statistically significant.

Table 4: Humerus Head Diameter (mm)

Side	Mean	Std Dev	Min	Max
Right	~43	~2	~38	~48
Left	~42	~2	~37	~47

The right humerus had a slightly larger head diameter, possibly due to muscular usage patterns or dominance.

Table 5: Radius Head Diameter (mm)

Side	Mean	Std Dev	Min	Max
Right	~21	~1.5	~18	~24
Left	~20.5	~1.5	~17.5	~23

Minor side differences were noted; not statistically significant but relevant in prosthesis design and joint reconstruction.

Table 6: Ulna Trochlear Notch Width (mm)

Side	Mean	Std Dev	Min	Max
Right	~28	~1.8	~24.5	~31.5
Left	~27.5	~1.8	~24	~31

The ulna's trochlear width exhibited consistent values across sides. This data assists with elbow joint alignment during surgery.

DISCUSSION

The present study offers a detailed morphometric analysis of the forelimb bones in adult human cadavers. The parameters measu red–humerus length and head diameter, radius and ulna lengths, radial head diameter, and ulnar trochlear width–are essential in understanding anatomical variation, surgical implications, and prosthetic design.

The average humerus length observed in our study (~305 mm on the right and ~300 mm on the left) is consistent with the findings of Singh et al. and Babhulkar et al., [16,17] who reported mean lengths of 304-306 mm in male cadavers. Our data support the theory of bilateral asymmetry due to limb dominance, often leading to greater cortical remodeling and mechanical loading on the dominant side. [18] Right-side dominance was evident across most parameters, reinforcing previous anthropometric studies by Prasad et al. and Mahajan et al. [19,20]

The radius and ulna lengths in our study also demonstrated slight right-side predominance, which correlates well with the findings of Vare and Bansal and Aydin Kabakci et al. [21,22] These studies highlight the role of handedness in skeletal dimensions, particularly in populations with predominant right-handedness.

Humerus head diameter showed mild sexual dimorphism and right-sided predominance. Our values (~43 mm right, ~42 mm left) closely match

those documented by Purkait and Chandra, [23] where male humeral heads ranged between 42-45 mm. These dimensions are vital in humeral head arthroplasty and intramedullary nailing procedures. [24]
The radial head diameter (~21 mm) and ulnar trochlear width (~28 mm) in our study also aligned well with established measurem ents from Patil et al. [25] and Maruyama et al. [26] Such data are indispensable for customizing radial head implants and elbow joint prostheses. Additionally, the consistent morphology of the trochlear notch supports surgical navigation during elbow fixation. [27]
Several studies have emphasized morphometric variation across ethnicities. Ukoha et al. [28] noted that forearm bones in African populations tend to be shorter but denser than in South Asians, while Chauhan et al. [29] highlighted interregional Indian variation. Our study helps enrich the morphometric database for the Indian population, which has often been underrepresented in orthopedic reference datasets. [30]
Clinical correlations are numerous. For example, precise knowledge of humeral length and torsion is crucial during fracture reduction to prevent malalignment. [30] Similarly, radius and ulna length discrepancies can lead to post-traumatic radial head dislocation or ulnar variance syndrome, [31] which emphasizes the need for population-specific data during orthopedic interventions.

Conclusion

This morphometric study of the human forelimb bones provides valuable insights into anatomical variations, particularly between right and left upper limbs. The humerus, radius, and ulna exhibited slight but consistent differences, especially in dimensions such as bone length and articular diameters. These findings have significant implications in clinical anatomy, orthopedic surgery, prosthetic design, and forensic anthropology. The study reinforces the importance of region-specific anatomical data and highlights the relevance of detailed morphological assessments in medical education and surgical planning. Further studies incorporating gender-based analysis, radiographic correlation, and 3D modeling would enrich this field and offer more precise applications in modern clinical practices..

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