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A MORPHOMETRIC ANALYSIS OF HUMERAL SHAFT DIMENSIONS AND TORSIONAL ANATOMY

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ABSTRACT

The humerus, the longest bone of the upper limb, demonstrates significant anatomical variation, particularly in its length and rotational features. While maximum humeral length (MHL) and humeral biomechanical length (HBL) are commonly used in anthropometry and orthopedics, the humeral torsion angle (HTA) plays a vital role in shoulder mechanics and joint orientation. However, the interrelationship between these parameters remains underexplored. This study aims to assess the morphometric relationship between MHL, HBL, and HTA in adult human humeri and to determine whether humeral length influences torsional alignment. A total of 36 dry adult humeri (16 right-sided and 20 left-sided) were selected from the osteological collection of the museum of Department of Rachana Sharir, National Institute of Ayurveda (NIA), Jaipur, Rajasthan. MHL, HBL, and HTA had been measured using standard osteometric procedures and digital imaging. Descriptive statistics and Pearson's correlation coefficient were used to evaluate relationships among the parameters. The mean MHL was 30.99 ± 1.56 cm, HBL was 30.57 ± 1.51 cm, and HTA was 64.08° ± 9.23°. A very strong positive correlation was found between MHL and HBL ($r = 0.99$, $p < 0.001$), whereas weak, non-significant correlations were found between MHL and HTA ($r = 0.10$, $p = 0.565$) and between. HBL and HTA ($r = 0.12$, $p = 0.479$). Side-wise analysis revealed significantly greater MHL and HBL values in right-sided humeri compared to the left ($p < 0.01$), while HTA did not significantly differ between sides ($p = 0.991$). Side-related correlations between length parameters and HTA remained weak and statistically not significant. While MHL and HBL are closely related morphometric indicators, neither shows a significant influence on the humeral torsion angle. These findings suggest that torsion is anatomically and functionally independent from shaft length, emphasizing the need for individual assessment in clinical and surgical planning. Additionally, the detected side related asymmetry in humeral length parameters highpoints possible influences of limb dominance or usual use, while the consistent torsional values across sides emphasize the age-related stability of HTA as an independent anatomical trait.

Key Words: Anatomy, Maximum humeral length, Humeral biomechanical length, Humeral torsion angle

INTRODUCTION

The humerus, as the longest and strongest bone of the upper limb, plays a central role in both locomotor and manipulative functions. Structurally, it bridges the shoulder and elbow joints, transmitting muscular forces and facilitating a wide range of motion. Among its many anatomical features, two length-based measurements, the Maximum Humeral Length (MHL) and the Humeral Biomechanical Length (HBL) are of particular interest in both clinical and anthropological disciplines. MHL, which spans from the humeral head to the most distal point of the trochlea, is a well-established indicator in stature estimation, reconstructive surgery, and orthopedic implant design [1]. Similarly, HBL, measured along the mechanical axis from the center of the head to the trochlear axis, is widely utilized in biomechanical modeling and for determining proper alignment during intramedullary fixation and shoulder prosthesis placement [2].

Humeral Torsion Angle (HTA) shows a rotational feature of the humerus and this angle determines how the humeral head is oriented in relation to the distal condyles and is crucial for proper alignment of the glenohumeral joint. It directly influences functional outcomes such as internal and external rotation of the shoulder, and improper understanding of HTA can lead to complications in shoulder arthroplasty, athletic performance analysis, and fracture management [3].

Importantly, HTA exhibits considerable variation across populations, sexes, and even between limbs, shaped by phylogenetic heritage, developmental processes, and habitual upper limb use [4] For example, Churchill's (1998) anthropological study highlighted that hunter-gatherer populations developed different humeral torsion profiles based on their upper limb activity. Moreover, functional factors such as handedness and sport-specific demands (e.g., in throwers) have been shown to affect humeral torsion asymmetry [5].

Conversely, MHL and HBL are generally considered structurally determined and less prone to adaptive changes after skeletal maturity. Their measurements are consistent and reproducible across skeletal collections and modern populations, making them reliable indices for anthropometry, implant sizing, and anatomical education [6].

Despite the well-documented significance of each of these parameters, the relationship between humeral length (MHL/HBL) and torsional alignment (HTA) remains poorly explored in the scientific literature particularly in South Asian populations, which are underrepresented in global morphometric databases. Understanding whether a longer or shorter humerus has any influence on its rotational orientation could provide valuable insights for preoperative planning, implant customization, and population-specific prosthesis design.

