



Morphometric Analysis of the Dried Humerus: An Osteological Study

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ABSTRACT

The humerus, as the largest bone of the upper limb, plays a crucial role in clinical orthopedics, forensic anthropology and anatomical research. Accurate morphometric analysis of its segments is essential for designing implants, managing fractures, reconstructive surgeries and estimating stature from skeletal remains-particularly in forensic scenarios where bones may be fragmented. This study aimed to examine specific morphometric parameters of dry adult humeri from the South Delhi population and assess their correlation with total humeral length to provide region-specific reference data. Fifty adult humeri (25 right and 25 left) were measured using standard osteometric instruments at the Department of Anatomy, HIMSR, Jamia Hamdard. Parameters included transverse and vertical diameters of the humeral head, distances to anatomical landmarks, bicipital groove dimensions, intercondylar widths and measurements of the trochlea, capitulum and olecranon fossa. Data were analyzed statistically using SPSS, with significance set at $p < 0.05$. Most parameters showed no significant bilateral differences, except for the breadth and depth of the bicipital groove and the distance from the articular segment to the greater tuberosity. A moderate positive correlation ($r^2 = 0.247$) was found between one segmental measurement and humeral length. Comparative analysis with previous Indian and international studies highlighted regional anatomical variability, emphasizing the importance of localized data in clinical and forensic contexts. In conclusion, this study provides valuable morphometric data for the North Indian population that can enhance orthopedic surgical planning, forensic stature estimation and anthropological assessments. These findings reinforce the necessity of population-specific anatomical reference models for accurate application in medical and legal investigations.

INTRODUCTION

The humerus, the long bone of the upper arm, is the largest and longest bone of the upper limb and plays a central role in upper extremity movement and structure. Anatomically, it spans from the shoulder to the elbow and consists of two expanded ends-the proximal and distal extremities-connected by a cylindrical shaft. At its proximal end, the rounded head of the humerus articulates with the glenoid cavity of the scapula, forming the glenohumeral (ball-and-socket) joint. This joint allows for extensive range of motion at the shoulder, while the distal end contributes to the elbow joint, which is comparatively more stable^[1,2].

The proximal humerus comprises several key anatomical landmarks: the head, anatomical neck and the greater and lesser tubercles. The hemispherical head is demarcated from the shaft by the anatomical neck. The lesser tubercle, located anteriorly, is separated from the more prominent greater tubercle by the intertubercular (bicipital) groove. Inferior to these is the surgical neck, a clinically important area that is prone to fractures due to its relatively narrow diameter and transitional position.

The shaft, or diaphysis, is a vertically oriented, elongated tube that connects the proximal and distal ends. Its length and shape are largely determined by the activity of the metaphyseal growth plates, influenced by both genetic and environmental factors. Consequently, variations in humeral length contribute significantly to overall body stature.

At the distal end, the humerus articulates with the radius and ulna, forming the elbow joint. This region features the medial and lateral epicondyles, which provide attachment sites for major forearm muscles involved in wrist and hand movement. The broader and curved articular surfaces at the distal humerus accommodate dynamic joint movements and load transmission.

Humeral fractures are common across all ages, particularly involving the proximal end, although injuries can also affect the shaft or distal region. In cases of complex trauma or avascular necrosis, prosthetic replacement may be necessary. Successful surgical intervention, especially in joint reconstruction, requires precise morphometric data to ensure that prostheses restore normal biomechanics and range of motion.

Beyond its clinical importance, the humerus is invaluable in forensic anthropology. It is frequently used in the estimation of an individual's stature, age and sex when skeletal remains are analyzed. Research has consistently shown that humeral length correlates strongly with overall body height. This has made the bone a critical tool in forensic investigations, especially when other major long bones such as the femur or

tibia are not available. Steele's work supports the use of the humerus for stature estimation in such scenarios.

However, skeletal morphology is subject to temporal and population-specific changes. As noted by Salles *et al.*^[3] modern human populations are generally taller than their historical counterparts, necessitating updated regression models tailored to contemporary demographics. This underscores the importance of using current and region-specific data to enhance the accuracy of anthropometric estimations.

Among the various statistical techniques employed, regression analysis remains the gold standard for estimating stature from long bones. It is particularly useful not only for complete bones but also for fragmented remains, allowing predictions of total bone length from partial measurements.

