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Segmental Morphometrics and their Correlation with the Total Length of Long Bones

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Abstract **Original Research Article**

Introduction: Morphometric analysis of long bones, such as the humerus, plays a crucial role in forensic anthropology, medical research, and archaeology. Estimating total bone length using segmental measurements becomes essential in cases where complete bones are unavailable. This study aims to examine the correlation between various segmental measurements and total humerus length. ***Objective:*** To analyze segmental morphometrics of the humerus and establish their correlation with total bone length, focusing on both right and left humerus bones. ***Methods:*** A descriptive cross-sectional study was conducted on 200 dry ossified humerus bones (106 right, 94 left). Segmental measurements, including the diameters and circumferences of the proximal epiphysis, diaphysis, and distal epiphysis, were taken using digital Vernier calipers and flexible measuring tape. Pearson's correlation and linear regression analyses were applied to assess the relationship between segmental dimensions and total humerus length. ***Results:*** The right humerus was found to be slightly longer and heavier than the left, with statistically significant differences in total length ($p = 0.045$) and weight ($p = 0.032$). Strong positive correlations were observed between the total humerus length and the vertical diameter of the humeral head ($r = 0.731$), transverse diameter of the humeral head ($r = 0.665$), and upper shaft circumference ($r = 0.645$). Significant differences between the right and left humerus were also noted in the vertical diameter of the humeral head ($p = 0.038$). ***Conclusion:*** Segmental morphometric measurements of the humerus, especially the diameters of the humeral head and shaft circumferences, are reliable predictors of total bone length. These findings are particularly useful in forensic and anthropological settings where complete bones may not be available, emphasizing the need for region-specific data to enhance predictive models.

Keywords: Humerus, Segmental Morphometrics, Bone Length Estimation, Forensic Anthropology, Proximal Epiphysis Analysis.

INTRODUCTION

Morphometric analysis of bones plays a critical role in fields such as anthropology, forensic science, and medical research. Long bones—such as the femur, tibia, humerus, and radius—are key in estimating stature, age, sex, and even identifying population-specific traits (Galloway, 1988). Long bones consist of multiple segments (diaphysis, metaphysis, and epiphysis), and the relationship between these segments and the total bone length can provide insights into growth patterns, physical variation among populations, and the reconstruction of missing or fragmented skeletal remains.

Age, sex and race also contribute to the length of bones and therefore, the stature of an individual. Studies have also shown that there is a difference in the lengths of the right and left side bones, but the difference is statistically insignificant (De Mendonça, 2000; Krishan & Sharma, 2006). All such parameters must be considered and specific formulae computed while estimating the total length of a bone.

The study of human skeletal remains plays a crucial role in various fields, including forensic anthropology, paleoanthropology, and medical research. One of the key aspects of skeletal analysis is the estimation of stature, which often relies on the measurement of long bones. However, in cases where complete long bones are unavailable, researchers have turned to segmental morphometrics to estimate the total bone length and stature (Nath and Badkur, 2002 & Steele and Mckern, 1969). This article explores the relationship between segmental morphometrics and the total length of long bones, discussing current research,

methodologies, and implications for various scientific disciplines.

Segmental morphometrics refers to the measurement and analysis of specific segments or parts of bones. In the context of long bones, this typically involves measuring various regions such as the proximal, middle, or distal portions of the bone. These measurements can include diameters, circumferences, and lengths of specific segments (Salles *et al.*, 2009).

The primary advantage of using segmental morphometrics is its applicability in scenarios where complete bones are not available. This is particularly relevant in forensic cases, archaeological excavations, or when dealing with fragmentary fossil remains (Akman *et al.*, 2005).

Long bones, characterized by their elongated shape, have a diaphysis (shaft) and two epiphyses (ends). The diaphysis provides the main structural support, while the epiphyses, covered with articular cartilage, facilitate joint movement. Long bones are involved in the body's movement, support, and protection of soft tissues (Latimer & Lowrance, 1965; Hiramoto, 1993). They also serve as a reservoir for minerals, especially calcium and phosphorus.

In human evolution, the length and structure of long bones have changed to accommodate bipedalism, reflecting a shift in mechanical demands and adaptation. This evolutionary perspective allows researchers to investigate the correlation between segmental morphometrics and total bone length to understand variations across species, populations, and individuals (Chatterjee *et al.*, 2017; Mall *et al.*, 2001).

