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Humerus morphometry with CT

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Abstract

Skeletal bones have a decisive role in sex determination. Studies using various methods, including the humerus, have demonstrated morphometric and macroanatomical differences. This study aimed to define the humerus through computed tomography (CT) based measurements, identify gender differences, and contribute to future research on sex determination. CT images of 43 female and 62 male humeri were analyzed. Ten parameters were examined, and the obtained measurements were evaluated. The mean circumference of the surgical neck (CSN) in men was 10.29 ± 0.72 cm, compared to 8.63 ± 0.87 cm in women (r=0.64, p<0.001). The mean length of the capitulum humeri (LCH) was 2.37 ± 0.28 cm in men and 2.03 ± 0.25 cm in women (r=0.53, p<0.001). The mean length of the trochlea humeri (LTH) was 2.54 ± 0.33 cm in men and 2.26 ± 0.33 cm in women (r=0.39, p<0.001). The mean epicondylar width (EW) was 6.48 ± 0.37 cm in men and 5.69 ± 0.37 cm in women (r=0.72, p<0.001). Statistically significant differences were found between the mean values of CSN, LCH, LTH, and EW according to gender (p<0.001). When comparing two-category independent variables for normally distributed quantitative data, significant differences were identified between male and female humeri (p<0.001). A statistically significant but weak negative correlation was observed between age and the values of the surgical neck, humeral shaft, and humeral trochlea. These findings demonstrate notable morphometric differences between sexes. Humeral parameters may provide useful data in clinical practice and contribute to gender and age-related identification in forensic medicine, forensic anthropology, and anatomical research.

Keywords: Humerus, morphometry, sex determination, computed tomography

Introduction

In contemporary research on the humerus, a variety of methods have been employed to reveal its morphometric and macro anatomical characteristics in detail [1,2]. Morphometry is a scientific approach that enables the quantitative evaluation of the shape and size of living organisms through image processing and analysis techniques. This methodology not only allows for the systematic assessment of fundamental biological structures but also provides insights into morphological features of clinical and anthropological significance. Indeed, morphometric methods serve as a foundation for interdisciplinary studies, enabling researchers from fields such as biology, anatomy, anthropology, and medicine to conduct more comprehensive analyses of the morphological characteristics of living organisms [3,4]. In this regard, morphometric investigations of the humerus contribute substantially to the literature, not only in the basic sciences but also in applied disciplines such as orthopedic surgery, traumatology, and forensic sciences. Since the physical characteristics of human populations vary, it is expected that bone structures also exhibit diversity. In this regard, knowledge of the mean values of humeral measurements makes an important contribution to the characterization of populations and to the comparability of anthropological data [5]. Moreover, considering that bones in the adult human skeleton generally have greater mass in males than in females, morphological studies provide a valuable means of identifying sex-related differences. Knowledge of these sex differences is of great importance in the fields of orthopedics and traumatology, orthopedic endocrinology with bone age estimation, anthropometry, anthropology for the analysis of unknown or unidentified skeletal remains, archaeology and forensic medicine [6,7]. Such morphometric approaches to sex estimation are not limited to the humerus; similar studies have

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been conducted on the pelvis [8], cranium [9], femur [10], and mandible, and these skeletal elements have also been shown to be useful in forensic anthropological applications for sex determination [11].

The humerus, however, has been preferred by many researchers due to its distinct anatomical features and robustness, making it a reliable reference bone in disciplines such as forensic medicine and forensic anthropology [12,13]. With the increasing emphasis on individual-specific anatomical characterization, the use of computed tomography (CT) data for morphometric measurements enables a more detailed description of bone morphology as well as a more accurate identification of sex-related differences. Accordingly, in the present study, humeral measurements derived from CT data were utilized to define bone morphology, to reveal sex differences, and to contribute to the growing body of morphometric literature, while also providing findings of clinical and forensic relevance.

Material and Methods

Ethical Consideration and Data Collection

Prior to the initiation of the study, approval was obtained from the Ethics Committee for Non- Interventional Clinical Research of Tokat Gaziosmanpaşa University (Approval date: 28.03.2024; Approval number: 24-KAEK-131). In this retrospective study, CT images of the humerus archived in the Picture Archiving and Communication System (PACS) of the Department of Radiology, Gaziosmanpaşa University Hospital, were utilized. A total of 105 individuals (43 females and 62 males), aged between 18 and 96 years, were included in the study. Special attention was paid to ensure that the selected CT images did not show any structural deformities of the humerus, and individuals with a history of surgical intervention in the arm region were excluded. Suitable CT images were selected using the SECTRA program and oriented to the orthogonal plane. The orthogonal plane was defined as the anatomical plane in which the sagittal, vertical, and transverse planes intersect in the humeral CT sections. A total of 10 different morphometric parameters were identified on the humerus, and measurements were performed based on these parameters. These measurements were conducted to evaluate the morphometric characteristics of the humerus and to determine sex-related differences.

Laterality (Right-Left) Information

This study was conducted retrospectively using CT images from the PACS archive. In a significant portion of the image recordings, information regarding the laterality of the humerus (right or left) is inconsistent and unreliable, making it impossible to reliably determine whether the humerus belongs to the right or left side. Therefore, all measurements were evaluated generally as humerus measurements, and no subgroup analysis based on laterality was performed. The primary comparison in this study was based on the evaluation of morphometric measurements of the humerus between male and female individuals, and all statistical analyses were performed considering the gender variable (Figure 1).

