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Original Article

Investigation of Morphological and Biomechanical Properties of the Scapula for Shoulder Joint

Omuz Ekleminde Skapulanın Morfolojik ve Biyomekanik Özelliklerinin İncelenmesi

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ABSTRACT

Objective: The glenopolar angle is a helpful criterion for recommending operative treatment. This study aims to determine the morphometric features of the scapula and provide essential information that supplies scapular biomechanics to produce a formula.

Methods: The study was carried out on 34 dry scapulae in the laboratory of the Anatomy Department of the Faculty of Medicine, Bursa Uludag University. We used calipers for the linear measurements and the ImageJ program for the area and angle parameters. A total of 23 parameters were evaluated in the study. Statistical analyzes were performed using SPSS 22.0 software.

Results: According to the results of the correlation analysis, the highest correlation value of (R=0.957) was found to be the distance between the superior angle (angulus superior)-top of the glenoid plane and the inferior angle (angulus inferior)-the top of the glenoid plane. To estimate the glenopolar angle, we applied linear regression analysis and developed the following formula: Glenopolar angle =115.589 – (6.401 x the distance between the coracoid process and the top of the glenoid cavity) – (0.368 x angle between the glenoid plane and the lateral edge of the scapula extending towards the endpoint of the glenoid plane) (Adjusted R^2=0.667).

Conclusions: Glenopolar angle can provide information about the fracture risk of the glenoid cavity and allows orthopedic surgeons to make quick decisions about the risk in the region. We believe that the study will provide a different perspective on designing different products in industrial designs for shoulder joints, especially in implantations.

Keywords: Scapula, glenoid cavity, glenopolar angle, shoulder

ÖZ

Amaç: Glenopolar açı, cerrahi tedaviyi önermek adına önemli bir kriterdir. Bu çalışma, skapulanın morfometrik özelliklerini belirlemeyi ve glenopolar açıyı tahmin edebilen bir formül üretmeyi amaçlamaktadır.

Yöntemler: Çalışma Bursa Uludağ Üniversitesi Tıp Fakültesi Anatomi Anabilim Dalı Laboratuvarı'nda 34 adet kuru skapula üzerinde gerçekleştirildi. Lineer ölçümler için kumpas, alan ve açı parametreleri için ImageJ programı kullanıldı. Çalışmada toplam 23 parametre değerlendirildi. İstatistiksel analiz SPSS 22.0 yazılımı ile yapıldı.

Bulgular: Korelasyon analizi sonuçlarına göre en yüksek korelasyon değeri (R=0,957) üst açı (angulus superior)-glenoid düzlemin üst noktası ile alt açı (angulus inferior)-glenoid düzlemin üst noktası arasında bulundu. Glenopolar açıyı tahmin etmek için lineer regresyon analizi uygulandı ve aşağıdaki gibi bir formül geliştirildi:

Glenopolar açı =115,589 – (6,401 x coracoid çıkıntı ile glenoid kavite tepesi arasındaki mesafe) – (0,368 x glenoid düzlem ile glenoid düzlemin uç noktasına doğru uzanan skapula'nın lateral kenarı arasındaki açı) (Düzeltilmiş R^2= 0,667).

Sonuçlar: Glenopolar açı, glenoid kavitenin kırık riski hakkında bilgi verebilir ve ortopedi cerrahlarının bölgedeki risk hakkında hızlı karar vermesine olanak tanır. Çalışmanın, özellikle implantasyonlarda omuz eklemi için endüstriyel tasarımlarda farklı ürünlerin tasarlanması konusunda farklı bir bakış açısı sağlayacağına inanmaktayız.

Anahtar kelimeler: Skapula, glenoid kavite, glenopolar açı, omuz

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INTRODUCTION

The scapula is involved in the shoulder joint structure, which is quite complex and has several motions. It forms the glenohumeral joint and the acromioclavicular joint on the outside. It connects the shoulder arch to the body and spine, with musculotendinous structures in the middle forming the scapulothoracic joint. Many muscles attach to the glenohumeral and scapulothoracic joints and contribute to shoulder biomechanics[1]. We know that in the human body, the most adaptive joint is the scapulothoracic articulation, and there is no true bone between the scapula and sternum, allowing for tremendous mobility in many directions. The lack of bony articulation in the scapulothoracic region led to pathological motion, making the glenohumeral joint heavily dependent on it for stability and normal movements[2].

