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ORIGINAL ARTICLE

Osteometric analysis of the intertubercular sulcus of the humerus

Análisis osteométrico del surco intertubercular del húmero

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Abstract

Background:

The anatomical variations and deviations from the expected intertubercular sulcus morphometry are associated with the physiology of the long head of the biceps brachii tendon. These variations may affect tendon biomechanics, potentially impacting shoulder joint stability.

Aim:

To evaluate the osteometric features of the intertubercular sulcus, including its dimensions, angles, and bony protrusions, and to compare these variables according to side and sex.

Methods:

The descriptive, cross-sectional study included a sample of 85 humeri. Morphometric analysis involved measurements of the intertubercular sulcus width, depth, and length; distances between its walls and the lesser and greater tubercles; and calculations of angles. Measurements were obtained using ImageJ (version 150i). Additionally, a non-metric method was used to determine sex based on the shape and prominence of structures at the distal end of the humerus.

Results:

The distances between the head and the greater and lesser tubercles were statistically significantly greater on the right humeri. The length of the lateral lip of the sulcus was greater in males compared with female humeri (114.2 mm vs. 108.7 mm). The right side's opening angle was higher than on the left (78.7° vs. 74.4°). Bony spikes were observed on the greater tubercle in four humeri (4.7%), on the lesser tubercle in seven humeri (8.2%), and supratubercular ridges were identified in a total of 10 humeri (11.8%).

Conclusions:

The dimensions of the intertubercular sulcus were larger on the right humeri. Analysis of the angles of the intertubercular sulcus provides a more precise account of its morphology.

Conflict of interest

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CRediT authorship contribution statement:

DR conceptualization, data curation, formal analysis, investigation, methodology, project administration, software, supervision, validation, visualization, writing - original draft, and writing - review & editing. **SD** data curation, formal analysis, methodology, project administration, software, and sualization. **NV** conceptualization, formal analysis, investigation, methodology, project administration, validation, visualization, and writing - review & editing. **DM** conceptualization, methodology, project administration, visualization, writing - original draft, and writing - review & editing. **RP** data curation, formal analysis, methodology, project administration, and visualization.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author, Dragana Radošević, MD, PhD. E-mail: dragana.radosevic@mf.uns.ac.rs. Datasets related to this article will be available upon request to the corresponding author.

Resumen

Antecedentes

Las variaciones anatómicas y las desviaciones de la morfometría esperada del surco intertubercular se asocian con la fisiología del tendón de la cabeza larga del bíceps braquial. Estas variaciones pueden afectar la biomecánica del tendón, lo que podría repercutir en la estabilidad de la articulación del hombro.

Objetivo

Evaluar las características osteométricas del surco intertubercular, incluidas las dimensiones, ángulos y prominencias óseas, y comparar dichas variables según la lateralidad y el sexo.

Métodos

El estudio descriptivo y transversal incluyó una muestra de 85 húmeros. El análisis morfométrico comprendió mediciones del ancho, la profundidad y la longitud del surco intertubercular; de las distancias entre sus paredes y los tubérculos mayor y menor; y el cálculo de ángulos. Las mediciones se obtuvieron con ImageJ (versión 150i). Además, se empleó un método no métrico para determinar el sexo, basado en la forma y la prominencia de las estructuras en el extremo distal del húmero.

Resultados

Las distancias entre la cabeza y los tubérculos mayor y menor fueron estadísticamente significativamente mayores en los húmeros derechos. La longitud del labio lateral del surco fue mayor en los húmeros masculinos vs. los femeninos (114.2 mm vs. 108.7 mm). El ángulo de apertura del lado derecho fue mayor que el del lado izquierdo (78.7° vs. 74.4°). Se observaron espículas óseas en el tubérculo mayor en cuatro húmeros (4.7%) y en el tubérculo menor en siete húmeros (8.2%), y se identificaron crestas supratuberculares en un total de 10 húmeros (11.8%).

Conclusiones

Las dimensiones del surco intertubercular fueron mayores en los húmeros derechos. El análisis de los ángulos del surco intertubercular proporciona una descripción más precisa de su morfología

Remark

1) Why was this study conducted?