One of the earliest methodologies for estimating total bone length from fragments was introduced by Muller, who identified distinct segments of the humerus based on anatomical landmarks and muscle insertion points. Building on this framework, the present study collected six specific linear measurements along the humeral shaft to evaluate their correlation with total bone length^[4]:

- **AF (MHH):** Maximum humeral height-distance from the most proximal point of the humeral head to the most distal point of the trochlea
- **AB (H1):** Distance from the most proximal point of the articular surface to the top of the greater tuberosity
- **AC (H2):** Distance from the most proximal point of the humeral head to the anatomical neck
- **DE (H3):** Distance from the top of the olecranon fossa to the most proximal point along its margin
- **EF (H4):** Distance from the base of the olecranon fossa to the trochlea
- **DF:** Distance from the upper margin of the olecranon fossa to the top of the trochlea

By applying regression equations to these measurements, this study aims to establish their predictive value for determining overall humeral length. The findings are expected to serve as updated reference data for both forensic and clinical use, particularly in cases where the humerus is incomplete or fragmented.

MATERIALS AND METHODS

This morphometric study was conducted from 2021 to 2022 in the Department of Anatomy, Hamdard Institute of Medical Sciences and Research (HIMSR), Jamia Hamdard, New Delhi, following ethical clearance from the Institutional Ethical Committee. The objective was to analyze morphometric parameters of dry adult



Fig. 1: Osteometric board



Fig. 2: Measuring tape and vernier caliper (digital)

humeri from the South Delhi population and correlate them with humeral length to establish anatomical relationships relevant in clinical, anthropological and forensic contexts. A total of 50 dry adult humeri (25 right-sided and 25 left-sided) were selected from the Bone Bank. Inclusion criteria comprised complete, unbroken adult humeri in good condition, while bones that were broken, incomplete, or poorly preserved were excluded to ensure the accuracy and reliability of the measurements.

Morphometric parameters and measurement techniques: All measurements were obtained using standard osteometric instruments, including an osteometric board, vernier calipers, measuring tape and weighing scale. The morphometric parameters assessed included transverse diameter of the head of humerus (HHTD), vertical diameter of the head of humerus (HHDV), distance between the most proximal point on the articular segment of the humeral head to the most proximal point of the greater tuberosity (HH-MPP-AS to MPP-GT) and distance between the most proximal point of the humeral head and the surgical neck (HH-MPP-HH-SN). Additional measurements encompassed bicipital groove dimensions (length, breadth and depth), presence or absence of supratrochlear ridge, intercondylar transverse measurement (ITTM), transverse and anteroposterior diameters of the trochlea (TROCH-TR and TROCH-AP) and capitulum (CAP-TR and CAP-AP), olecranon fossa length and breadth and total length and dry weight of each humerus (Fig. 1-8).



Fig 3: Weighing machine



Fig 4: Transverse diameter head of humerus



Fig 5: Vertical diameter head of humerus



Fig. 8: Breadth of olecranon fossa



Fig. 6: Intercondylar Measurements



Fig.7: Transverse measurements of trochlea

Statistical analysis: The collected data were subjected to statistical analysis using the Statistical Package for

the Social Sciences (SPSS). Mean values and percentages were calculated using Microsoft Excel. Regression analysis was applied to determine correlations between various morphometric parameters and total humeral length. All measurements were expressed in millimeters and statistical significance was determined at $p < 0.05$.

RESULT

The present study was conducted on a total of 50 adult dry humeri, comprising 25 from the right side and 25 from the left side, to assess various morphometric parameters.

The transverse diameter of the head of the humerus showed a mean value of 32.14 ± 2.26 mm on the right side and 32.30 ± 43.00 mm on the left side. The p -value for this parameter was 0.828, indicating no statistically significant difference between the right and left sides. These findings are presented in Table 1.

For the vertical diameter of the head of the humerus, the mean value on the right side was 39.568 ± 2.82 mm, while on the left side it was 40.704 ± 3.00 mm. The calculated p -value was 0.175, suggesting no significant difference between the two sides. These values are shown in Table 2.