Pathologies are quite common because there are several movements in the scapulohumeral region. Pathologies manifested by shoulder pain and loss of shoulder function can be overlooked in the diagnostic phase and are very difficult to treat[3]. Comparing the scapula functions of a person with shoulder problems and a healthy person, we find differences in scapular kinematics[4]. Understanding the normal biomechanics of the scapula can provide information about the pathomechanics of injury or dysfunction to be understood[5].

The glenopolar angle is a radiographic parameter used to understand shoulder deformity after fractures of the scapula neck, obviously[6]. It can be helpful as a criterion for recommending operative treatment[7]. The glenopolar angle is defined on plain radiographs as the angle between a line connecting the glenoid's most superior and inferior margins and a line between the most superior margin of the glenoid and the most caudal margins point of the scapular body[5,8]. This angle has been recorded at angles varying between 36° to 43°[9]. Therefore, accurate and reproducible measurement of this angle in these patients is required for pre- and postoperative assessment and comparison of results from studies of clinical outcomes[5,8].

Considering this information, the current study aimed to determine the morphometric features of the scapula and provide essential information that supplies scapular biomechanics, producing a formula that can estimate the glenopolar angle. The hypothesis is that there is a relationship between the glenopolar polar angle and scapula morphometry by scapula biomechanics.

MATERIALS and METHODS

The study was carried out on 34 dry scapulae in the laboratory of the Anatomy Department of the Faculty of Medicine, Bursa Uludag University. Bones that had deformities or fractures were excluded from the study. A Somet Inox brand mechanical caliper with an accuracy of 1/20 mm was used for the linear measurements. For the area, perimeter and angle parameters, photographs of the bones were taken with the Nikon D5000 camera in the standard position with the ruler on one side for calibration. The ImageJ program was used for the area and perimeter measurements. A total of 23 parameters were evaluated in the study (Figures 1-6). The line passing through between the top and end points of the glenoid

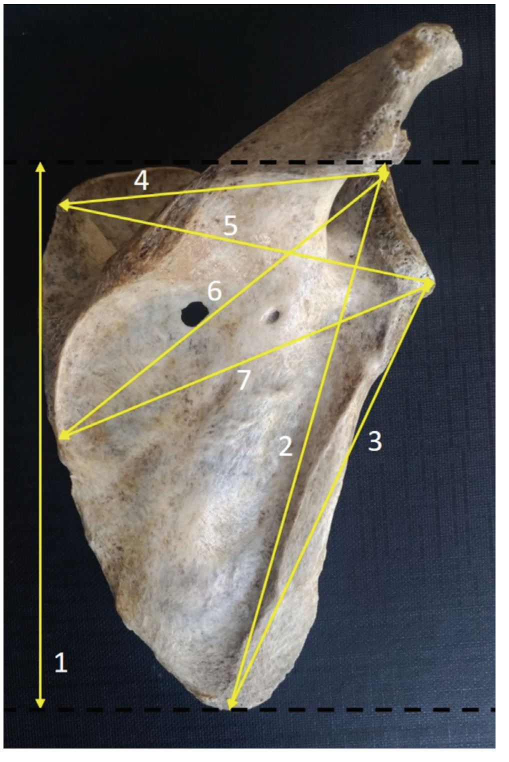

Figure 1. Parameters of the scapula in dorsal view.

1. The maximum length of the scapula; 2. The distance between the inferior angle and the top of the glenoid cavity; 3. The distance between the inferior angle and the lowermost point of the glenoid cavity; 4. The distance between the superior angle and the top of the glenoid cavity; 5. The distance between the superior angle and the lowermost point of the glenoid cavity; 6. The distance between the outermost point of the medial border scapula and the upper end of the glenoid cavity; 7. The distance between the outermost point of the medial border of the scapula and the lowermost point of the glenoid cavity.