This study, therefore, aims to investigate the morphometric relationship between MHL, HBL, and HTA in a sample of dry adult human humeri from Rajasthan, India. By examining these parameters in tandem, it seeks to clarify whether linear and rotational characteristics of the humerus are interrelated or independent anatomical traits.

OBJECTIVES

General Objective: To evaluate the morphometric relationship between humeral length parameters and torsion angle in adult human humeri.

Specific Objectives: To measure MHL, HBL, and HTA in a sample of dry adult humeri.

To compute descriptive statistics for each parameter.

To determine the correlation between: MHL and HTA HBL and HTA MHL and HBL

METHODOLOGY

Sample Selection: This study utilized 36 dry adult humeri from the NIA museum collection in Rajasthan, India, including 16 right and 20 left bones. Bones with signs of deformity, fracture, or erosion were excluded. Sex differentiation was not considered.

Picture 01: Right Side Humeri

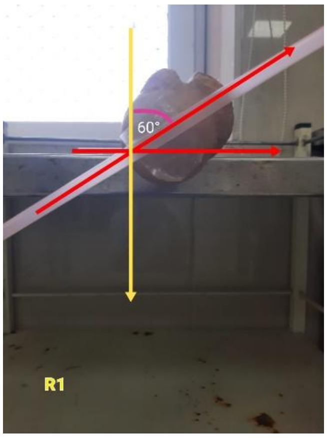
Picture 02: Left Side Humeri

(Humeri were taken from the osteological collection of the museum of Department of Rachana Sharir, National Institute of Ayurveda (NIA), Jaipur, Rajasthan.)

Measurements: The Maximum Humeral Length (MHL) is determined as the distance between the highest point of the head of humerus and the lowest point of the trochlea, and humeral Biomechanical Length (HBL) is the distance from the center of the head of humerus to the axis of trochlear. [7]

Picture 03: Measuring of HML and HBL

Humeral Torsion Angle (HTA): Measured as the angle between the humeral head axis and the transepicondylar axis using a goniometer and confirmed with image-based software. [8]



Picture 04: Measuring of HTA

Descriptive statistics (mean, standard deviation, range) were calculated for statistical analysis. Pearson's correlation coefficient was applied to examine relationships between the three parameters. Statistical significance was set at $p < 0.05$. Data analysis was performed using SPSS (version X).

Results

Measurements

Table 01: Measurements of MHL, HBL and HTA of Right and Left Humeri

No	MHL		HBL		HTA (Angle of Torsion)	
	Right - cm	Left - cm	Right - cm	Left – cm	Right - °	Left -°
1	33.7	33.8	32.9	33.2	60	60
2	36.4	34.3	35.5	34.1	58	73
3	28.8	33.5	28.3	33.2	58	70
4	29.2	29.5	28.9	29.4	50	53
5	30.5	34.9	30.1	34.5	65	50
6	31.3	32.3	31.1	31.8	60	69
7	31.4	31.9	31.1	31.8	61	70
8	31.3	32.1	30.9	31.6	78	72
9	30.2	30.6	30	30.4	60	58
10	32.1	33.3	31.3	32.6	62	79
11	32.9	32.8	32.5	32.1	62	72
12	32.9	31.2	32.4	30.8	80	67
13	30.9	30.9	30.6	30.7	52	60
14	31.9	32.3	31.6	31.9	78	63
15	33	31.2	32.6	30.9	79	49
16	34.1	29.3	33.9	29	62	82
17		29.4		29.3		60
18		33.3		32.6		54
19		32.1		31.7		58
20		29		28.7		63

Statistical Analysis : Table 02: Mean of MHL, HBL and HTA

Parameter	Mean
MHL	30.99 ± 1.56 cm
HBL	30.57 ± 1.51 cm
HTA	64.08° ± 9.23°

Table 03: Correlations of parameters

Correlation	(r, p)
MHL vs HTA	r = 0.10, p = 0.565
HBL vs HTA	r = 0.12, p = 0.479
MHL vs HBL	r = 0.99, p < 0.001 (very strong correlation)

Side-Wise Analysis

To further explore potential anatomical asymmetries, the sample was divided into right-sided (n = 16) and left-sided (n = 20) humeri, and a separate statistical analysis was conducted.