Regarding the distance between the most proximal point on the articular segment of the humeral head to the most proximal point of the greater tuberosity (HH-MPP-AS to MPP-GT), the mean value was 6.44 ± 0.56 mm for the right side and 6.32 ± 0.67 mm for the left side. Interestingly, the p -value for this parameter was 0.000, indicating a statistically significant difference between the two sides. These findings are summarized in Table 3.

Continuing the morphometric analysis, the distance between the most proximal point of the head of the humerus and the surgical neck (HH-MPP-HH-SN) was measured. The mean value for the right-sided

humeri was 39.56±2.82 mm, while for the left side it was 40.70±0.175 mm. The p-value was 0.175 for both sides, indicating no statistically significant difference. These results are detailed in Table 4.

Further analysis was conducted on the Bicipital Groove (BG), evaluating its length, breadth, depth and the presence or absence of the supratrochlear ridge. For the right-sided humeri, the mean length was 22.6±2.68 mm, breadth was 9.04±1.62 mm and depth was 5.9±1.29 mm. The supratrochlear ridge was absent in 11 cases (44%) and present in 14 cases (56%). For the left-sided humeri, the mean length was 23.7±3.17 mm, breadth was 7.6±1.49 mm and depth was 4.6±1.05 mm. The supratrochlear ridge was absent in 6 cases (24%) and present in 19 cases (76%).

Statistical analysis revealed that the breadth and depth of the bicipital groove showed significant differences between the right and left sides, with p-values of 0.002 and 0.001, respectively. However, the length of the bicipital groove did not show a statistically significant difference between sides (p = 0.216). The presence or absence of the supratrochlear ridge was not significantly different between sides (p = 0.13). These observations are presented in Table 5.

The Intercondylar Transverse Measurement (ITTM) was evaluated for both right and left-sided humeri. The mean value for the right humeri was 48.86±6.56 mm, which was identical to that of the left humeri (48.86±6.56 mm). The p-value was 1.000, indicating no statistically significant difference between the sides. These findings are presented in Table 6.

Measurements of the trochlea included both the transverse (TR) and anteroposterior (AP) diameters. For the right humerus, the mean transverse diameter was 20.8±2.35 mm and the anteroposterior diameter was 22.33±3.89 mm. Identical measurements were observed on the left side as well, with the transverse

and anteroposterior diameters being 20.8±2.35 mm and 22.33±3.89 mm, respectively. The p-values for both parameters were 1.000, confirming that there was no significant difference between the right and left sides. These results are summarized in Table 7.

Further morphometric analysis was conducted on the capitulum of the humerus, specifically evaluating its transverse and anteroposterior (AP) diameters. The mean transverse diameter was 18.1±3.50 mm on both the right and left sides, while the mean anteroposterior diameter was 23.6±3.71 mm on both sides. The p-values for both transverse and AP measurements were 1.000, indicating no statistically significant difference between the right and left humeri. These results are presented in Table 8.

Measurements of the olecranon fossa included both its length and breadth. The mean length was found to be 19.4±2.02 mm on both the right and left sides and the breadth measured 22.4±3.53 mm on both sides as well. The p-values for both parameters were 1.000, showing no significant difference between the two sides. These findings are summarized in Table 9.

Table 1: Transverse diameter of head of humerus-[TDHH]

N= no. of humerus	Right side of humerus	Left side of humerus
Mean value	32.14±02.26	32.30±43.00
p-value	0.828	0.828

Table 2: Vertical diameter of humerus head-[VDHH]

N= no of humerus (n= 50)	Right side humerus (n= 25)	Left side humerus (n= 25)
Mean value	39.568±2.82	40.704±3.00
P value	0.175	0.175

Table 3: Distance between the most proximal point on articular segment of humeral head to most proximal point of greater tuberosity [HH-MPP-AS-TO-MPP-GT]

N = no of humerus (50)	Right side humerus	Left side humerus
Mean value/S.D	6.44±0.56	6.32±0.67
p-value	0.000	0.000

Table 4: Distance between the most proximal point of head humerus and surgical neck of humerus [HH-MPP-HH-SN]

N = no of humerus (n = 50)	Right side humerus	Left side humerus
Mean value/S.D	39.56±2.82	40.70±0.175
p-value	0.175	0.175

Table 5: Measurements of bicipital groove [BG]