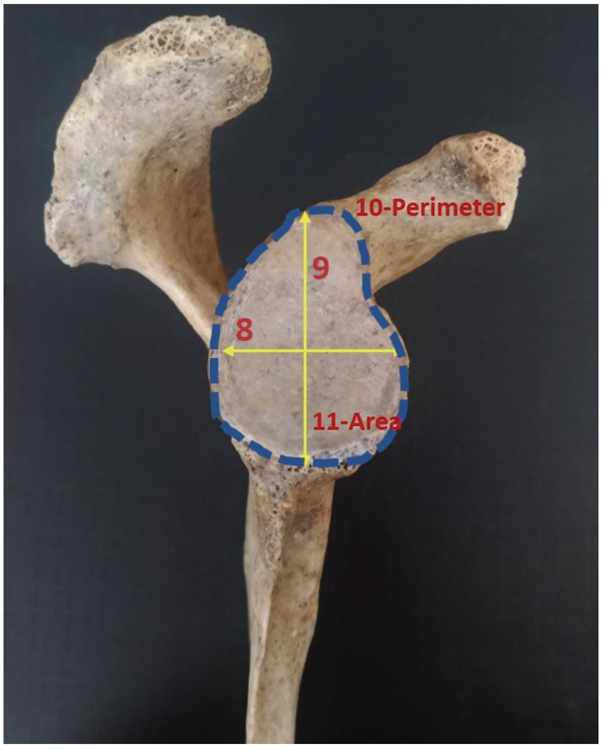

Figure 2. Parameters of the glenoid cavity.

8. The antero-posterior length of the glenoid cavity; 9. The supero-inferior length of the glenoid cavity; 10. The perimeter of the glenoid cavity; 11. The area of the glenoid cavity.

Figure 3. Parameters of the acromion.

12. The maximum width of the acromion; 13. The maximum length of the acromion.

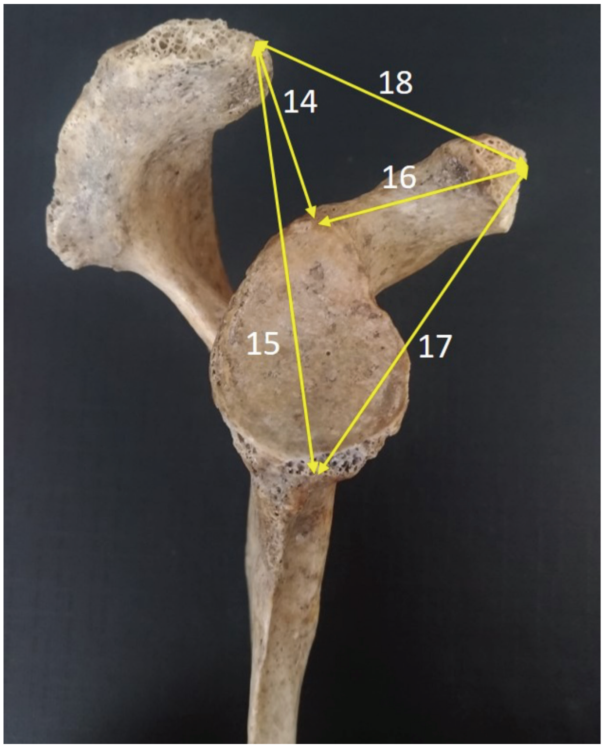

Figure 4. Parameters of the coracoid process.

14. The distance between the acromion and the highest point of the glenoid cavity; 15. The distance between the acromion and the lowest point of the glenoid cavity; 16. The distance between the coracoid process and the upper point of the glenoid cavity; 17. The distance between the coracoid process and the lowest point of the glenoid cavity; 18. The distance between the coracoid process and the acromion.

cavity was accepted as the glenoid plane. According to this, the parameters were, respectively[6,8-11];

1. Maximum length of the scapula: The distance between superior and inferior angles.

2. The inferior angle (angulus inferior)-top of the glenoid plane: The distance between the inferior angle and the upper end of the glenoid plane.

3. The inferior angle (angulus inferior)-the most inferior point of the glenoid plane: The distance between the inferior angle and the lowest point of the glenoid plane.