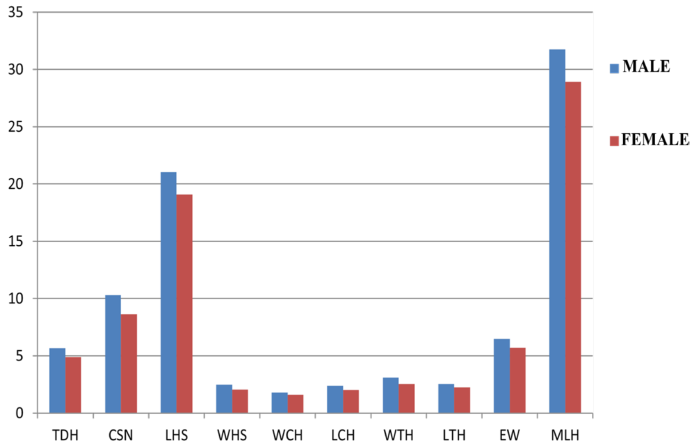

Figure 1. Comparison of variables by gender (cm), TDH: Transverse Diameter of the Humeral Head, CSN: Circumference of the Surgical Neck, LHS: Length of the Humeral Shaft, WHS: Width of the Humeral Shaft, WCH: Width of the Capitulum Humeri, LCH: Length of the Capitulum Humeri, WTH: Width of the Trochlea Humeri, LTH: Length of the Trochlea Humeri, EW: Epicondylar Width, MLH: Maximum Length of the Humerus

The following ten morphometric parameters of the humerus were measured:

1. Transverse diameter of the humeral head (TDH)
2. Circumference of the surgical neck (CSN)
3. Length of the humeral shaft (LHS)
4. Width of the humeral shaft (WHS)
5. Width of the capitulum humeri (WCH)
6. Length of the capitulum humeri (LCH)
7. Width of the trochlea humeri (WTH)
8. Length of the trochlea humeri (LTH)
9. Epicondylar width (EW)
10. Maximum length of the humerus (MLH)

For the measurement of these parameters, the Geometric Morphometrics (GM) procedure was applied to ensure the accurate calculation of the TDH. The landmark-based GM method is an effective analytical tool used to describe the shape of an organism and to statistically evaluate shape differences between groups [14]. Two landmarks were defined on the articular surface of the humeral head:

- **TD1:** The most ventral point on the margin of the articular surface of the humeral head
- **TD2:** The most dorsal point on the margin of the articular surface of the humeral head (Figure 2).

Transverse Diameter of the Humeral Head (TDH)

TDH was defined as the distance between the most ventral and most dorsal points on the edge of the articular surface. Reference points, the most ventral and most dorsal points on the articular

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surface of the humeral head, were determined on CT images in accordance with GM standards, and measurements were performed using SECTRA software. These reference points, designated TD1 and TD2 in the GM standards, were used as reference points in calculating the transverse diameter [14] (Figure 2, Figure 3).

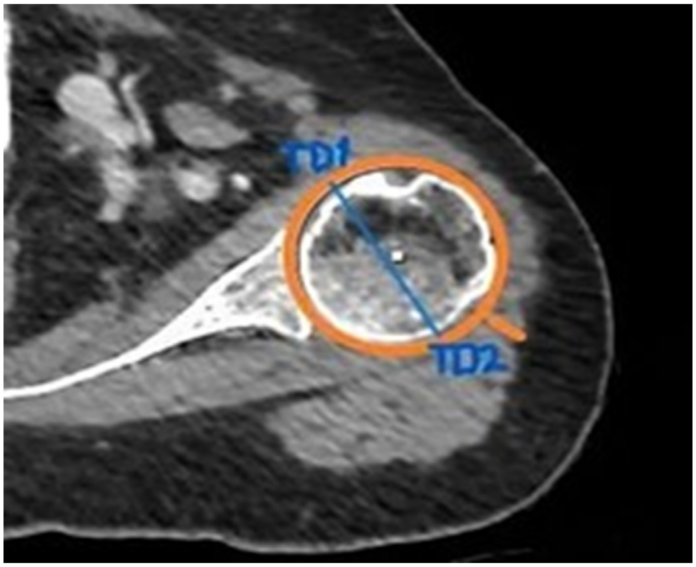

Figure 2. Measurement of the transverse diameter of the humeral head on the transverse plane, TD1: The most ventral point on the margin of the articular surface of the humeral head; TD2: The most dorsal point on the margin of the articular surface of the humeral head

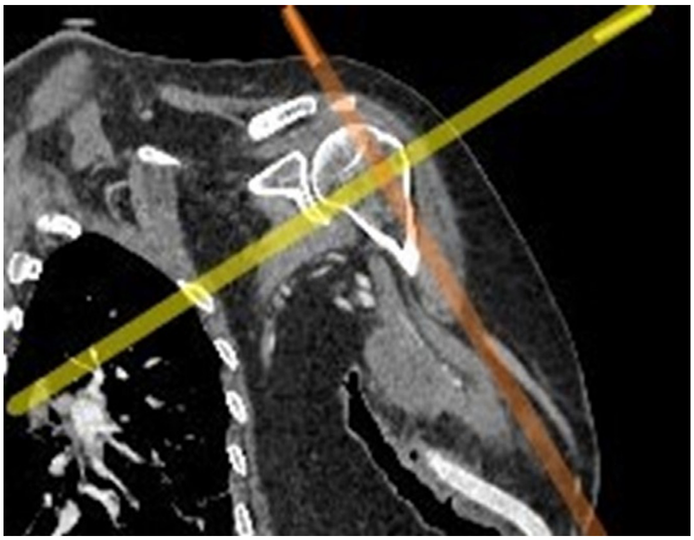

Figure 3. Representative CT image demonstrating alignment of the humeral head to the orthogonal plane [intersection point of the vertical axis (orange line) and the transverse axis (yellow linein the frontal plane]

Circumference of the Surgical Neck (CSN)

The CSN is defined as the area 1 cm below the lowest point of the humeral head articular surface. The CT scan was measured 1 cm below the articular surface using the most appropriate angle for the humerus [15] (Figure 4, Figure 5).