This study examined the morphological characteristics of the intertubercular sulcus, including dimensions, angles, and bony protrusions at the proximal humeral end. The aim was to investigate the variations of the intertubercular sulcus, as well as the structures that form it. Considering the anthropological aspect of the study, comparisons of the parameters were also conducted between the sexes and by side of the body. Also, the aim was to detect and describe bony protrusions within the sulcus, as their presence is associated with the biomechanics of the tendon and the shoulder joint

2) What were the most relevant results of the study?

The most significant finding of the study is that the intertubercular sulcus of the humerus is more prominent in males than in females. The opening angle of the intertubercular sulcus is greater in right humeri compared to left ones, which may suggest increased instability of the tendon of the long head of the biceps brachii within the shoulder joint. Bony protrusions were also identified within the sulcus (bony spurs and supratubercular ridges).

3) What do these results contribute?

These results contribute to a better understanding of anatomical bony variations of the shoulder joint. A precise definition of the angles that characterize the intertubercular sulcus can more accurately determine the position of the tendon of the long head of the biceps brachii within the sulcus. The results provide a basis for further clinical studies examining the relationship between variations in the intertubercular sulcus and pathological conditions

Introduction

The tubercles (greater and lesser) on the proximal end of the humerus delimit the intertubercular sulcus (ITS), whose direction forms an obtuse angle open inwards and downwards. The medial wall of the intertubercular sulcus is limited by the lesser tubercle, the lateral lip by the greater tubercle, and the gap is bridged by the transverse humeral ligament [1]. The intertubercular sulcus is also covered by the tendons of the subscapularis, supraspinatus, and pectoralis major [2]. In this sulcus is the tendon of the long head of the biceps brachii. According to Rajani and Man [3], the intertubercular sulcus and the transverse humeral ligament stabilize the shoulder joint and reduce the possibility of dislocation of the tendon of the long head of the biceps brachii during multidirectional movements.

Based on published biometric studies across different populations, the average width of the intertubercular sulcus is 8.0-10.0 mm, the depth is 4.0-6.0 mm, and the length is 80.0-100.00 mm, respectively [3-6]. The opening angle (the angle between the walls of the intertubercular sulcus and tubercles) is most commonly analyzed to more precisely determine the morphometric characteristics of the sulcus as a whole, as well as its relationship with the tendon of the long head of the biceps brachii. The values of this angle lie approximately between 70° and 100°, and it seems to be associated with shoulder joint stability [3-5].

The literature suggests that humans' intertubercular sulcus is unique in its depth, width, and length compared to those of other primates [7,8]. Deviations from the standard values of the intertubercular sulcus can lead to tendon loading, traumatic injuries, tendonitis, and sheath inflammations [9-11]. Changes in the angle formed by the two tubercles with the lips of the intertubercular sulcus, as well as the sulcus width and tendon thickness, can also contribute to these issues [8]. Any deviation from the usual anatomy of the shoulder joint elements can result in shoulder impingement syndrome and a limited range of motion [12,13]. A shallow sulcus can lead to increased mobility in the shoulder joint and possible dislocation of the tendon, while a deep sulcus can cause pathological changes in the muscle tendon [14,15]. A supratubercular ridge can alter the direction of the long head of the biceps brachii tendon, potentially leading to inflammation, dislocations, and tendon ruptures [16]. Additionally, degenerative changes, such as spurs near the supratubercular ridge, can be present in the sulcus [17]. The intertubercular sulcus is important for orientation during shoulder joint surgery and prosthetic reconstruction of the upper end of the humerus [18].

Since anatomical variations in shoulder anatomy are related to the shoulder joint functionality and stability, the aim is to determine the intertubercular sulcus osteometric characteristics by measuring its dimensions and angles, identifying bony spurs and ridges, and comparing these features by side and sex.

Material and Methods

The descriptive study was conducted in the Department of Anatomy, Faculty of Medicine, University of Novi Sad. The Ethics Committee approved the research (decision number 01-39/269). Humeri without visible damage in the upper and lower regions were selected from the osteological collection of the department of anatomy. The total sample consisted of 85 dry bones (56 right-sided and 29 left-sided) from cadavers of unknown age, on which the same researcher conducted further measurements.