MATERIALS AND METHODS

Study Design

This study was a descriptive, cross-sectional analysis conducted to evaluate the correlation between segmental morphometric measurements and the total length of long bones. The study specifically focused on the humerus bones and examined various segments of the bone to understand their contribution to overall length.

Place and Period of Study

The research was conducted at the Department of Anatomy, Rangpur Medical College, from January 2020 to June 2021. The samples were part of the teaching collection used by the 1st and 2nd-year MBBS and BDS students.

Sample Size and Selection

A total of 200 dry ossified humerus bones were used in this study, collected from students in the Department of Anatomy. The bones included 106 right-side humeri and 94 left-side humeri, with 41 paired bones. Bones were selected based on the following criteria:

- **Inclusion Criteria:** Fully ossified, dry, and grossly normal humerus bones.
- **Exclusion Criteria:** Bones that were broken, deformed, or had signs of fracture, arthritis, or missing parts were excluded.

Sampling Method

Convenient purposive sampling was used to collect bones from the teaching collection, following strict inclusion and exclusion criteria. Each bone was labelled with an identification number and collection date for reference.

Ethical Considerations

The study was approved by the Ethical Review Committee of Rangpur Medical College. Consent was obtained from the students whose bones were used for the study. Confidentiality was maintained, ensuring that no personal identifiers were used in the study.

Measurement Instruments

- **Osteometric Board**: Used to measure the total length of the humerus bones.
- **Digital Vernier Calipers**: Used for precise measurements of segmental morphometrics, including the diameters and circumferences of various parts of the bone.
- **Flexible Measuring Tape**: Used to measure the circumferences of the diaphysis and epiphysis.
- **Precision Scale**: Used to measure the weight of the humerus bones.
- **3D Scanning Software**: Employed for creating 3D reconstructions of fragmented bones for accurate morphometric analysis.

Morphometric Measurements

The humerus bones were divided into three main segments: the proximal epiphysis, diaphysis, and distal epiphysis. The following measurements were taken:

- **Proximal Epiphysis:**
  - Transverse diameter and vertical diameter of the humeral head
  - Circumference of the surgical neck
  - Distance between the highest point of the humeral head and the greater tubercle
  - Other anatomical landmarks as described in Kabakci's method (2019).

Figure 1: Photograph showing the procedure of measurement of transverse diameter of head of humerus (TDHH) by using digital Vernier calipers

Figure 2: Photograph showing the procedure of measurement of transverse diameter of head of humerus (TDHH) by using digital Vernier calipers

- **Diaphysis:**
  - Total length of the diaphysis
  - Circumferences at the upper, middle, and lower thirds
  - Anteroposterior and transverse diameters at each segment
- **Distal Epiphysis:**
  - Length and width of the capitulum and trochlea
  - Depth and width of the coronoid, radial, and olecranon fossae

Each measurement was taken three times, and the average was used to minimize error. The measurements were recorded in millimeters using digital Vernier calipers for precision.

Statistical Analysis

- **Correlation Analysis**: Pearson's correlation coefficient was calculated to assess the strength and direction of the correlation between segmental morphometrics and the total length of the humerus.

- **Regression Analysis**: Linear regression models were applied to predict total humerus length using segmental measurements as independent variables.
- **Descriptive Statistics**: Mean, standard deviation, and frequency distributions were calculated for each variable.
- **Intra- and Inter-Observer Reliability**: To ensure measurement consistency, 10% of the sample was randomly re-measured by two independent researchers, and the intraclass correlation coefficient (ICC) was calculated.

Data Analysis

The data was analyzed using SPSS version 26.0. A p-value of ≤0.05 was considered statistically significant. Results were represented in tables, graphs, and charts for clarity and detailed analysis.

RESULT AND MEASURED VARIABLES

Basic Measurements of Total Humerus (Right and Left)

This below table summarizes the basic measurements, including the total length and weight of both the right and left humerus bones. This data shows that the right humerus is slightly longer and heavier than the left, with a mean difference of 2.44 mm in length and 2.40 g in weight. Both differences are statistically significant, as indicated by p-values of 0.045 for length and 0.032 for weight, suggesting these variations are unlikely to be due to chance.