N = no of humerus (n = 50)	Right side humerus (n = 25)					Left side humerus (n = 25)				
	Length	Breadth	Depth	A	p-value	Length	Breadth	Depth	A	p-value
Mean value	22.6±2.68	9.04±1.62	5.9±1.29	11(44.0%)	14(56.0%)	23.7±3.17	7.6±1.49	4.6±1.05	6(24.0%)	19 (76.0%)
p-value	.216	0.002	0.001	0.13		0.216	0.002	0.001		0.13

Table 6: Intercondylar transverse measurement [ITTM]

N = no of humerus (n= 50)	Right side humerus (n = 25)	Left side humerus (n = 25)
Mean value	48.86±6.56	48.86±6.56
P-value	1.000	1.000

Table 7: Transverse and antero-posterior measurement of trochlea [TR, AP]

N = no of humerus (n = 50)	Right side humerus (n = 25)		Left side humerus (n = 25)	
	Transverse	Antero posterior	Transverse	Antero posterior
Mean Value	20.8±2.35	22.3±3.89	20.8±2.35	22.3±3.89
p-value	1.000	1.000	1.000	1.000

Table 8: Transverse and ap measurement of capitulum [CAP- TR, AP]

Mean value	Transverse	Antero posterior	Transverse	Antero posterior
		18.1±3.50	23.6±3.71	18.1±3.50
p-value	1.000	1.000	1.000	1.000

Table 9: Measurements of olecranon fossa.. [o-f length and breadth]

N = no of humerus (n = 50)	Right side humerus (n = 25)		Left side humerus (n = 25)	
	Length	Breadth	Length	Breadth
Mean value	19.4±2.02	22.4±3.53	19.4±2.02	22.4±3.53
P-value	1.000	1.000	1.000	1.000

Table 10: Descriptive statistics of length of humerus

N = no. of humerus	Right side humerus	Left side humerus
Length of humerus	281.5±3 6.76	287.42±22.11
P-value	0.088	0.088

Table 11: Descriptive statistics of weight of dry humerus

N = no of humerus (n = 50)	Right side humerus (n = 25)	Left side humerus (n = 25)
Mean value	58.90 ±21.61	73.62±21.63
p-value	0.088	0.088

In our present study, we observed that the mean transverse diameter of the capitulum in the right-sided humerus was 18.128 mm, while the anteroposterior diameter measured 23.656 mm. In the left-sided humerus, the transverse diameter was also 18.128 mm, showing no difference between sides. The p-value for both transverse and anteroposterior measurements was 1.000, indicating no statistically significant difference between the right an.

The length of the humerus was also analyzed in this study. For the right-sided humeri, the mean length was recorded as 281.5±3.76 mm, while the left-sided humeri showed a mean length of 287.42±22.11 mm. The p-value was 0.088, indicating that the difference in length between the two sides was not statistically significant. These findings are presented in Table 10.

The weight of the dry humerus was assessed next. The mean weight of the right-sided humerus was 58.90±21.61 grams, whereas the left-sided humerus had a mean weight of 73.62±21.63 grams. The p-value, again, was 0.088, suggesting no significant difference in the mean weight between the right and left humeri. These results are summarized in Table 11.

A correlation analysis was conducted to assess the relationship between the length of the humerus and the distance between the most proximal point on the articular segment of the humeral head to the most proximal point of the greater tuberosity on the left side humerus. As shown in Fig. 1, a positive linear correlation was observed, with a coefficient of determination (R²) value of 0.247, suggesting a moderate correlation. This indicates that as the distance from the articular segment to the greater tuberosity increases, there is a corresponding increase in the overall length of the left humerus.

A correlation analysis was conducted to assess the relationship between the length of the humerus and the distance between the most proximal point on the articular segment of the humeral head to the most proximal point of the greater tuberosity on the left side humerus. As shown in Fig. 1, a positive linear correlation was observed, with a coefficient of determination (R²) value of 0.247, suggesting a

moderate correlation. This indicates that as the distance from the articular segment to the greater tuberosity increases, there is a corresponding increase in the overall length of the left humerus.