The humeri were photographed horizontally from the front and upper sides, from the fixed position, using a digital camera, Olympus SP-560UZ, with an 18x optical zoom. All parameters were determined in ImageJ (version 150i, public-domain software). During photography, rules for the validity of results obtained through image analysis were observed (consistent distance and angles between the camera lens and the target structure, with the same degree of illumination in the surroundings). Initially, non-metric determination of the cadaver's sex was performed, followed by a detailed inspection of the intertubercular sulcus and noting the presence of bony protrusions in the form of spurs and supratubercular ridges.

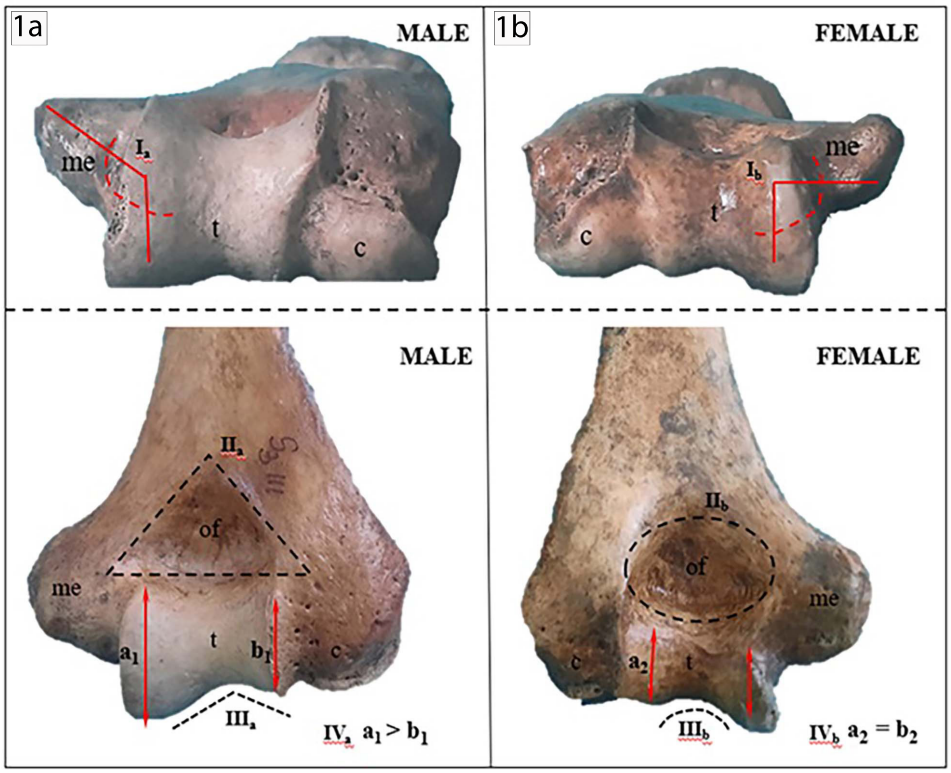

Figure 1. Determination of the sex of the humerus based on the appearance of the structure of the lower end (me: medial epicondyle, t: trochlea, c: capitulum, of: olecranon fossa)

Sexual differentiation of the humeri was non-metrically performed based on structural differences between males and females at the lower end of the bone. The following four parameters were analyzed [19,20] (Figure 1):

1. The angle formed by the medial epicondyle (me) with the rest of the lower end open forward: this angle is obtuse in males (Ia) and straight in female humeri (Ib).

2. The shape of the olecranon fossa (of): triangular in males (IIa) and more oval in females (IIb).

3. The shape of the trochlea's lower surface (t): characterized by an angular notch in males (IIIa) and a notched arch in female humeri (IIIb).

4. Symmetry of the trochlea in relation to the capitulum (c) of the humerus: asymmetric in males (IVa) and symmetric in females (IVb).

For a bone to be classified as male or female, it had to meet at least three of the four listed criteria for the respective sex. Thus, 53 male and 32 female humeri were further analyzed.

Osteometric Analysis

The osteometric analysis included measuring the dimensions of structures forming the intertubercular sulcus, the angles formed by these elements, and the corresponding bony structures on the upper end of the humerus.