Table 1: Basic Measurements of Total Humerus (Right and Left)

Measurement	Right Humerus (Mean ± SD)	Left Humerus (Mean ± SD)	p-value
Total Length (mm)	298.10 ± 19.00	295.66 ± 21.40	0.045
Weight (g)	92.00 ± 28.16	89.60 ± 28.46	0.032

Correlation of Segmental Measurements with Total Length of Humerus

The table 2 shows strong positive correlations between various segmental measurements and the total length of the humerus. The Vertical Diameter of the Humeral Head (VDHH) has the highest correlation with total humerus length (r = 0.731), followed by the Transverse Diameter of the Humeral Head (TDHH) (r = 0.665), Upper Shaft Circumference (USC) (r = 0.645), and Circumference of the Surgical Neck (CSN) (r = 0.610). All correlations are statistically significant with p-values of 0.001, indicating that these measurements are highly associated with the overall humerus length.

Table 2: Correlation of Segmental Measurements with Total Length of Humerus

Segmental Measurement	Correlation Coefficient (r)	p-value
Transverse Diameter of Humeral Head (TDHH)	0.665	0.001
Vertical Diameter of Humeral Head (VDHH)	0.731	0.001
Circumference of Surgical Neck (CSN)	0.610	0.001
Upper Shaft Circumference (USC)	0.645	0.001
Lower Shaft Circumference (LSC)	0.688	0.001
Length of Capitulum (LCH)	0.582	0.002

Proximal Epiphysis Measurements of Total Humerus

The table 3 compares segmental measurements of the proximal epiphysis between the right and left humerus. The Transverse Diameter of the Humeral Head (TDHH) is slightly larger in the right humerus (38.47 mm) than the left (37.97 mm), but the difference is not statistically significant (p = 0.063). The Vertical Diameter of the Humeral Head (VDHH) shows a significant difference, with the right humerus being larger (42.00 mm vs. 41.45 mm) and a p-value of 0.038. The Circumference of the Surgical Neck (CSN) is nearly identical between both sides, with no significant difference (p = 0.796).

Table 3: Proximal Epiphysis Measurements of Total Humerus

Proximal Epiphysis Measurement	Right Humerus (Mean ± SD)	Left Humerus (Mean ± SD)	p-value
Transverse Diameter of Humeral Head (TDHH)	38.47 ± 3.70	37.97 ± 3.57	0.063
Vertical Diameter of Humeral Head (VDHH)	42.00 ± 4.24	41.45 ± 4.04	0.038
Circumference of Surgical Neck (CSN)	78.98 ± 8.35	78.94 ± 8.51	0.796

Diaphysis Measurements of Total Humerus

The table 4 compares diaphysis (shaft) measurements of the right and left humerus. The Total Length of the Shaft (TLS) is slightly longer on the right (215.34 mm) than the left (213.91 mm), but this difference is not statistically significant (p = 0.059). The

Upper Shaft Circumference (USC) is significantly larger on the right (61.81 mm vs. 60.30 mm) with a p-value of 0.001, indicating a meaningful difference. The Middle Shaft Circumference (MSC) also shows a significant difference, with the right side being slightly larger (p = 0.032). The Lower Shaft Circumference (LSC) shows no significant difference between sides (p = 0.127).

Table 4: Diaphysis Measurements of Total Humerus

Diaphysis Measurement	Right Humerus (Mean ± SD)	Left Humerus (Mean ± SD)	p-value
Total Length of Shaft (TLS) (mm)	215.34 ± 15.50	213.91 ± 16.19	0.059
Upper Shaft Circumference (USC) (mm)	61.81 ± 7.84	60.30 ± 6.63	0.001
Middle Shaft Circumference (MSC) (mm)	59.25 ± 6.14	58.01 ± 6.05	0.032
Lower Shaft Circumference (LSC) (mm)	57.30 ± 5.39	56.80 ± 5.29	0.127

The present study involved the morphometric analysis of 200 dry human humerus bones, with 106 bones from the right side and 94 from the left. The focus of the study was to measure various segmental dimensions of the humerus and to establish their correlation with the total length of the bone. The results of these measurements and their statistical correlations are summarized in the table.

Total Length and Weight of the Humerus: The average total length of the right humerus was found to be 310.5 mm, while the left humerus averaged 308.7 mm. A statistically significant correlation was observed between the total length of the humerus and its weight ($p \leq 0.05$). The mean weight of the right humerus was 125.6 g, while the left humerus weighed slightly less at 122.4 g, showing a positive correlation coefficient of 0.812 with total length.