4. The distance between the superior angle (angulus superior) and the top of the glenoid plane.

5. The superior angle (angulus superior)-the most inferior point of the glenoid plane: The distance between

the superior angle and the lowermost point of the glenoid plane.

6. The outermost point of the medial border-the top of the glenoid plane: The distance between the outermost point of the medial border of the scapula and the upper end of the glenoid plane.

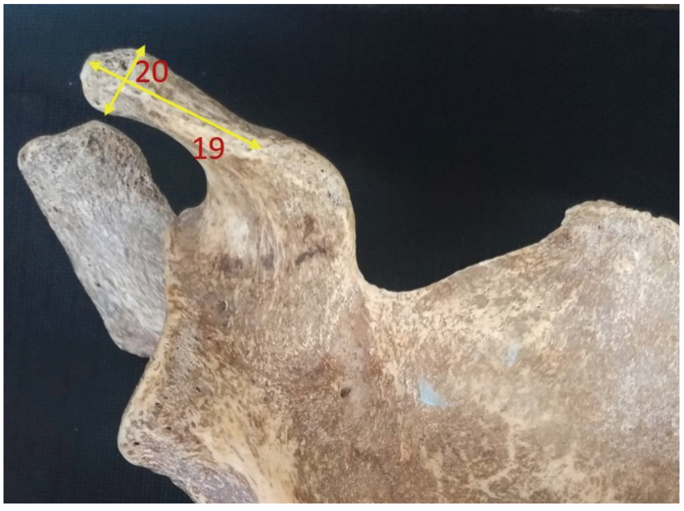

Figure 5. Parameters of the scapula in the lateral view.

19. The maximum length of the coracoid process; 20. The maximum width of the coracoid process.

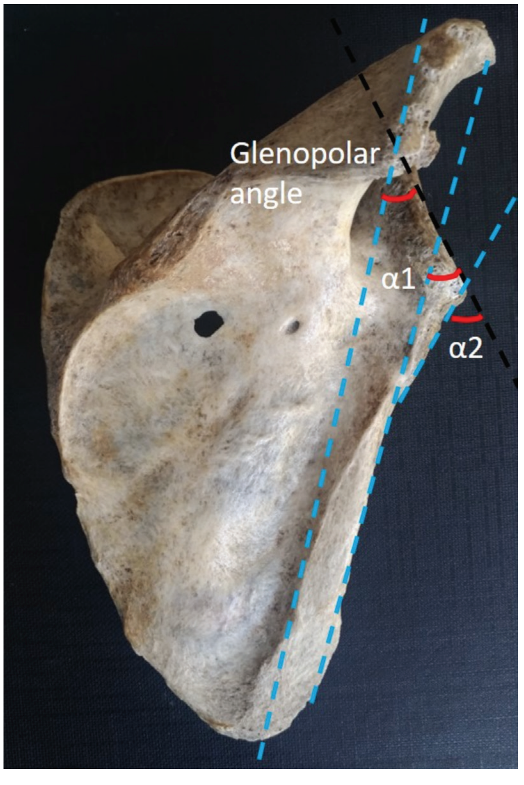

Figure 6. Angular measurements of the scapula.

Glenopolar angle; α1-angle; α2-angle.

7. The outermost point of the medial border, the most inferior point of the glenoid plane: The distance between the outermost point of the medial border scapula and the lowermost point of the glenoid plane.

8. The anteroposterior length of the glenoid cavity.

9. The superinferior length of the glenoid cavity.

10. The perimeter of the glenoid cavity.

11. The area of the glenoid cavity.

12. The maximum width of the acromion.

13. The maximum length of the acromion.

14. Acromion-the top of the glenoid cavity: The distance between the acromion and the upper end of the glenoid cavity.

15. Acromion-the most inferior point of the glenoid cavity: The distance between the acromion and the lowest point of the glenoid cavity.

16. The coracoid process-the top of the glenoid cavity: The distance between the coracoid process and the upper end of the glenoid cavity.

17. Distance between the coracoid process and the most inferior point of the glenoid cavity: Distance between the coracoid process and the lowest point of the glenoid cavity.