The measurement and calculation of parameters defining the dimensions of the intertubercular sulcus included (Figures 2 a and 2b):

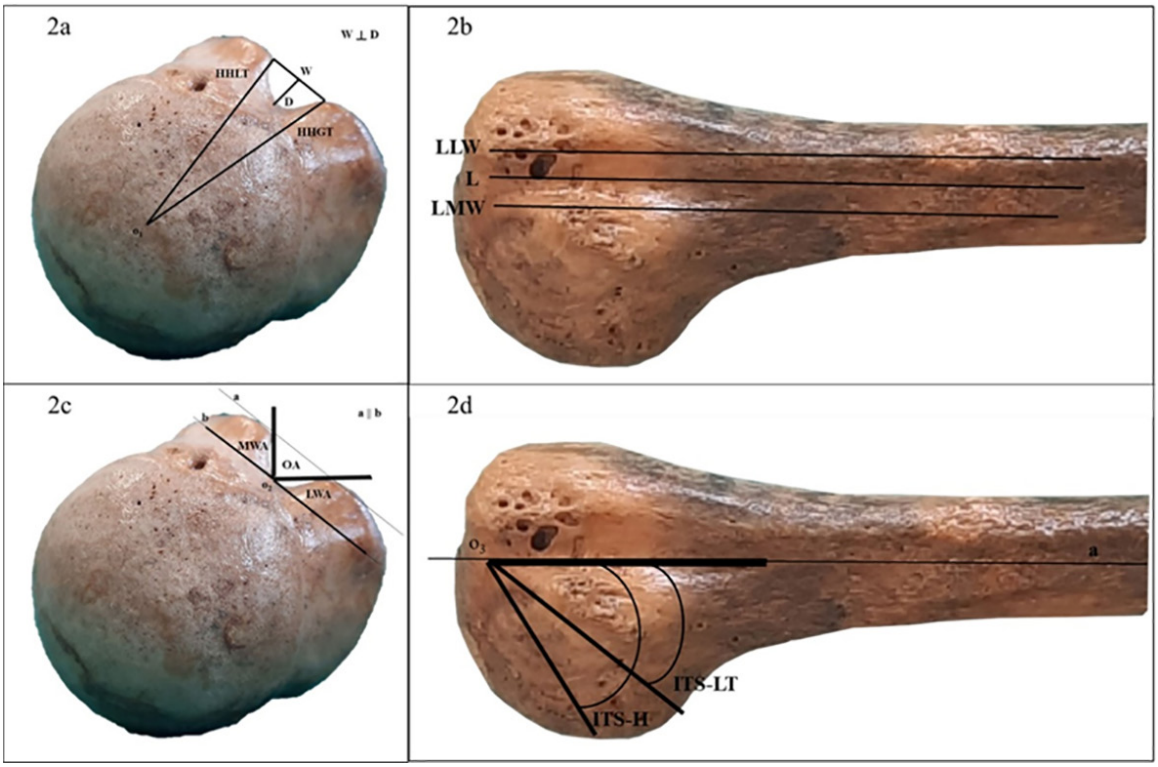

Figure 2. Representation of parameters of the intertubercular sulcus calculated at the upper end of the humerus (W: width, D: depth, HH-LT: distance between the center of the axis of the humeral head and the most protruding point of the lesser tubercle, HH-GT: the distance between the center of the axis of the humeral head and the most protruding point of the greater tubercle, W ⊥ D: D forms a right angle with the direction of the extension of W (2a). LLW: length of the lateral wall, L: length, LMW: length of the medial (2b). MWA: medial wall angle, OA: opening angle, LWA: lateral wall angle, a || b: line a passing through the most prominent points of the sulcus is parallel to line b passing through the deepest point of the sulcus (02) (2c). ITS-LT: angle formed by a line passing through the most medial point of the lesser tubercle and a line coinciding with the direction of the L, with the vertex at the most proximal point of the sulcus, ITS-H: angle formed by a line passing through the most medial point of the humeral head and a line coinciding with the direction of the L, with the vertex at the most proximal point of the sulcus (2d)).

- W (width of the sulcus): the distance between the most protruding points of the lesser and greater tubercle.
- D (depth of the sulcus): the distance between the deepest point of the intertubercular sulcus and the width.
- L (length of the sulcus): the distance between the proximal and distal points of the intertubercular sulcus.
- LMW: length of the medial wall of the intertubercular sulcus.
- LLW: length of the lateral wall of the intertubercular sulcus.
- HH-LT: distance between the center of the axis of the humeral head and the most protruding point of the lesser tubercle.
- HH-GT: the distance between the center of the axis of the humeral head and the most protruding point of the greater tubercle.