DISCUSSION

The humerus is acknowledged as one of the longest bones in the human body and is the longest and largest bone of the upper limb. Its anatomical and forensic relevance is well established, particularly in anthropological and medico-legal contexts where it is often employed for the identification of individuals and for estimating stature through segmental measurements. Numerous studies have confirmed a strong correlation between the length of the humerus and the height of an individual, making it a reliable indicator for stature estimation. Furthermore, these measurements exhibit notable variations influenced by racial, ethnic, sex-related and regional factors, both within and across national boundaries. Such variations are critical in understanding population-specific characteristics and play a fundamental role in assessing overall body size, sexual dimorphism and general health status.

Segmental measurements of the humerus are of considerable importance in various applied fields. For instance, in clinical orthopaedics, these parameters assist in the design of prostheses and implants tailored to specific populations. They are equally significant in surgical planning, particularly in the management of humeral fractures where precise anatomical knowledge is essential for optimal outcomes.

In the present study conducted in Delhi, India, the maximum transverse diameter of the head of the humerus was measured at 32.14±2.26 mm on the right side and 32.30±3.00 mm on the left side. Statistical analysis revealed no significant difference between the two sides (p = 0.828). These values were comparatively lower than those reported in previous studies conducted in other regions of India. For instance, Kabacki *et al.*^[5] in Bihar recorded values of 39.21 mm (right) and 36.91 mm (left); Chatterjee *et al.*^[6] reported 38.29 mm and 38.66 mm, respectively. Chatterjee *et al.*^[6] observed values of 39.99 mm (right) and 39.53 mm (left), while Chatterjee *et al.*^[6] reported 38.94 mm and 35.37 mm. Further, Sinha *et al.*^[7] documented 39.06 mm and 41.43 mm, Jahan *et al.*^[8] measured 38.18 and 38.85 mm and Lokanadham *et al.*^[9] recorded 37.78 and 35.92 mm, for the right and left sides respectively^[10,11].

Maximum vertical diameter of the head of humerus:

The present study observed that the maximum vertical diameter of the head of the humerus was 36.62 ± 3.52 mm on the right side and 40.07 ± 2.79 mm on the left side. When compared to previous research, significant variations were noted. Studies conducted by Hertzog *et al.*^[4], Kabakci *et al.*^[5], Sinha *et al.*^[7], Jahan and Srivast^[8] and Lokanadham *et al.*^[9] reported higher values for this parameter than those recorded in our study. However, Chatterjee *et al.*^[6] reported lower values. These differences were found to be statistically significant ($p < 0.001$), indicating that regional and ethnic factors may contribute to the anatomical variations in the vertical diameter of the humeral head. For instance, Kabakci *et al.*^[5] recorded diameters of 43.04 mm (right) and 41.96 mm (left), while Chatterjee *et al.*^[6] found values of 38.29 mm (right) and 38.66 mm (left). Shirin Jahan's study in Kanpur noted 41.63 mm (right) and 38.89 mm (left). On the other hand, the study by Moumita Chatterjee in Kolkata reported smaller values of 32.66 mm (right) and 29.06 mm (left). The significant discrepancies in vertical diameters observed between the current study and previous literature underscore the anatomical diversity across different regions and populations in India.

Distance between the most proximal point on the articular segment of the humeral head to the most proximal point of the greater tuberosity:

The distance between the most proximal point on the articular segment of the humeral head and the most proximal point of the greater tuberosity was measured as 6.32 ± 0.67 mm on the right side and 6.44 ± 0.56 mm on the left side in the present study. These values fall within the range of 5.1-7.5 mm as reported in previous studies conducted by Somesh *et al.*^[12], Prasad *et al.*^[13] and Prashanth *et al.*^[14]. The similarity in findings across these studies indicates consistency in this anatomical measurement and the results were statistically significant ($p < 0.001$).

Specifically, Jaiswal *et al.*^[10] reported lower values of 5.3 mm (right) and 5.1 mm (left), while Prasad *et al.*^[13] observed higher values of 6.7 mm (right) and 7.5 mm (left). Desai *et al.*^[11] found measurements of 6.9 mm (right) and 7.1 mm (left) and Somesh *et al.*^[12] reported 5.8 mm (right) and 5.9 mm (left). Aydin documented 6.3 mm (right) and 5.8 mm (left), while Shirin Jahan noted 7.2 mm (right) and 6.2 mm (left). Despite slight regional differences, the measurements from the current study in Delhi align well with the broader national data, supporting anatomical consistency across Indian populations^[15].