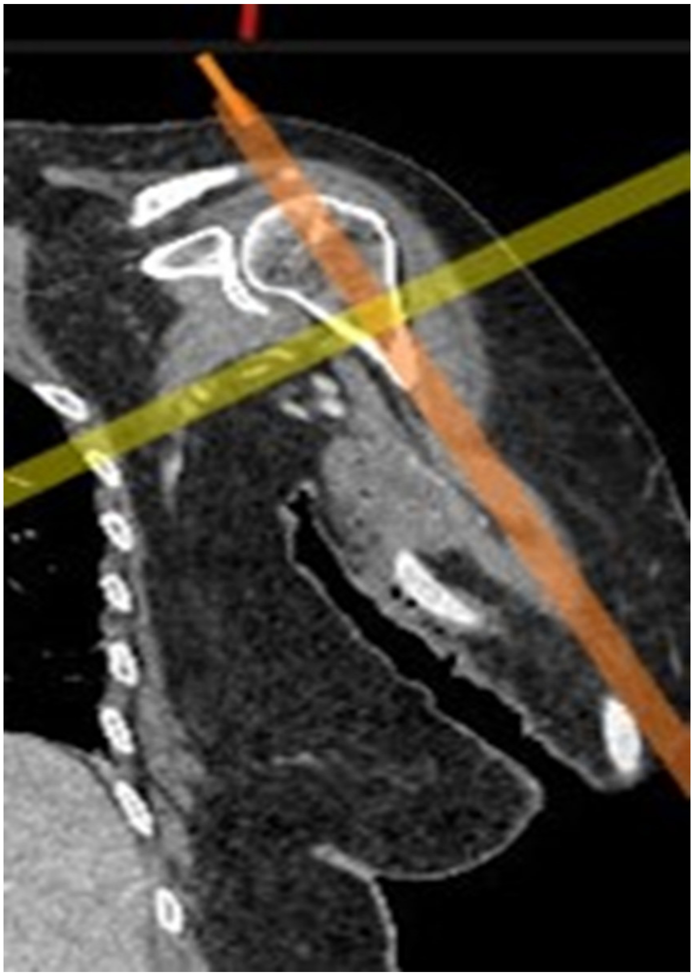

Figure 4. Representative CT image demonstrating alignment of the surgical neck (collum chirurgicum) to the orthogonal plane [intersection point of the vertical axis (orange line) and the transverse axis (yellow line) in the frontal plane]

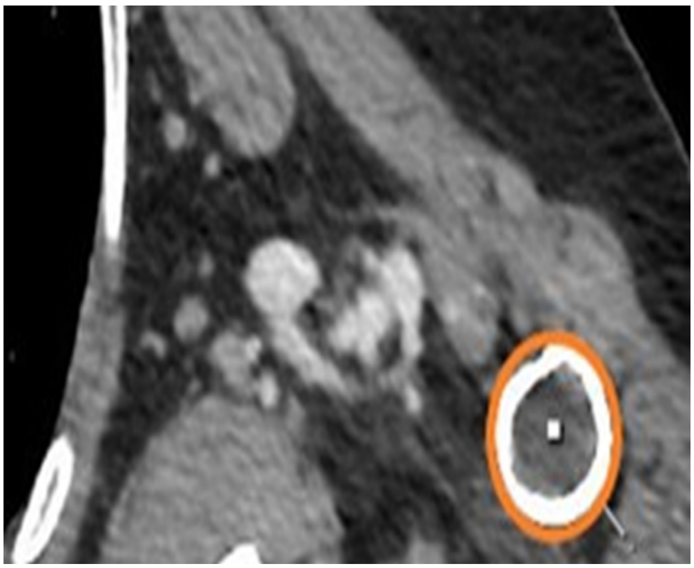

Figure 5. Measurement of the circumference of the surgical neck on the transverse plane

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Length of the Humeral Shaft (LHS)

For the measurement LHS, the distance between the proximal metaphyseal–diaphyseal junction and the distal metaphyseal–diaphyseal junction was measured on CT images. The angle providing the clearest visualization of the anatomical structure was adjusted, and the shaft length was determined accordingly.

Width of the Humeral Shaft (WHS)

Since the humeral shaft has a cylindrical structure in the upper part and a pyramidal structure in the lower part, the shaft width was measured via CT using the midline close to the cylindrical region as the reference point.

Width of the Capitulum Humeri (WCH)

The WCH was defined as the transverse distance between the most lateral point of the capitulum and the vertical groove separating the capitulum humeri from the trochlea humeri. CT images were adjusted to the orthogonal plane, and after obtaining the correct angle, the distance was measured on the transverse plane [16] (Figure 6, Figure 7, Figure 8).