The measurement and calculation of angles formed by intertubercular sulcus structures included the following parameters (Figures 2 c and 2d):

- MWA (medial wall angle): angle formed by the medial wall of the intertubercular sulcus with a line (b) passing through the deepest point of the sulcus (O_2) and parallel to a line (a) coinciding with the width (W) of the intertubercular sulcus.
- LWA (lateral wall angle): angle formed by the lateral wall of the intertubercular sulcus with a line (b) passing through the deepest point of the sulcus (O_2) and parallel to a line (a) coinciding with the width (W) of the intertubercular sulcus.
- OA (opening angle): angle formed by the medial and lateral walls of the intertubercular sulcus at the level of the most protruding points of the lesser and greater tubercles.
- ITS-LT: angle formed by a line passing through the most medial point of the lesser tubercle and a line coinciding with the direction of the length (L) of the intertubercular sulcus, with the vertex at the most proximal point of the sulcus.
- ITS-H: angle formed by a line passing through the most medial point of the humeral head and a line coinciding with the direction of the length (L) of the intertubercular sulcus, with the vertex at the most proximal point of the sulcus.

The data obtained was analyzed using the SPSS 24.0 software package (SPSS, Inc., Chicago, IL). The results are presented as parameters of descriptive statistics (mean, standard deviation (SD), and minimum and maximum values (Min-Max)). The Student's t-test was used to determine differences between groups, and a statistically significant difference was considered if p <0.05. The results obtained are presented through figures, tables, and graphs.

Results

Bony spurs in the form of spikes were found on the greater tubercle in four bones (4.7%), with spikes on the lesser tubercle found in seven bones (8.2%), and supratubercular ridges were identified on a total of 10 humeri (11.8%) (Figure 3).

Results of osteometric analysis

The statistical descriptive analysis of parameters that more precisely determine the dimensions and angles of the intertubercular sulcus structures is presented in Table 1. The mean value of the width of the sulcus was 9.3 mm, the depth was 3.8 mm, and the length was 104.2 mm. The opening angle amounted to 77.2° and simultaneously had the highest standard deviation among all measured angles (± 22.4°) (Table 1).

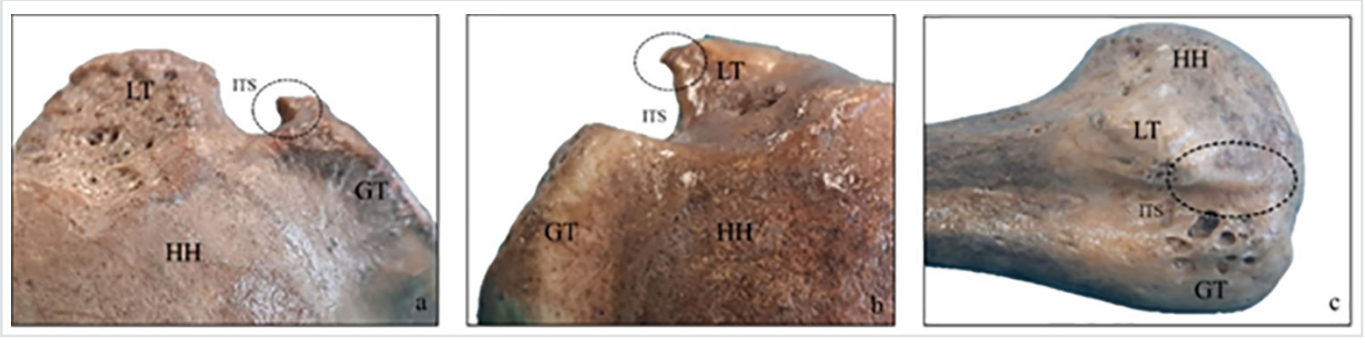

Figure 3. Representation of projections in the form of spikes on the greater tubercle (a), lesser tubercle (b), and supratubercular ridge (c). HH: humeral head, LT: lesser tubercle, GT: greater tubercle, ITS: intertubercular sulcus

Table 1. Presentation of the results of descriptive analysis of parameters of dimensions and angles of the intertubercular sulcus in all examined humeri (N= 85).