Distance between the most proximal point of the head of humerus and the surgical neck:

The distance between the most proximal point of the humeral head

and the surgical neck of the humerus was found to be 39.5 ± 2.82 mm on the right side and 40.7 ± 3.00 mm on the left side in the present study. Although the statistical significance was noted as $P = 0.175$, these measurements were generally consistent with those reported by Desai *et al.*^[11], who recorded 39.9 mm (right) and 39.1 mm (left). However, noticeable variations were observed when compared to other studies. For instance, Jaiswal *et al.*^[10] (Kota, Rajasthan) reported lower values of 34.9 mm (right) and 35.7 mm (left) and Somesh *et al.*^[12] (Mangalore) found values of 37.1 mm (right) and 37.7 mm (left). More significant differences in the findings of Prashanth *et al.*^[14] and Ashwini and Venkateshu *et al.*^[15] with values ranging from 32.5-33.8 mm. These differences suggest regional anatomical variations in the humeral structure across different parts of India^[16].

Length of the bicipital groove: The distance between the most proximal point of the humeral head and the surgical neck of the humerus was found to be 39.5 ± 2.82 mm on the right side and 40.7 ± 3.00 mm on the left side in the present study. Although the statistical significance was noted as $p = 0.175$, these measurements were generally consistent with those reported by Desai *et al.*^[11], who recorded 39.9 mm (right) and 39.1 mm (left). However, noticeable variations were observed when compared to other studies. For instance, Jaiswal *et al.*^[10] (Kota, Rajasthan) reported lower values of 34.9 mm (right) and 35.7 mm (left) and Somesh *et al.*^[12] (Mangalore) found values of 37.1 mm (right) and 37.7 mm (left). More significant differences were seen in the findings of Ashwini and Venkateshu *et al.*^[15] and Senthil *et al.*^[16] with values ranging from 32.5 mm to 33.8 mm. These differences suggest regional anatomical variations in the humeral structure across different parts of India.

Breadth of the bicipital groove: The breadth of the bicipital groove in the present study was found to be 9.04 ± 1.62 mm on the right side and 7.62 ± 1.49 mm on the left side and this difference was statistically significant ($p = 0.002$). These findings are generally consistent with values reported in previous studies by Ashwini *et al.*^[15] indicating a broad alignment in anatomical dimensions across different regions in India.

For instance, Ashwini *et al.*^[15] (Karnataka) recorded measurements of 8.5 mm (right) and 7.9 mm (left), while Kabakci *et al.*^[5] (Bihar) noted 8.6 mm (right) and 8.1 mm (left). Senthil *et al.*^[16] (Chennai) reported 8.3 mm (right) and 8.7 mm (left) and Arun Kumar (Tamil Nadu) documented 8.7 mm (right) and 8.3 mm (left). A slightly lower value was observed in Dr. Nand Kishor's (Jharkhand) study, which reported 6.7 mm (right) and 7.5 mm (left). While regional variations exist, the present study from Delhi shows relatively

higher breadth on the right side, contributing to the existing anatomical data and highlighting subtle differences in humeral morphology across Indian populations^[18].

Depth of the bicipital groove: The depth of the bicipital groove in the present study was recorded as 5.90 ± 1.29 mm on the right side and 4.68 ± 1.05 mm on the left side, with the differences being statistically significant ($p = 0.001$). Compared to previous studies, the values from our research show noticeable variation, particularly with those conducted by Ashwini *et al.*^[17] and Vinay *et al.*^[18].

For instance, Ashwini *et al.*^[15] (Karnataka) reported higher depths of 6.4 mm (right) and 6.1 mm (left), while Kabakci *et al.*^[5] (Bihar) documented 4.8 mm (right) and 4.4 mm (left). Senthil *et al.*^[16] (Chennai) observed lower values of 4.7 mm (right) and 4.2 mm (left) and Nand Kishor (Jharkhand) noted 4.1 mm (right) and 5.0 mm (left). Arun Kumar (Tamil Nadu) reported 5.0 mm (right) and 6.0 mm (left). These variations indicate regional anatomical differences, with the present study from Delhi showing a relatively deeper groove on the right side and a shallower groove on the left side when compared to most previous studies. Such data contribute to the growing understanding of humeral morphology across different populations.