18. The distance between the coracoid process and the acromion.

19. The maximum length of the coracoid process.

20. The maximum width of the coracoid process.

21. Glenopolar angle: The angle between the glenoid plane (line passing through the top and bottom of the glenoid cavity)-the line joining the inferior angle of the scapula and the top of the glenoid cavity.

22. $\alpha 1$: Angle between the glenoid plane and the lateral edge of the scapula.

23. $\alpha 2$: Angle between the glenoid plane and the lateral edge of the scapula extending toward the endpoint of the glenoid plane.

Statistical Analysis

Statistical analysis was carried out using SPSS 22.0 software (IBM). Pearson correlation analysis for parametric parameters and Spearman correlation analysis for nonparametric variables were used to determine the relationships between variables. A mathematical equation was developed using linear regression to estimate the variables. The adjusted R^2 was considered a value that indicates the percentage of accuracy.

RESULTS

Because of the statistical analysis, the descriptive values of the 23 parameters of the scapula are given in Table 1. According to the results of the bivariate correlations, Spearman correlation analysis, the highest correlation value of (R=0.957) was found to be the distance between the inferior angle-top of the glenoid plane and the inferior angle-the most inferior point of the glenoid plane. There was also a high correlation between the total height of the scapula and the distance between the inferior angle and the top of the glenoid plane (R=0.880). Also, the total height of the scapula and the distance between the inferior angle-the most inferior of the glenoid planes (R=0.856). The correlation between the glenopolar angle and the α2-angle was also high, and the R-value was-0.617. There was no result with a high valid correlation among other parameters.

Table 1. Descriptive mean values of the parameters (mm) and mean area values of the parameters (mm^2).

Description of the parameter	Mean ± SD
Maximum length of the scapula	140.9±13.4
The inferior angle-top of the glenoid plane	147.8±13.8
The inferior angle-the most inferior of the glenoid plane	120.1±12.0
The superior angle-the top of the glenoid plane	90.6±10.2
The superior angle-the most inferior of the glenoid plane	106.8±10.0
The outermost of the medial border-the top of the glenoid plane	105.4±8.2
The outermost of the medial border-the most inferior of the glenoid plane	110.3±7.6
The antero-posterior length of the glenoid cavity	25.8±7.7
The supero-inferior length of the glenoid cavity	37.6±3.3
The perimeter of the glenoid cavity	103.5±11.2
The area of the glenoid cavity	73.6±16.2
The maximum width of the acromion	27.5±3.7
The maximum length of the acromion	46.4±7.5
Acromion-the top of the glenoid cavity	31.7±3.9
Acromion-the most inferior point of the glenoid cavity	56.2±5.3
The maximum length of the coracoid process	41.7±5.0
The maximum width of the coracoid process	15.7±3.1
The coracoid process-the top of the glenoid cavity	27.1±3.3
The coracoid process-the most inferior point of the glenoid cavity	49.5±3.7
The coracoid process-the acromion	41.2±8.6
Glenopolar angle (angle)	38.60±4.54
α1 angle	37.27±4.79
α2 angle	125.56±7.77

To estimate the glenopolar angle, we applied linear regression analysis and the formula with high accuracy and developed an equation such:

Glenopolar angle =115.589 – (6.401 x the distance between the coracoid process and the top of the glenoid cavity) – (0.368 x α2).

The R-value was 0.834, the adjusted R^2 value was 0.667, and the standard error of the estimate was 2.77. P values for the distance between the coracoid process and the top of the glenoid cavity and α2 variables were 0.032 and 0.001 respectively.

DISCUSSION

In this study, we showed that the glenopolar angle used in radiographs for shoulder fractures and surgical planning had different results when measured on real dry bones. We have shown that this angle affects the morphometry of the scapula and therefore its biomechanics.

The glenopolar angle is defined as the angle between the line connecting the superior and inferior points of the glenoid cavity and the top of the glenoid plane, the inferior angle of the scapula. Romero et al.[12] used this angle as a parameter showing the relationship between scapular neck fractures and function in radiological images. On Y-view radiographs, the scapula and the angles between them can be evaluated by drawing parallel lines to the proximal and distal parts, and this angle is a radiological parameter in determining the lateral margin offset and the surgical indication for opening. It is also used in axillary radiography and can easily detect fractures of the acromion and coracoid process[13]. According to the literature, this angle can provide information about the glenoid cavity fracture risk and allows orthopedic surgeons to make quick decisions about the risk in this region[14].