Figure 6. Representative CT image demonstrating alignment of the capitulum humeri to the orthogonal plane [intersection point of the sagittal axis (red line) and the transverse axis (yellow line) on the sagittal plane]

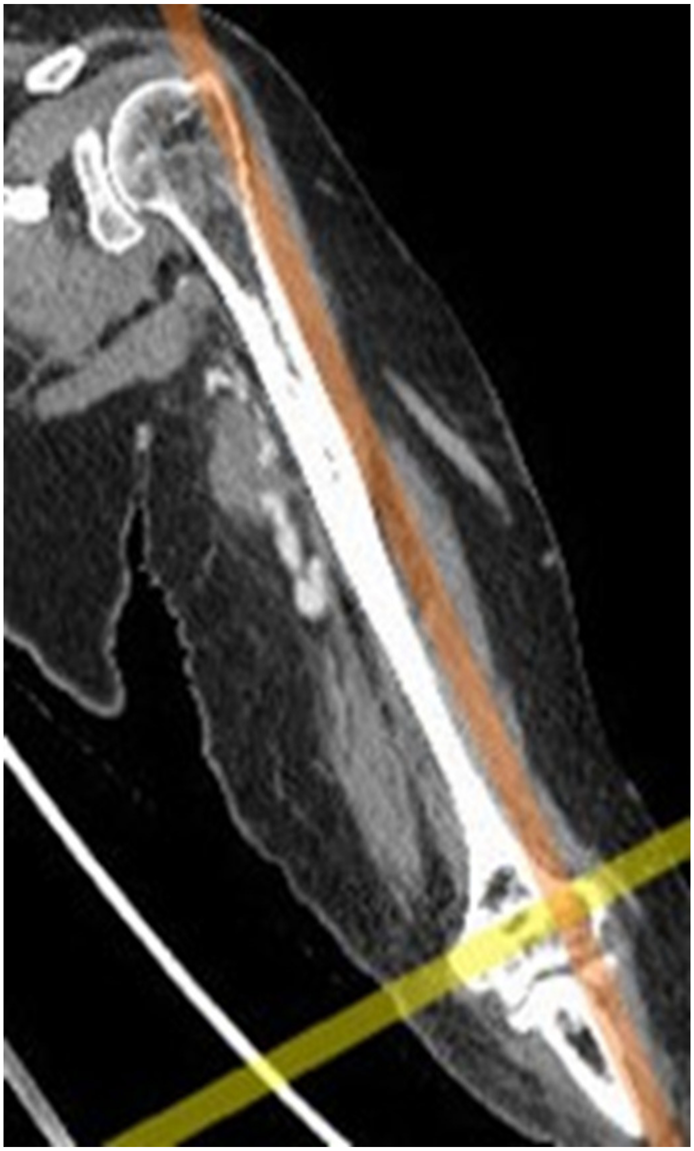

Figure 7. Representative CT image demonstrating alignment of the capitulum humeri and trochlea humeri to the orthogonal plane [intersection point of the vertical axis (orange line) and the transverse axis (yellow line) in the frontal plane]

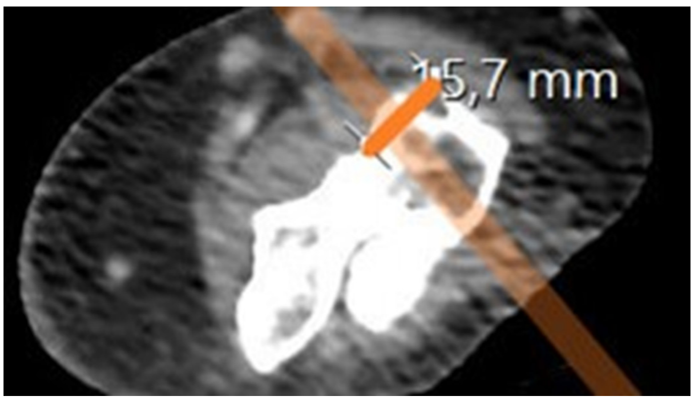

Figure 8. Measurement of the width of the capitulum humeri on the transverse plane

Length of the capitulum humeri (LCH)

LCH is the vertical distance between the transverse axes, which extend between the highest and lowest points of the humeri capitulum. The anatomical structure where the humeri capitulum and humeri trochlea are most prominent was aligned in the vertical plane using a CT image. The highest and lowest points of the transverse axis were determined, and the distance to the LCH was measured [16] (Figure 6, Figure 7).

Width of the Trochlea Humeri (WTH)

The WTH was defined as the transverse distance between its medial and lateral margins along the vertical axis. CT images were oriented to the orthogonal plane, and after adjusting to the correct angle, the measurement was performed on the transverse plane [16] (Figure 7).

Length of the Trochlea Humeri (LTH)

The LTH was defined as the vertical distance between the most superior and most inferior boundaries of its medial portion along the transverse axis. On CT images, the section in which the trochlea humeri appeared most clearly was adjusted to the vertical plane. The superior and inferior landmarks on the medial aspect of the transverse axis were identified, and the length of the trochlea humeri was measured accordingly [16] (Figure 7).

Epicondylar Width (EW)

The EW was defined as the transverse distance between the most prominent point on the lateral epicondyle and the most prominent point on the medial epicondyle. CT images were oriented to the orthogonal plane, and after adjusting to the correct angle, the most protruding landmarks were identified on the transverse plane, and the measurement was performed accordingly (Figure 6, Figure 7).