Intercondylar transverse measurement: The intercondylar transverse measurement in the present study was found to be 48.86 ± 6.56 mm on both the right and left sides, with the results showing no statistically significant difference ($p = 1.000$) between the two sides. These values closely align with the findings of Aydin Kabakci *et al.*, who reported 49.4 mm (right) and 46.3 mm (left). However, substantial variations were observed when compared to other studies, all of which reported significantly higher values^[5-19].

For instance, Neelam Kumari (Bihar) recorded 57.1 mm (right) and 58.6 mm (left), while Zarana (Gujarat) reported 56.6 mm (right) and 55.8 mm (left). Vinay (Karnataka) observed 57.4 mm (right) and 56.2 mm (left) and Pranoti Sinha (Sikkim) documented 56.1 mm (right) and 57.6 mm (left). The relatively smaller values found in our Delhi-based study may reflect regional anatomical differences or population-specific variations in distal humerus morphology^[18,19].

Transverse diameter of the trochlea: The transverse diameter of the trochlea in the present study was measured as 20.83 ± 2.35 mm on both the right and left sides, with no statistically significant difference between the two sides ($p = 1.000$). These values are closely aligned with those reported by Somesh *et al.*^[11],

Desai *et al.*^[11] Somesh *et al.*^[12], Prasad *et al.*^[13] and Prashanth *et al.*^[14], suggesting a general consistency in this anatomical measurement across various regions in India.

For example, Prasad (Bihar) recorded 22.6 mm (right) and 21.7 mm (left), while Pratima Jaiswal (Kota) observed 20.8 mm (right) and 19.7 mm (left). S.D. Desai *et al.*^[11] (Karnataka) reported 21.2 mm (right) and 20.7 mm (left) and Kabakci *et al.*^[5] found 21.1 mm (right) and 20.7 mm (left). However, a striking difference was noted in the findings of Vinay *et al.*^[18] (Karnataka), who reported significantly larger values of 24.4 mm (right) and 23.5 mm (left). This notable variation may be attributed to regional or methodological differences and highlights the importance of population-specific data in anatomical research.

Anterior-posterior diameter of the trochlea: The anterior-posterior diameter of the trochlea in the present study was recorded as 22.34 ± 3.89 mm on both the right and left sides, with no statistically significant difference between the two ($p = 1.000$). These measurements are within a moderate range and provide a baseline for the Delhi population. However, marked differences were observed when compared to values from other regional studies.

For instance, Neelam Kumari (Bihar) reported significantly larger diameters of 28.4 mm (right) and 28.6 mm (left), whereas Vinay *et al.*^[18] (Karnataka) noted considerably smaller values of 17.0 mm (right) and 16.3 mm (left). These discrepancies highlight the potential for regional anatomical variation in the dimensions of the trochlea and underscore the importance of localized anthropometric data in clinical and orthopedic applications.

Transverse diameter of the capitulum: The transverse diameter of the capitulum in our study was found to be 18.12 ± 3.50 mm on both the right and left sides, with no statistically significant difference ($p = 1.000$). This is in close correspondence with Vinay *et al.*^[19] findings (17.0 mm right, 16.3 mm left) but smaller than those recorded by Moumita Chatterjee, who found higher values of 20.1 mm on the right and 21.2 mm on the left. Such variation could be attributed to differences in ethnicity, sample size, or measurement technique.

Length of the olecranon fossa: The length of the olecranon fossa in the present study was measured as 19.43 ± 2.02 mm on both the right and left sides, showing no statistically significant difference ($p = 1.000$). These values closely align with those reported by Somesh *et al.*^[12] suggesting a level of consistency in this anatomical parameter among certain Indian populations.

For example, Somesh *et al.*^[12] (Mangalore) recorded 19.0 mm (right) and 20.1 mm (left), while Kabakci *et al.*^[5] (Bihar) noted 19.1 mm (right) and 19.4 mm (left). In contrast, notable variations were observed in studies by Prasad *et al.*^[13], Sanjeev Kumar and Prem Chand (Karnataka) reported significantly higher values of 22.6 mm (right) and 21.7 mm (left), whereas Sanjeev Kumar (Bihar) and Prem Chand (Karnataka) reported lower values, ranging between 17.6 mm and 18.4 mm. These differences highlight possible regional anatomical variations and reinforce the value of localized morphometric data for accurate clinical reference.