N= 85			
Parameter	**Media ± SD**	**Min**	**Max**
Width (mm)	9.3±1.6	6.5	13.4
Depth (mm)	3.8 ± 0.8	1.8	6.1
Length (mm)	104.2 ± 13.9	73.7	143.8
Length of medial wall (mm)	98.7 ± 13.1	73.2	133.9
Length of lateral wall (mm)	112.2 ± 13.8	83.9	155.2
Humeral head-lesser tubercle (mm)	24.4 ± 2.6	19.3	30.7
Humeral head-greater tubercle (mm)	25.8 ± 2.7	20.8	32.5
Medial wall angle (°)	53.6 ± 15.2	21.6	93.7
Lateral wall angle (°)	53.0 ± 14.9	12.6	91.1
Opening angle (°)	77.2 ± 22.4	24.0	138.5
Angle between the lesser tubercle and the most protruding point of the intertubercular sulcus (°)	44.4 ± 6.7	25.1	50.6
Angle between humeral head and most protruding point of intertubercular sulcus (°)	70.1 ± 7.6	50.6	90.9

N: number of the sample, Media: average value, SD: standard deviation, Min: minimum value, Max: maximum value.

Table 2 presents an analysis of the descriptive statistics and differences between the right and left humeri in parameters defining the dimensions of the intertubercular sulcus. A statistically significant difference (p= 0.03) was found in the distances between the center of the humeral head axis and the most prominent point of the lesser tubercle and the most prominent point of the greater tubercle between the right and left humeri.

Table 3 presents descriptive statistics for the measured dimensions and angles of the intertubercular sulcus, along with sex comparisons. All parameters have slightly higher values in male humeri. Although not statistically significant, the parameter showing the greatest difference between the sexes is the length of the lateral wall of the intertubercular sulcus, with a value of 114.2 mm in male humeri compared to 108.7 mm in female humeri. The average values of the angles formed between the most proximal point of the intertubercular sulcus with the lesser tubercle, and with the humeral head do not show a significant difference between the sexes (Table 3).

Table 2. Results of descriptive statistics and differences in dimensions and angles of the intertubercular sulcus according to the side.

N= 85	Right humeri (N= 56)			Left humeri (N= 29)			*p*
Parameter	**Media ± SD**	**Min**	**Max**	**Media ± SD**	**Min**	**Max**	
Width (mm)	9.5 ± 1.7	6.5	13.4	8.8 ± 1.3	6.5	11.8	0.08
Depth (mm)	3.8 ± 0.8	1.8	6.1	3.8 ± 0.8	2.2	5.8	0.92
Length (mm)	104.7 ± 14.1	73.7	143.8	103.3 ± 13.7	80.3	140.0	0.68
Length of medial wall (mm)	99.4 ± 13.5	73.2	133.9	97.2 ± 12.6	75.8	129.3	0.47
Length of lateral wall (mm)	112.6 ± 14.3	83.9	155.2	111.3 ± 12.8	87.0	144.9	0.70
Humeral head-lesser tubercle (mm)	24.8 ± 2.5	19.8	30.7	23.6 ± 2.7	19.3	30.2	0.03*
Humeral head-greater tubercle (mm)	26.3 ± 2.6	21.5	32.5	24.9 ± 2.8	20.8	31.0	0.03*
Medial wall angle (°)	52.5 ± 16.5	21.6	93.7	55.7 ± 12.4	31.3	80.9	0.37
Lateral wall angle (°)	52.4 ± 15.9	12.6	91.1	54.2 ± 12.9	34.7	79.4	0.60
Opening angle (°)	78.7 ± 23.7	24.0	138.5	74.4 ± 19.8	48.6	114.6	0.41
Angle between the lesser tubercle and the most protruding point of the intertubercular sulcus (°)	44.8 ± 7.1	25.1	59.7	45.0 ± 10.3	31.2	88.7	0.95
Angle between humeral head and most protruding point of intertubercular sulcus (°)	69.9 ± 8.0	50.6	90.9	70.6 ± 6.8	58.1	85.0	0.7

* p <0.05, N: number of the sample, Media: average value, SD: standard deviation, Min: minimum value, Max: maximum value.

Table 3. Results of descriptive statistics and differences in dimensions and angles of the intertubercular sulcus according to sex.