Maximum Length of the Humerus (MLH)

The MLH was defined as the distance between the most superior point of the humeral head and the most distal point of the trochlea humeri [17]. On CT images, the angle that provided the clearest visualization of the anatomical structure was adjusted, and the maximum humeral length was measured accordingly.

Data Analysis

The data were analyzed using IBM SPSS Statistics v23. Normality was assessed with the Kolmogorov–Smirnov and Shapiro–Wilk tests. For quantitative variables showing normal distribution, comparisons of two independent groups were performed using the Independent Samples t-test, whereas for those not normally distributed, the Mann–Whitney U test was applied. Descriptive statistics for quantitative variables were expressed as mean ± standard deviation and median (minimum–maximum). The level of statistical significance was set at $p<0.05$.

The relationship between the measured humeral parameters and age was analyzed using IBM SPSS Statistics v23. For variables that did not follow a normal distribution, associations were evaluated with Spearman's rho correlation test. The level of statistical significance was set at $p<0.05$.

Results

In the preliminary phase of the study, a power analysis was performed using Power Analysis and Sample Size Software (PASS) based on data from the literature. The results indicated that, in order to achieve a 95% confidence level and 95% test power, the minimum required sample size was 84 participants, with 42 individuals in each group. In the present study, morphometric measurements of the humerus were performed on CT images of a total of 105 patients, consisting of 43 females and 62 males. Since information on the laterality of the humeri was not available, measurements were analyzed without differentiating between right and left humeri.

Demographic Characteristics of Participants

In the study population, males accounted for 60% and females for 40%. The mean age of males and females was 43.62 ± 17.42 years and 56.36 ± 20.84 years, respectively. The overall mean age of all participants was 48.71 ± 19.78 years. A statistically significant difference was observed between the mean ages of males and females ($p=0.002$). The statistical data on the ages of male and female participants are presented in Table 1.

Considering all humeruses included in the study, TDH 5.36 ± 0.51 cm, CSN 9.62 ± 1.13 cm, LHS 20.25 ± 1.72 cm, WHS 2.30 ± 0.35 cm, WCH 1.72 ± 0.24 cm, LCH 2.23 ± 0.32cm, WTH 2.86 ± 0.42 cm, LTH 2.43 ± 0.35 cm, EW 6.16 ± 0.53 cm, MLH 30.61 ± 2.14 cm (Table 2).

Table 1. Age index of individuals included in the study

Variable (Units)	N	Age (year)	SD (cm)	Median (min-max) (cm)	Test statistics	p value
Female	43	56.36	± 20.84	56.5 (18 - 96)		
Male	62	43.62	± 17.42	39 (18 - 80)	859	**0.002***
Total	105	48.71	± 19.78	47 (18 - 96)		

*Mann Whitney U test, Mean± Standard deviation, Median (minimum-maximum)

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Table 2. Mean values of measurements taken from all individuals

Measured parameter N=105	Mean ± SD (cm)	Min. (cm)	Max. (cm)
TDH	5.36 ± 0.51	4.47	7.38
CSN	9.62 ± 1.13	6.76	12.09
LHS	20.25 ± 1.72	13.94	23.77
WHS	2.3 ± 0.35	1.73	3.84
WCH	1.72 ± 0.24	1.23	2.71
LCH	2.23 ± 0.32	1.4	2.96
WTH	2.86 ± 0.42	2.13	4.59
LTH	2.43 ± 0.35	1.42	3.32
EW	6.16 ± 0.53	4.54	7.29
MLH	30.61 ± 2.14	23.39	34.78

x: Mann Whitney U Test, y: Independent Samples T-Test, (TDH: Transverse Diameter of the Humeral Head, CSN: Circumference of the Surgical Neck, LHS: Length of the Humeral Shaft, WHS: Width of the Humeral Shaft, WCH: Width of the Capitulum Humeri, LCH: Length of the Capitulum Humeri, WTH: Width of the Trochlea Humeri, LTH: Length of the Trochlea Humeri, EW: Epicondylar Width, MLH: Maximum Length of the Humerus)

For quantitative data showing a normal distribution, the mean value was taken as basis. The mean value of CSN in men was 10.29 ± 0.72 cm while it was 8.63 ± 0.87 cm in women. There was a statistically significant difference between the mean values of CSN according to gender (r=0.64, p<0.001). The mean value of LHS in men was 21.04 ± 1.61 cm while it was 19.09± 1.15 cm in women. There was a statistically significant difference between the mean values of LHS according to gender (r=0.55, p<0.001). The mean value of LCH in men was 2.37 ± 0.28 cm while it was 2.03 ± 0.25 cm in women. There was a statistically significant difference between the mean values of LCH according to gender (r=0.53, p<0.001). The mean value of LTH in men was 2.54 ± 0.33 cm while it was 2.26 ± 0.33 cm in women. There was a statistically significant difference between the mean LTH values by gender (r=0.39, p<0.001). The mean EW value in men was 6.48 ± 0.37 cm, while it was 5.69 ± 0.37 cm in women. There was a statistically significant difference between the mean EW values by gender (r=0.72, p<0.001). The mean MLH value in men was 31.74 ± 1.76 cm, while it was 28.91 ± 1.40 cm in women. There was a statistically significant difference between the mean MLH values according to gender (r=0.66, p<0.001) (Table 3, Figure 1).