Breadth of the olecranon fossa: The breadth of the olecranon fossa in the present study was recorded as 19.43 ± 2.02 mm on both the right and left sides, with no statistically significant difference observed ($p = 1.000$). These values are relatively moderate and represent the humeral morphology in the Delhi region. However, visible differences were noted when compared to values reported in previous studies by Jaiswal *et al.*^[10] and Prasad *et al.*^[13].

Specifically, Jaiswal *et al.*^[11] (Kota, Rajasthan) reported a significantly greater breadth of 24.5 mm (right) and 24.1 mm (left), while Prasad *et al.*^[13] (Karnataka) observed even larger values of 24.1 mm (right) and 26.9 mm (left). The considerable discrepancy between these findings and those of the present study may be attributed to regional anatomical variations or differences in sample populations and methodologies. This highlights the importance of region-specific anthropometric data in clinical, orthopedic and forensic applications.

Length of the humerus: The length of the humerus was measured by placing the bone flat on an osteometric board and recording the distance from the most proximal point of the humeral head to the most distal end, in millimeters. In the present study, the mean length on the right side was 281.43 mm with a standard deviation of 6.76, while the mean length on the left side was 289.58 mm with a standard deviation of 22.1. Both values were statistically non-significant ($p = 0.88$). Interestingly, this study shows a higher average length on the left side, which contrasts with most other studies where the right humerus was consistently longer.

When compared with previous research, visible differences were observed. Desai *et al.*^[11] reported values of 292.3 mm (right) and 289.45 mm (left), while Ashiani *et al.*^[15] documented 303.9 mm (right) and 303.2 mm (left). Pranoti Sinha *et al.*, also from Delhi, recorded 290.17 mm (right) and 283.36 mm (left). Sinha *et al.*^[7] (Malaysia) noted lengths exceeding

306 mm on both sides and Prashant *et al.*^[14] (Karnataka) reported even greater measurements of 307.5 mm (right) and 302.7 mm (left).

A striking difference was noted between the present study and those of Prashant *et al.*^[14] and Ashiani *et al.*^[17], all of whom reported mean humeral lengths above 300 mm, suggesting possible population-based anatomical variation.

It is important to note that the correlation between humeral length and individual height could not be established, as the bones were studied in isolation and not linked to specific individuals. This limits the ability to draw conclusions about stature estimation in this context.

CONCLUSION

The humerus, being one of the longest and most robust bones in the human body, holds significant anatomical and clinical importance. Accurate measurements of its total length and various segments are essential, as these can be extrapolated for applications such as estimating an individual's stature. However, in this study, a direct correlation between humeral length and body height could not be established due to the absence of corresponding individual data. Morphometric analysis of the humerus is particularly valuable across multiple disciplines, including anatomy, forensic science, anthropology and orthopedic surgery. These measurements assist in determining attributes such as ethnicity, race, sex and age and are crucial for designing appropriate prosthetics and implants. In clinical practice, especially in managing fractures at the proximal and distal ends of the humerus, as well as in reconstructive surgeries around the elbow joint, such data proves to be of immense relevance. Fractures involving the olecranon fossa, which constitute approximately 10% of all upper limb fractures, further emphasize the importance of precise anatomical knowledge of this region. Morphometric alterations may also result from trauma or pathological changes, highlighting the need for baseline reference data. Notably, this study revealed marked differences in humeral dimensions when compared to data from Malaysian and some South Indian (Karnataka) populations, likely reflecting underlying genetic, ethnic and racial variations. While the current findings align closely with data from other North Indian studies-primarily representing the Aryan population-the variations observed among Malaysian individuals, who are predominantly of Mongoloid descent, underscore the influence of racial and geographical factors on bone morphology.

In addition to genetics and ethnicity, functional factors such as limb dominance, occupation, lifestyle and environmental influences also contribute to the

modeling and remodeling of bone. These cumulative influences help shape the skeletal characteristics of different populations, reflecting the adaptive nature of human anatomy across diverse civilizations.

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