N= 85	Male humeri (N= 53)			Female humeri (N= 32)			*p*
Parameter	**Media ± SD**	**Min**	**Max**	**Media ± SD**	**Min**	**Max**	
Width (mm)	9.5 ± 1.6	6.6	13.4	8.9 ± 1.5	6.5	11.9	0.14
Depth (mm)	3.8 ± 0.8	2.3	6.1	3.8 ± 0.9	1.8	5.8	0.97
Length (mm)	105.8 ± 16.1	73.7	143.8	101.5 ± 8.9	79.4	119.4	0.17
Length of medial wall (mm)	100.3 ± 15.2	73.2	133.9	95.9 ± 8.4	77.0	113.7	0.14
Length of lateral wall (mm)	114.2 ± 15.8	83.9	155.2	108.7 ± 8.8	87.9	120.5	0.07
Humeral head-lesser tubercle (mm)	24.7 ± 2.7	19.8	30.7	24.0 ± 2.5	19.3	30.2	0.55
Humeral head-greater tubercle (mm)	26.2 ± 2.8	21.5	32.5	25.2 ± 2.6	20.8	30.8	0.13
Medial wall angle (°)	53.7 ± 15.7	21.6	93.7	53.4 ± 14.6	31.5	86.5	0.91
Lateral wall angle (°)	52.8 ± 12.6	29.3	80.2	53.3 ± 18.3	12.6	91.1	0.89
Opening angle (°)	77.9 ± 19.4	24.0	128.6	76.2 ± 27.0	28.4	138.5	0.74
Angle between the lesser tubercle and the most protruding point of the intertubercular sulcus (°)	44.4 ± 7.6	25.1	61.1	45.8 ± 9.3	36.5	88.7	0.45
Angle between humeral head and most protruding point of intertubercular sulcus (°)	70.3 ± 8.1	50.6	90.9	69.8 ± 6.7	57.7	84.9	0.76

N: number of the sample, Media: average value, SD: standard deviation, Min: minimum value, Max: maximum value.

Discussion

The etiology of variations in the humeri stems from different developmental and shaping processes of the intertubercular sulcus, whether related to embryological origin, different lifestyles, or their combined action. In cases of congenital absence of the long head of the biceps brachii, the formation of the intertubercular sulcus does not occur [21], indicating their embryological, anatomical, and functional interdependence. Muscle activity dictates the reshaping of bone structures, leading to the adaptation of morphology to function. Soft tissues around the intertubercular sulcus play a crucial role in biceps brachii tendon functionality and joint stability [22,23].

In our sample of 85 humeri, four bones possessed protrusions in spurs on the greater tubercle (4.7%), while the incidence of protrusions on the lesser tubercle was higher (8.2%). Bony spurs can be considered as osteophyte formation that occurs during inflammation or ossification of the synovial sheath of the long head of the biceps brachii tendon [24,25]. Venkatesan et al.[17] determined the prevalence of protrusions on the lesser tubercle as 15.5% and on the greater tubercle as 1.95% in a sample of 200 bones. Our findings similarly demonstrate a higher frequency of bony spurs on the lesser tubercle than on the greater tubercle. Considering that the tendon changes its direction to a more horizontal orientation relative to the humeral head after exiting the intertubercular sulcus and attaches to the supraglenoid tubercle of the scapula, the tendon may have a closer anatomical and functional relationship with the lesser tubercle.

Some authors suggest a connection between the supratubercular ridge and tendinitis of the long head of the biceps brachii [26], while others emphasize that this association is not significant [25]. In our sample, ten bones (11.8%) have a supratubercular ridge, which is somewhat lower than the results of other authors [16,17,25,26].

Osteometric Analysis

Osteometric analysis of the parameters of the intertubercular sulcus has shown that the average value of the sulcus width is 9.3 mm, the depth is 3.8 mm, and the length is 104.2 mm. In the study conducted by Cone et al.[25], 90% of the examined sample had a depth of less than 3 mm, which the authors considered pathological. The measured angles (medial wall angle (53.6°), lateral wall angle (52.4°), and opening angle (77.2°)) obtained in our research do not show significant deviations from other available data [15,25,27]. According to the reviewed works, our study is the first to consider the angular relationship between the lesser tubercle and the humeral head at the most proximal point of the intertubercular sulcus, yielding values of 44.4° and 70.1°, respectively. We believe that analyzing these angles, along with other parameters, could significantly contribute to a more precise understanding of the size and structure of the sulcus and, therefore, a more detailed assessment of biceps brachii tendon position within the shoulder joint.