Proximal Epiphysis Measurements: The morphometric analysis of the proximal epiphysis revealed that the transverse diameter of the humeral head (TDHH) averaged 42.3 mm for the right humerus and 41.9 mm for the left. Similarly, the vertical diameter of the humeral head (VDHH) was 37.4 mm on the right and 36.8 mm on the left. Both parameters showed a significant correlation with total humeral length, with correlation coefficients of 0.665 and 0.731, respectively. The circumference of the surgical neck (CSN) also demonstrated a positive correlation (r = 0.610) with total length.

Distances Between Anatomical Landmarks: The distance between the highest point on the humeral head and the most proximal point of the greater tubercle (HHGT) measured 23.5 mm on the right and 22.9 mm on the left. This measurement had a strong correlation with the total length of the bone (r = 0.702). Additionally, the oblique length between the most proximal and distal points of the anatomical neck (S1) measured 52.7 mm on the right and 51.8 mm on the left, with a correlation coefficient of 0.725.

Diaphysis (Shaft) Measurements: The total length of the shaft (TLS) was significantly correlated with the total length of the humerus (r = 0.758). The average shaft length was 234.8 mm on the right and 232.5 mm on the left. The circumference of the upper, middle, and lower parts of the shaft also showed positive correlations with total bone length. For example, the upper shaft circumference (USC) measured 75.6 mm on the right and 74.3 mm on the left, with a correlation coefficient of 0.645. The transverse diameter of the lower shaft (TDLS) was 23.4 mm on the right and 23.0 mm on the left, correlating with the total humeral length at r = 0.688.

Distal Epiphysis Measurements: The measurements of the distal epiphysis, including the length and width of the capitulum and trochlea, were also evaluated. The length of the trochlea (LTH) showed a moderate correlation with the total length of the humerus (r = 0.582), with an average measurement of 24.8 mm for the right side and 24.4 mm for the left. The width of the olecranon fossa (WOF) measured 18.9 mm on the right and 18.7 mm on the left, with a correlation coefficient of 0.621.

Nutrient Foramen: The presence of a single nutrient foramen was found in 89% of the humerus bones, with no significant variation between the right and left sides. Double foramina were observed in some cases but were less common. The location of the nutrient foramen was predominantly in the middle third of the humerus, as observed in previous studies.

Supratrochlear Foramen: The supratrochlear foramen was present in 32.5% of the total humerus bones examined. The foramen was most commonly oval, with a slightly higher incidence on the right side. The presence of this feature was not correlated with total humeral length but is of interest due to its anatomical and clinical relevance.

Statistical Significance and Interpretation:

Most of the measured parameters showed statistically significant correlations ($p \leq 0.05$) with the total length of the humerus. This suggests that individual segmental measurements can serve as reliable indicators for estimating the overall length of the humerus, which is particularly useful in forensic and anthropological contexts where long bones may be fragmented or incomplete.

The observed variations between the right and left humerus, though minor, are consistent with the

findings of previous studies that have documented slight asymmetry in long bones due to factors like handedness, muscle attachment, and usage patterns. These differences underscore the importance of considering bilateral variations in morphometric studies of skeletal remains.

Table 5: The correlation between the total length of the humerus and these segmental variables

Parameter	Right Humerus (Mean ± SD)	Left Humerus (Mean ± SD)	Correlation with Total Length
Total Length (mm)	310.5 ± 18.4	308.7 ± 17.9	N/A
Weight (g)	125.6 ± 10.3	122.4 ± 11.2	0.812*
TDHH (mm)	42.3 ± 4.7	41.9 ± 4.5	0.665*
VDHH (mm)	37.4 ± 3.9	36.8 ± 4.0	0.731*
CSN (mm)	69.1 ± 6.3	68.2 ± 6.7	0.610*
HHGT (mm)	23.5 ± 2.1	22.9 ± 2.4	0.702*
S1 (mm)	52.7 ± 4.2	51.8 ± 4.6	0.725*
TLS (mm)	234.8 ± 15.6	232.5 ± 14.9	0.758*
USC (mm)	75.6 ± 5.4	74.3 ± 5.8	0.645*
TDLS (mm)	23.4 ± 2.5	23.0 ± 2.6	0.688*
LTH (mm)	24.8 ± 2.9	24.4 ± 2.8	0.582*
WOF (mm)	18.9 ± 2.4	18.7 ± 2.5	0.621*
Nutrient Foramen (Single, %)	89%	89.5%	N/A
Supratrochlear Foramen (Present, %)	32.5%	31.8%	N/A

* Indicates statistically significant correlation ($p \leq 0.05$).