Table 3. Comparison of variables by gender

(cm)	Gender		Test statistics	r	p
	Male mean median (min-max)	Female mean median (min-max)			
TDH	5.68 ± 0.39 5.6 (4.67 – 7.38)	4.89 ± 0.26 4.89 (4.47 – 5.53)	86.500	0.61	<0.001^x
CSN	10.29 ± 0.72 10.27 (9.01 – 12.09)	8.63 ± 0.87 8.64 (6.76 – 10.56)	10.646	0.64	<0.001^y
LHS	21.04 ± 1.61 21.04 (13.94 – 23.77)	19.09 ± 1.15 19.22 (16.18 – 21.14)	6.754	0.55	<0.001^y
WHS	2.48 ± 0.33 2.42 (2 – 3.84)	2.06 ± 0.22 1.99 (1.73 – 2.53)	342.500	0.58	<0.001^x
WCH	1.8 ± 0.2 1.79 (1.4 – 2.49)	1.61 ± 0.25 1.61 (1.23 – 2.71)	621.000	0.39	<0.001^x
LCH	2.37 ± 0.28 2.39 (1.4 – 2.96)	2.03 ± 0.25 2 (1.48 – 2.67)	6.405	0.53	<0.001^y
WTH	3.08 ± 0.4 3 (2.42 – 4.59)	2.53 ± 0.19 2.54 (2.13 – 2.91)	152.500	0.63	<0.001^x
LTH	2.54 ± 0.33 2.57 (1.42 – 3.25)	2.26 ± 0.33 2.22 (1.67 – 3.32)	4.282	0.39	<0.001^y
EW	6.48 ± 0.37 6.47 (5.26 – 7.29)	5.69 ± 0.37 5.72 (4.54 – 6.65)	10.559	0.72	<0.001^y
MLH	31.74 ± 1.76 31.99 (24.25– 34.78)	28.91 ± 1.40 29.17 (23.39 – 31.05)	101.573	0.66	<0.001^y

x: Mann Whitney U Test, y: Independent Samples T-Test, Measurement values are given in cm. (TDH: Transverse Diameter of the Humeral Head, CSN: Circumference of the Surgical Neck, LHS: Length of the Humeral Shaft, WHS: Width of the Humeral Shaft, WCH: Width of the Capitulum Humeri, LCH: Length of the Capitulum Humeri, WTH: Width of the Trochlea Humeri, LTH: Length of the Trochlea Humeri, EW: Epicondylar Width, MLH: Maximum Length of the Humerus

For quantitative data that did not show a normal distribution, the median value was taken as basis. The median value of TDH in men was 5.6 ± 0.39 cm while it was 4.89 ± 0.26 cm in women (r=0.61, p<0.001). The median value of WHS in men was 2.42 ± 0.33 cm while it was 1.99 ± 0.22 cm in women (r=0.58, p<0.001). The median value of WCH in men was 1.79 ± 0.2

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cm while it was 1.61 ± 0.25 cm in women (r=0.39, p<0.001). The median value of WTH in men was 3 ± 0.4 cm while it was 2.54 ± 0.19 cm in women (r=0.63, p<0.001). There were a statistically significant difference between TDH, WHS, WCH and WTH median values according to gender (Table 3, Figure 1). Significant negative correlations were observed between age and CSN, LHS, WTH, and MLH in the overall sample (Table 4), whereas sex-specific analysis revealed significant positive correlations between age and TDH and EW only in females, with no significant associations observed in males (Table 5).

Table 4. Examining the relationship between the variables related to the humerus and the age variable

Measured parameter N=105	Age	
	r*	p
TDH	-0.145	0.140
CSN	-0.329	0.001
LHS	-0.301	0.002
WHS	-0.102	0.300
WCH	0.017	0.862
LCH	-0.129	0.191
WTH	-0.338	<0.001
LTH	-0.085	0.387
EW	-0.118	0.232
MLH	-0.306	0.002

Spearman's rho correlation, (TDH: Transverse Diameter of the Humeral Head, CSN: Circumference of the Surgical Neck, LHS: Length of the Humeral Shaft, WHS: Width of the Humeral Shaft, WCH: Width of the Capitulum Humeri, LCH: Length of the Capitulum Humeri, WTH: Width of the Trochlea Humeri, LTH: Length of the Trochlea Humeri, EW: Epicondylar Width, MLH: Maximum Length of the Humerus)

Table 5. Examining the relationship between the male and female variables of the humerus and the age variable

Measured parameter N=105	Female		Male	
	r*	p	r*	p
TDH	0.347*	**0.024**	0.026	0.837
CSN	-0.267	0.088	-0.133	0.297
LHS	-0.144	0.363	-0.160	0.210
WHS	0.216	0.057	-0.040	0.758
WCH	0.160	0.313	0.192	0.132
LCH	0.202	0.199	0.042	0.742
WTH	-0.094	0.555	-0.188	0.139
LTH	0.142	0.368	0.055	0.667
EW	0.333*	**0.031**	0.078	0.543
MLH	-0.129	0.415	-0.148	0.246

Spearman's rho correlation, * The correlation is significant at the 0.05 level. (TDH: Transverse Diameter of the humeral head, CSN: circumference of the surgical neck, LHS: Length of the humeral shaft, WHS: Width of the humeral shaft, WCH: Width of the capitulum humeri, LCH: Length of the capitulum humeri, WTH: Width of the trochlea humeri, LTH: Length of the trochlea humeri, EW: Epicondylar width, MLH: Maximum Length of the humerus)

Discussion

Many studies have been conducted to identify differences among individuals, such as age, height, and sex, which are influenced by the structural characteristics unique to different populations [18,19]. The adult human skeleton is widely recognized as an important reference point in the determination of these demographic variables.