In this study, the average intertubercular sulcus length on the right humeri is 104.7 mm, while this parameter is 103.3 mm on the left. The obtained depth values deviate from the results of other studies, with our values being lower, and the distribution of our data closer to the results obtained in the Indian population. Furthermore, in the study by Itamura et al. [18] on cadaver humeri, the depth was only 50.2 mm, indicating heterogeneity in the results, possibly stemming from differences in ethnic and anthropological characteristics. Only Ghalawat et al.[4] found a significant difference in width, which is larger on the right humeri. It is important to note that lifestyles, professional-specificities, and sports orientation require greater engagement of the musculature of the corresponding body part. Intensive manual work is expected to exert greater pressure on the biceps brachii tendon at the intertubercular sulcus, leading to bone reshaping and alignment of the sulcus dimensions and shape. For the distances between the humeral head and the most protruding point of the lesser tubercle, values on the right bones are statistically significantly higher (p= 0.03). A significant difference (p= 0.03) was also found in distances between the humeral head and the most protruding point of the greater tubercle when comparing the right (26.3 mm) and left (24.9 mm) humeri. The prominence of these parameters on the right humeri compared to the left supports the notion that right bones are slightly larger, considering that right-handed individuals represent 90 - 95% of the total world population [28].

The value of the medial wall angle on the right humeri in our study is 52.5°, and on the left, it is 55.7°, while the opening angle value is 78.7° (right) and 74.4° (left). The average angle values are almost identical to those reported in studies conducted in the Indian population [3,17,26]. Based on the classification by Wafae et al. [5], the opening angle value for the Serbian population falls into the medium opening angle category; however, the interval is extremely wide (24.0° - 138.5°). Hitchcock and Bechtol [29] highlight that an angle <45° predisposes to injuries to the long head of the biceps brachii tendon and instability of the shoulder joint.

Among the analyzed parameters, the dimensions and angles of the intertubercular sulcus showed that most differ between males and females, i.e., the dimensions and measured angles are larger in male than in female humeri. The greatest difference is in the length of the lateral wall of the intertubercular sulcus (111.2 mm vs. 108.7 mm). In the study by Khan et al. [6], the values obtained are similar to ours without established statistically significant differences between the sexes. These results confirm constitutional differences in sexual morphology between the sexes. Still, the absence of a statistically significant difference may be due to the sample size and the fact that the bones originated from adults, without visible osseous defects. Also, differences in methodological approaches and phenotypic expression can significantly account for differences in qualitative and morphometric variability across studies [30].

The morphometric characteristics of the intertubercular sulcus and the presence of bony growths like spurs and supratubercular ridges are potential contributors to shoulder joint instability. A shallow intertubercular sulcus and the presence of a supratubercular ridge have been linked to biceps brachii tendon trauma [14,31]. Yoo et al.[27] discovered a significant correlation between the biceps brachii's long head tendinitis and the intertubercular sulcus pronounced opening angle. However, some authors argue that the intertubercular sulcus helps prevent trauma to the rotator cuff muscles (subscapularis, supraspinatus, infraspinatus, and teres minor) [32]. Similarly, precise knowledge of the osteometric characteristics of the intertubercular sulcus is necessary during biceps brachii tendon tenotomy and tenodesis [21,33].

This study has limitations that have to be noted. Sex determination was performed using a non-metric method based on differences in the appearance of morphological structures on the distal end of the humerus. We did not have data on the cadaver's dominant hand, as it is assumed that the intensity of muscle activity dictates the architecture of the bone with which it is in contact. Although all the bones belonged to adults, we did not have more precise age data. However, future studies should incorporate an analysis of professional orientation alongside the use of various radiological modalities, which have proven nearly as effective as anatomical repairs in enhancing the precision of preoperative planning [34,35].

Conclusions

Our findings suggest that the intertubercular sulcus dimensions are generally more prominent on the right humeri. The analysis of angles provides a more precise explanation of sulcus morphology. The anatomical variability of the intertubercular sulcus elements observed in this study could serve as a basis for further clinical investigations into the impact of bony variations on the functionality and stability of the shoulder joint. This may also be significant for other morphological and anthropological research, as anatomical variations represent its fundamental basis.

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