Pace et al.[15] found this angle as 39° (ranging from 26°-50°) on AP radiographs of 9 patients; Kim et al.[16] reported 38° (ranging from 35°-42°) on AP chest radiographs in 16 patients. Tuček et al.[6] reported a glenopolar angle of 42.3° (between 30°-56°) in 100 scapulae; AP chest radiographs in 50 subjects, 37.1° (between 26°- 63°); and AP shoulder radiographs in 50 subjects, 35.9° (between 28°-46°). In the 3D reconstruction images of computed tomography (CT), the glenopolar angle was reported as 43.0° (between 35°-51°). Pazarcı et al.[14] compared the glenopolar angle in patients with the anterior shoulder dislocation with the control group. They found a glenopolar angle of 32.31°±2.01° in the patient group, and 34.5°±2.32° in the control group[14]. While a statistically significant difference was found between the two groups, they did not observe a difference between the sexes or parties. In our study, the average of this angle was 38.595°. Looking at the literature, we found that the results were different in radiological images and in studies where dry bone was used[6,14-16]. It also appears that the supraglenoid and infraglenoid tubercles, the attachment points of the biceps and triceps brachii muscles, influence the glenopolar angle. In particular, the long head of the biceps brachii muscle has a significant influence on glenohumeral movements and increases the stability of the shoulder joint[17].

In the other part of the study, we compared the data obtained to examine the effect of this angle on the morphometry of the bone with the literature data to associate it with the angle and to show that there are different results in different populations. The scapula plays an important role in orthopedics and traumatology, particularly in developing prostheses, surgical procedures, physical therapy, and rehabilitation for various lesions of the scapula. For these reasons, it is important to know the anatomical features and morphometry of the scapula.

Aydemir et al.[18] determined a mean length of the scapula of 147 mm and a mean width of 105 mm in their study. Kabakçı et al.[19] reported a scapula length of 140.8 mm and width of 98.5 mm in 69 scapulae of unknown sex. In Kale et al.[20], the average scapula length was 186 mm and the average width was 107 mm. It can be seen that the values belonging to the Turkish population are compatible with our data.

In other studies conducted in India, the length of scapula was 141.94 mm and 141.49 mm and the width of scapula was 103.65 mm and 98.69 mm respectively[10,21]. The length and width of the scapula were reported for different populations: 151.16 mm and 107.22 mm for the Egyptians[22], 147.6 mm and 101.9 mm for the Greeks[23], and 131.1 mm for the Thais[24]. When we compared our results with these studies, our averages were generally shorter than those of the Egyptians and Greeks and longer than those of the Thais.

The length of the glenoid cavity was measured as 37.6 mm and its width was 25.8 mm. For these parameters, Cezayir et al.[25] reported 37.64±2.8 mm and 27.19±2.9 mm for 115 bones; Kale et al.[20] reported 36.1 mm and 25.5 mm for 31 scapulae Coskun et al.[26] reported 24.6±2.5 mm and 36.3±3 mm for 90 scapulae. Çırpan et al.[27] reported these mean values as 37.12 mm and 25.96 mm in 62 scapulae; Kabakçı et al.[19] reported 36.8 and 25.1 mm with 69 scapulae; Mısır et al.[28] stated as 36.8 mm and 25.2 mm respectively. In the study conducted with the same parameters in Thai subjects, the length of the glenoid cavity was 35.8 mm and the width of the glenoid cavity was 27.3 mm[24]. In a study conducted in Egypt, it was reported that the length of the glenoid cavity was 38.95 mm and the width was 28.15 mm[22]. According to the study data, it was found that the length of the glenoid cavity was less than in the African and Japanese populations and seemed to be slightly higher in other studies conducted in Turkey.