A review of the literature demonstrates that various skeletal elements have been evaluated for this purpose. The cranium has frequently been analyzed to determine sex and population-specific differences [20,21]. Similarly, the vertebrae [22], humerus [23], mandible, teeth [24,25] have also been investigated as reliable skeletal markers. Collectively, these studies highlight the crucial role of skeletal structures in anthropological, clinical, and forensic research.

Udhaya and colleagues, in a study conducted on humeral bones from 170 adults of both sexes aged between 30 and 60 years in South India, reported the mean humeral length as 30.10 cm. This value is very close to the mean length obtained in our study, which was 30.61 cm. The researchers noted that the length of long bones can be used in the estimation of an individual's stature. They further emphasized that, in archaeological contexts, the estimation of stature from human skeletal remains plays an important role in assessing health status, sexual dimorphism, general body size trends in past populations, and life expectancy. In addition, they concluded that the average values of humeral length provide important scientific evidence reflecting the characteristic features of a population in forensic investigations and anthropometric studies [26].

Drew and colleagues generated CT data from 58 paired cadaveric humeri (43 male, 15 female) to evaluate sex- and laterality-related differences in humeral diaphyseal morphology. Their measurements revealed that biomechanical length showed statistically significant differences with respect to both sex and laterality. In addition, the humeral head radius was found to be significantly larger in males compared to females, and retroversion was greater in the right humerus than in the left [27].

Cohen and colleagues conducted a study in the western region of Israel, examining human skeletal remains. By applying both morphological and metric analysis methods, they were able to determine the age, sex, possible articulations, and anatomical positions of each bone. Based on this comprehensive evaluation, they concluded that the remains belonged to a single individual [28].

In a study conducted on 100 dry humeruses, Mutluay and colleagues performed 28 segmental measurements (distances between parameters) from eight different anatomical points. These segmental measurements were then compared with the maximum length of the humerus. While no statistically significant differences were found between humeral segments, the researchers reported a high level of correlation between all segments [29].

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Prashanth and colleagues evaluated a total of 166 dry humeri, regardless of gender, in their study of the humerus. Seven different parameters were determined from the distal portion of each bone, and the mean MLH value was measured as 30.5 cm humerus. The researchers concluded that such regression analyses are an important tool for estimating humeral length, and hence height, in anthropological and archaeological studies [30]. In this context, the MLH value of 31.05 cm obtained in our study is consistent with the findings reported in the literature.

Şenol and colleagues performed morphometric measurements on 42 dry humeri of unknown age and sex. The parameter values measured in their study and in ours were as follows, respectively: mean TDH 4.25 ± 0.28 cm vs. 5.36 ± 0.51 cm; mean MLH 30 cm vs. 30.61 ±2.14 cm; mean CSN 7.2 ± 0.87 cm vs. 9.62 ± 1.13 cm; mean WTH 1.56 ± 0.44 cm vs. 2.86 ±0.42 cm; mean LTH 2.07 ± 0.44 cm vs. 2.43 ± 0.35 cm; mean WCH 1.62 ± 0.41 cm vs. 1.72± 0.24 cm; mean LCH 2.06 ± 0.17 cm vs. 2.23 ± 0.32 cm; and mean EW 5.9 cm vs. 6.16 ±0.53 cm. According to these findings, the morphometric measurements obtained in our study were generally higher compared to the data reported by Şenol and colleagues [31].

Chada and Mahato, emphasized the importance of determining sex from bone structures in medical research. For this purpose, they performed morphometric analysis on250 humeri to evaluate sexual dimorphism. The sample included 145 male and 105 female humeri, and it was found that all measurements were statistically significantly higher in males compared to females. In their study, the mean EW was calculated as 5.92± 0.45 cm in males and 5.26 ± 0.36 cm in females, while the mean TDH was 4.14 ± 0.27 cm in males and 3.51 ± 0.29 cm in females [32]. In our study, however, higher values were observed: the mean EW was measured as 6.48 ± 0.37 cm in males and 5.69 ± 0.37 cm in females, and the mean TDH as 5.68 ± 0.39 cm in males and 4.89 ± 0.26 cm in females.

Gazi Huri et al. measured the mean HMU in six male cadavers as 27.18 cm, using the technique of determining muscle locations in humerus fractures without interfering with the fracture line. In our study, the HMU was found to be larger than that, and the mean HMU in male subjects was measured as 31.74 cm [33].

In the study conducted by Ara and colleagues, the distal humeral parameters were found to be larger in males compared to females [34].

Christopher King conducted a study to investigate sex determination using the humerus in individuals from China, Japan, and Thailand, and to investigate size and sexual dimorphism within the population. Eighty-seven skeletons of known sex were collected from cemeteries near the cities of Qingdao (Shandong) and Chang Chun (Liaoning) in China; 90 skeletons from Japan, whose skeletons are held in the Department of Anatomy at Jikei Medical University in Tokyo; and 104 Thai skeletal remains from Chiang Mai and surrounding villages who died at Chiang Mai University Hospital between 1993 and 1996. Morphometric measurements were performed using six parameters from the most similarly sized left humerus bones. The study revealed that male humeruses are larger than females. Specifically, the maximum humerus length was found to be greater in the Chinese population than in other groups. According to this result, it is also clearly stated that the humerus bone is a good bone for determining sex in Chinese, Japanese and Thai people and that the degree and distribution of sex dimorphism varies both within and between different regions [35].