Table 04: Mean Comparisons (Right vs Left)

Parameter	Right Mean ± SD	Left Mean ± SD	t-value	p-value
MHL	31.95 ± 1.83 cm	30.21 ± 0.59 cm	3.33	0.004 **(Significant)**
HBL	31.57 ± 1.87 cm	29.77 ± 0.59 cm	3.47	0.003 **(Significant)**
HTA	64.06° ± 9.50°	64.10° ± 9.24°	-0.01	0.991 *(Not significant)*

Table 05: Side-Specific Correlation between Length and Torsion

Correlation	Right Side (r, p)	Left Side (r, p)
MHL vs HTA	0.22, p = 0.408	-0.10, p = 0.670
HBL vs HTA	0.24, p = 0.374	-0.02, p = 0.945

DISCUSSION This study found no significant correlation between the humeral torsion angle and either maximum or biomechanical humeral length, suggesting that torsional alignment develops independently from linear bone growth. The observed HTA mean (64.08°) aligns with the globally accepted normal range (60°–80°) [9]. Torsion angle influences shoulder joint mechanics, particularly internal and external rotation, and is critical in shoulder arthroplasty and intramedullary procedures [10]. However, the development of this angle is often determined by functional loading, hand dominance, and muscle tension during growth, rather than linear length parameters. The high correlation between MHL and HBL (r = 0.99) reflects their shared structural axis and confirms previous anthropometric studies that use either measurement reliably for reconstructive estimation [11]. The lack of correlation between HTA and shaft lengths emphasizes that preoperative planning for shoulder surgeries must evaluate torsional anatomy separately, as incorrect assumptions based on bone length could result in rotational misalignment or prosthetic failure.

The side-wise analysis revealed a statistically significant difference in both MHL and HBL between right and left humeri, with right-sided bones showing greater length. This observation is consistent with literature noting that dominant upper limbs typically the right in most populations may develop slightly longer shafts due to increased muscular activity and mechanical loading during growth [12].

However, no significant difference was found in the humeral torsion angle (HTA) between right and left sides (p = 0.991). This suggests that torsional alignment is less influenced by dominance or side-specific loading, and may be governed more by developmental and genetic factors, as previously reported by Mavrotas et al. (2014)

In side-specific correlation analysis, weak positive correlations were seen between MHL/HBL and HTA on the right side (r ≈ 0.22–0.24), while left-sided correlations were negligible or even slightly negative, though all were statistically non-significant ($p > 0.3$). These patterns imply that no consistent directional relationship exists between linear dimensions and rotational orientation in either limb, reinforcing the conclusion that torsional features are functionally and morphologically distinct.

Overall, the right-left comparison enriches our understanding by confirming that structural asymmetry in humeral length does occur, potentially as an adaptation to limb dominance. Meanwhile, torsional symmetry across sides underscores its relative independence from length-based biomechanics, an insight valuable for orthopedic planning and anthropological profiling.

In addition to anatomical and biomechanical importance, the morphometric parameters considered, particularly MHL and HBL, have deep-rooted applications in forensic anthropology, especially for height estimation and sex determination. Several studies have demonstrated that MHL exhibits sexual dimorphism, with male humeri tending to be longer and more robust than female ones. Regression models derived from humeral length are frequently used to estimate stature in both forensic and archaeological contexts. Furthermore, the combination of MHL and HBL can assist in reconstructing fragmentary remains, enabling forensic experts to make biological profile assessments even in partial skeletal recoveries.

The humeral torsion angle (HTA), although less commonly applied in routine forensic practice, has growing relevance in biomechanical profiling and reconstructing habitual activity patterns in both modern and archaeological remains. Higher or asymmetric HTA values, for instance, may indicate occupational stress, repetitive throwing motions, or specific limb usage patterns, which can help contextualize lifestyle or cause-of-death analyses in forensic cases.

The formation of the humeral torsion angle is fundamentally influenced by the biological process of endochondral ossification, a complex mechanism through which long bones develop from a cartilaginous template into mature osseous structures. This process is highly dependent on the growth dynamics of the proximal and distal epiphyseal centers of the humerus, whose timing of appearance and rate of maturation directly affect the overall geometry and alignment of the bone.

These epiphyseal centers begin to ossify during intrauterine life, typically becoming radiologically evident during the later stages of fetal development. However, their complete maturation continues well into postnatal growth, and this period represents a critical window during which external mechanical forces can modulate the shape and orientation of the developing bone.[13]

In the early stages of life, the humeral torsion angle tends to be significantly more pronounced, often exhibiting greater degrees of retroversion. This is considered a normal developmental feature. As the child progresses through various functional milestones such as initiating crawling, transitioning to upright posture, standing, and progressively engaging in purposeful upper limb movements repetitive muscular contractions and biomechanical loading begin to act on the developing humerus.