In our study, the measured perimeter of the glenoid cavity was 103.5 mm and its area was 73.6 mm^2. In a study conducted in China, the perimeter of the glenoid cavity was 97.31 mm on the right side and 97.12 mm on the left side. In the same study, the area of the glenoid cavity was 716.79±124.82 mm^2 on the right side and 710.22±126.50 mm^2 on the left side[29].

The acromion length was 46.4 mm, and the width of the acromion was 27.5 mm in our study. In a study conducted in North India, these parameters were reported as 41 mm and 21.82 mm respectively[30]. In Indians, the length was reported as 41.6 mm on the right side and 42.5 mm on the left side, and the width of the acromion was 23.2 mm on the right side and 24.9 mm on the left side[31]. In another study conducted in Egypt, the value for the length was 52.81 mm and the width was 32.05 mm[22].

Kale et al.[20] found that the length of the acromion was 48.9 mm. Koşar et al.[32] reported the average length as 46.07±6.22 mm and gave the longest value for acromion length as 51.67±4.09 mm and the shortest value as 41.38±4.84 mm. When examining the results, these values seem quite different in the studies.

The distance between the acromion-upper point of the glenoid cavity was 31.7 mm, and the distance between the acromion-distal point of the glenoid cavity was 56.1 mm. Kabakçı et al.[19] determined the distance between the acromion and the upper point of the glenoid cavity to be 26.3 mm, and Kale et al.[20] reported this distance to be 18.5 mm.

When we examined the different studies, the average value between the acromion and the superior point of the glenoid cavity was 27.39 mm in Egyptians[22], 17.7 mm in Greeks[23], and 18.1 mm in Thais[24]. These distances are essential for rotator cuff tears and Romero Syndrome[12].

The length and width of the coracoid process were 41.7 mm and 15.6 mm, respectively. Çırpan et al.[27] reported that the length of the coracoid process was 42.36 mm in 62 bones. The width of the coracoid process was measured at two different points. The width of the root of the acromion was 13.95 mm and the widest part was 13.98 mm[27].

Salzmann et al.[33] determined the length of the coracoid process to be 43.1 mm in their study of 23 fresh cadavers in Germans. In the study conducted in China using the 124 images from CT, the length was 43.56 mm in males, 37.90 mm. in females, and the width of coracoid process was 29.09 mm in males and 25.52 mm in females[34].

The distance between the uppermost point of the glenoid cavity and the coracoid process was 27.1 mm, and the distance between the lowermost point of the glenoid cavity and the coracoid process was 49.4 mm. Çırpan et al.[27] found that the distance between the top of the glenoid cavity and the coracoid process was 27.56 mm; Kabakçı et al.[19] reported this distance as 20.0 mm.

Because a study on estimating the glenopolar angle does not exist in the literature, our study was essential in determining the average glenopolar angle across the bone. When we compare the measurements of the radiological images and the dry bone, we think the bone will be more beneficial for the literature. It should also be remembered that the formula that estimates the glenopolar angle can be used to make interpretations between healthy individuals and different patient groups. We believe that this study will provide a different perspective on designing products in the medical industry, especially in implantations. There are few studies on measuring the glenopolar angle in the Turkish population. Moreover, it should be remembered that the differences between the morphological measurements of the bones may differ in different areas, even in different regions of Anatolia. The limitation of this study was the small number of samples and unknown sex.

CONCLUSION

Information on the osteometric values of the scapula helps physicians in identifying various shoulder joint diseases, treating injuries due to sports, and designers in the shoulder prosthesis industry in designing the implant for the shoulder joint. We also believe that this study will be a prior study for future studies.

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Ethics

Ethics Committee Approval: This study does not contain human participants or experiments on humans/animals and the skulls are the donation of the cadavers and belong to the anatomy department.

Informed Consent: This study does not require patient consent.

Peer-review: Externally and internally peer-reviewed.

Author Contributions

Surgical and Medical Practices: N.T.C., Concept: N.T.C., Design: N.T.C., Data Collection and/or Processing: N.T.C., N.G.S., Analysis and/or Interpretation: N.T.C., N.G.S., S.B., Literature Search: N.T.C., N.G.S., S.B., Writing: N.T.C., N.G.S., S.B., I.A.

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