Jeong and colleagues conducted a study in Korea with a sample consisting of 100 patients who underwent CT imaging at Myongji Hospital, with a mean age of 48 years (range: 17–83 years), aiming to investigate the anatomy of the proximal humerus. In this study, nine parameters were defined, and the data were compared according to age and sex. Based on their findings, they concluded that humeral measurement values specific to the Korean population could be utilized in the design of arthroplasty prostheses and may contribute to achieving a more accurate anatomical reconstruction of the shoulder joint [36].

Ismail and colleagues, in their comparative study of two different populations, examined thearm bones (humerus, radius, and ulna) of 151 Yoshigo individuals (Aichi, Japan) and 156 Dilkaya individuals (Van, Türkiye). This research was conducted to assess sex determination using discriminant analysis based on data obtained from the measurements of arm bones belonging to ancient Anatolian and Japanese populations. After determining the sex and age of the skeletons, standard osteometric measurement techniques were applied, and 15 different measurements were taken from each individual using an osteometric board, calipers, and a measuring tape. According to their findings, the accuracy rate for sex estimation ranged from70.5% to 86.3% in the Yoshigo population, and from 70% to 92.6% in the Dilkaya population, with the latter yielding more reliable results [37].

Although numerous studies on sex determination have been conducted across different populations, there are also investigations focusing specifically on humeral variations between races and sexes. In a study carried out by Adnan Öztürk and colleagues at the Department of Anatomy, Istanbul University Faculty of Medicine, a total of 114 humeri of unknown age and sex were examined. The presence of the supratrochlear foramen on the humerus was identified and morphometric measurements were performed. The findings revealed that this foramen was present in 9 humeri. Furthermore, it was reported that the occurrence of the supratrochlear foramen was more frequent in the left humerus compared to the right, in Black individuals compared to White individuals, and in females compared to males [38].

Morphometric measurements of the humerus are considered to contribute both to the literature and to upper extremity surgery. Factors such as female sex, advanced age, and social deprivation have been reported as risk factors for proximal humeral fractures. The treatment of proximal humeral fractures involves various challenges, and the diversity of fracture types makes their classification complex. Therefore, morphometric measurements of the humerus bear clinical significance [39]. Distal humerus fractures are often difficult to fix due to joint stiffness, functional weakness, compound fractures, or painful pseudoarthrosis accompanied by nonunion of the fractured area. Therefore, an olecranon osteotomy may be necessary to stabilize the anterior joint fragments. Furthermore, osteopenic bone, increased fragmentation, and increased trauma-related joint destruction in elderly patients present challenges in achieving anatomic reduction and stable fixation [40]. Therefore, morphometry of the distal humerus can be helpful in reconstructive surgery using implants, as orthopedic surgeons struggle to repair complex fractures. One of the significant limitations of this study is the inconsistent availability of humeral laterality information in the retrospectively used PACS based CT data, preventing the differentiation of the right and left humeruses. Studies in the literature report that humeral morphology may differ depending on laterality, and it has been suggested that these differences may be related to functional dominance and mechanical loading. Therefore, the inability to perform laterality based analysis limits the interpretation of the results, especially in terms of side-specific morphometric assessments. However, the main aim of this study is to reveal gender related morphometric differences in the humerus. The literature reports that the effect of gender dimorphism on humeral morphometry is more pronounced than the effects of laterality. Accordingly, it is believed that the main findings of this study regarding gender remain valid. Future prospective studies are recommended to use designs that control for laterality information and analyze the right and left humeruses separately. Despite these limitations, the data obtained make a significant contribution to the literature in terms of revealing sex related morphometric differences in the humerus.

Conclusion

Although numerous studies on humeral morphometry have been reported in the literature, in the present study a total of 105 adult individuals (43 females and 62 males) were evaluated using CT images, and ten different parameters were measured to provide a detailed assessment of humeral morphology. The findings demonstrated that humeral measurements were significantly higher in males compared to females across all parameters. In addition, a statistically significant but weak negative correlation was observed between age and certain parameters (transverse diameter of the humeral head, length of the capitulum, and width of the trochlea). This indicates that some morphometric structures tend to decrease with advancing age.

The main limitation of this study is that the measurements were not performed directly on dry bones using conventional anthropometric methods, but rather on CT images. Nevertheless, the majority of the parameters analyzed have been widely studied in the literature, and our results show a high degree of consistency with previous findings.

The data obtained in this research demonstrate that sex-related morphometric differences in the humerus are statistically significant. Therefore, humeral measurements may serve as valuable guidance in orthopedic surgical applications, particularly in implant selection and preoperative planning. Furthermore, these data can provide an important reference in forensic medicine and forensic anthropology for age and sex estimation during identification processes. Beyond these applications, the findings are also expected to contribute to paleoanthropological studies by shedding light on human evolution and anatomical diversity, thus offering original data that may be utilized across multiple disciplines.

Ethical Approval

Approved by the Ethics Committee for Non- Interventional Clinical Research of Tokat Gaziosmanpaşa University (No: 24-KAEK-131; Date: 28 March 2024).

Patient Consent

Informed consent was waived due to the retrospective design.

Conflict of Interest

The authors declare no conflict of interest.

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