These activities induce remodeling forces that particularly affect the proximal metaphyseal region of the humerus, contributing to a gradual reduction in the torsion angle over time. Such remodeling is largely driven by the tension generated through the action of surrounding musculature, especially the deltoid and rotator cuff muscles, which play pivotal roles in shoulder stabilization and motion.[14]

Thus, the humeral torsion angle is not merely a fixed anatomical attribute predetermined by genetics but is instead shaped dynamically by the interplay of developmental biology and mechanical stimulation. This explains why variations in torsion angle among individuals may reflect not only inherited traits but also the extent and nature of physical activity during early growth phases.

Clinically, understanding these parameters is vital for shoulder arthroplasty, fracture management, and prosthetic alignment. Imprecisions in reproducing a patient's native HTA leads in instability of joint, changes in range of motion, and failure in implant [10]. MHL and HBL also inform the selection of appropriately sized intramedullary nails and joint replacement components, particularly in personalized or side-matched orthopedic procedures. Therefore, comprehensive morphometric assessment including torsional values is essential for optimizing surgical outcomes and preventing long-term complications.

Recognizing that humeral torsion is anatomically independent of shaft length holds significant clinical value, especially in orthopedic and sports medicine contexts. In shoulder arthroplasty, accurately restoring a patient's native humeral torsion angle (HTA) is crucial for maintaining normal joint biomechanics. Relying solely on shaft length or standard anatomical models may lead to incorrect alignment of the humeral head, which can compromise shoulder function. Such misalignment may result in restricted motion, instability, rotator cuff problems, or even premature failure of the implant.[15]

Recognizing that humeral torsion is anatomically independent of shaft length holds significant clinical importance, especially in orthopedic procedures, rehabilitation, and sports medicine. The humeral torsion angle (HTA) plays a vital role in determining the orientation of the humeral head relative to the distal condyles, directly affecting glenohumeral joint biomechanics. In shoulder arthroplasty, accurately replicating a patient's native HTA is critical to achieving physiological range of motion and stable joint function. If torsion is incorrectly inferred based solely on humeral shaft dimensions or generalized anatomical models, it may lead to mal positioning of the prosthetic humeral head. Such misalignment can disrupt joint congruency and muscle-tendon balance, potentially resulting in decreased internal or external rotation, joint instability, and impingement syndromes, and increased risk of rotator cuff dysfunction. Over time, these biomechanical imbalances can contribute to eccentric loading, abnormal joint wear, and early loosening or failure of the implant. Moreover, these complications may require revision surgeries, adding to the burden on patients and healthcare systems.[16]

To minimize these risks, it is recommended that individualized, imaging-based assessments, such as CT or MRI, be integrated into preoperative planning. These allow for accurate measurement of HTA and facilitate personalized prosthetic alignment, ultimately improving functional outcomes and implant longevity. Incorporating such patient-specific parameters is especially crucial in populations where anatomical variation is underrepresented in current prosthetic design datasets.[17]

Furthermore, anthropometric variability in HTA across populations underscores the need for culturally and regionally specific prosthetic designs. South Asian populations, frequently understated in global orthopedic datasets, may show diverse morphometric patterns, as well as shorter humeral lengths or distinctive torsional alignments, requiring modifications in implant sizing and alignment procedures. Incorporating such population-specific data into prosthesis design and surgical training can significantly improve clinical outcomes and reduce the risk of complications associated with one-size-fits-all approaches.[18]

CONCLUSION : This morphometric study shows a strong anatomical correlation between MHL and HBL, but no significant relationship between these length parameters and humeral torsion angle (HTA). Torsion appears to be a functionally and developmentally distinct anatomical feature, highlighting the importance of individual assessment in clinical practice. These findings contribute important region-specific anatomical data for orthopedic, forensic, and anthropological applications in the Indian population.

In addition, the side-wise analysis revealed significantly greater MHL and HBL values in right-sided humeri compared to the left, suggesting structural asymmetry potentially influenced by limb dominance or habitual activity patterns. Nevertheless, no major difference in torsion angle was observed between right and left sides, supporting the idea that torsional morphology remains mainly symmetrical and independent of bone length. These findings reinforce the need for individualized morphometric evaluation—especially in clinical settings such as prosthesis design and preoperative planning—where assumptions based solely on limb dominance or shaft dimensions may not adequately account for torsional variation.

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