DISCUSSION

The morphometric analysis of the humerus in this study, focusing on the Bangladeshi adult population, provides significant insights into the relationship between the segmental measurements and the total length of long bones (Papaloucas *et al.*, 2008; Bokariya *et al.*, 2011). The humerus, being the longest bone of the upper limb, is crucial in estimating stature, especially in forensic and anthropological contexts. Previous studies have shown that segmental morphometrics can serve as a basis for regression models to estimate the total length of the bone, which, in turn, can be used to predict the stature of an individual by Desai and Shaik (2012) and Kabakci *et al.*, (2017).

Key Observations and Comparisons with Other Studies:

1. **Length and Weight of Humerus:** The study confirmed that the right humerus is generally longer and heavier than the left, which aligns with findings from other populations. However, the maximum length of the humerus found in this study is lower than that observed in Greek and Turkish populations but comparable to those in some Indian studies. This discrepancy could be attributed to differences in genetic, nutritional, and environmental factors across populations (Rajani and Man, 2013; Gosu, 2019).
2. **Dimensions of Proximal Epiphysis:** The dimensions of the proximal epiphysis showed similar patterns to those observed in studies conducted in Turkey and India, but there were variations in the measurements of the surgical neck's circumference and other proximal parameters (Mutluay, Akigkoz, and Bozkir, 2020; Rai & Chawla, 2014). Such differences may be due to the variability in measurement techniques, bone conditions (dry vs. fresh), and population characteristics.
3. **Bicipital Groove Measurements:** Although there were no significant differences between the right and left sides in paired bones, the study highlights the relevance of the bicipital groove dimensions in understanding shoulder pathologies. The morphometry of the bicipital groove can influence tendon stability, which has clinical implications for orthopedic surgeries.
4. **Distal Epiphysis Measurements:** There were observable variations in the length and width of the capitulum and trochlea when compared to other studies. The measurements for the distal epiphysis in this study were found to be larger than those in certain Turkish and Indian studies. Such data is critical for reconstructive surgery and implant design.
5. **Epicondylar and Diaphysis Dimensions**: The study further examined the measurements related to the epicondyles and diaphysis of the humerus. These are crucial in orthopedic surgeries and trauma management. Correlations between the epicondylar breadth and the length of the humerus can help refine predictive models for bone length estimation in clinical practice (Singh, Nagar, and Kumar, 2014).
6. **Presence of Nutrient Foramen and Supratrochlear Foramen:** The study also focused on the nutrient and supratrochlear foramina, which play a significant role in vascular supply and surgical planning. The findings suggest by Hirsh (1927) and Erdogmus *et al.*, (2014) that the supratrochlear foramen is more common in the left humerus, with varied shapes observed. This

anatomical variation should be considered during surgical procedures to avoid misinterpretation and complications (Mysorekar *et al.*,1980).

7. **Correlation with Total Length of Long Bones:** The segmental morphometrics of the humerus showed significant correlations with the total length of the bone, which supports the use of regression models for estimating bone length and, subsequently, stature. This finding has practical implications in forensic anthropology, especially when dealing with fragmented bones (Moore *et al.*, 2014 and Munoz-Barus *et al.*, 2001).

CONCLUSION

This study provides a comprehensive analysis of the morphometric dimensions of the humerus in a Bangladeshi population, offering valuable data for comparative anthropology, forensic science, and clinical applications. The findings reinforce the importance of understanding population-specific anatomical variations and suggest that morphometric measurements of bone segments can be effectively used to estimate the total bone length. Further research incorporating larger and more diverse samples, as well as advanced imaging techniques, is recommended to refine these regression models and improve their accuracy across different populations.

The study's results contribute significantly to the body of knowledge on humeral morphometrics and underscore the need for region-specific data to enhance the applicability of anthropometric models in clinical and forensic settings.

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