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ANTHROPOMETRIC STUDY OF PROXIMAL HUMERUS AND CAVITAS GLENOIDEALIS: NORMAL GLENOHUMERAL RELATIONSHIPS

PROKSIMAL HUMERUS VE CAVITAS GLENOIDEALIS'İN ANTROPOMETRİK ÇALIŞMASI: NORMAL GLENOHUMERAL İLİŞKİLER

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ABSTRACT

Objective: The shoulder joint has a complex anatomical structure due to its unique irregular shape. The anatomy of the shoulder joint should be known in detail for surgical treatment of shoulder joint disorders and surgical interventions such as arthroscopic procedures. In addition, knowing whether there are racial or gender-related morphometric differences in the shoulder joint can be useful in anthropology and some clinical areas, especially in forensic medicine. However, despite the importance of the subject, there are few studies on the quantitative anatomy of the shoulder joint. The aim of this study is to present the measurements of the shoulder joint in detail.

Methods: A total of 107 people (54 men, 53 women) were measured. 18 measurements were performed, 6 in the proximal humerus and 12 in the cavitas glenoidealis. An MRI device was used in the measurements. The shape of Cavitas Glenoidalis was evaluated (teardrop, pear-shaped, round, ovoid, inverted comma-shaped) and their percentages were calculated.

Results: All values in the proximal humerus were higher in men ($p < 0.05$). In comparisons by age (> 40 and <40), all values except the vertical diameter of the humerus and BF length were found to be higher over 40 years of age.

Conclusion: These findings can provide a reproducible reference point for articulatio humeri in osseous anthropometry, offer a valuable reference in shoulder replacement surgery and help characterize osseous glenohumeral instability.

Keywords: Proximal humerus, cavitas glenoidealis, anthropometry, shoulder arthroplasty

ÖZ

Amaç: Omuz eklemi benzersiz düzensiz şekli nedeniyle karmaşık bir anatomik yapıya sahiptir. Omuz eklem bozukluklarının cerrahi tedavisi ve artroskopik işlemler gibi cerrahi müdahaleler için omuz ekleminin anatomisinin detaylı olarak bilinmesi gerekir. Ayrıca omuz ekleminde ırk veya cinsiyete bağlı morfometrik farklılıkların olup olmadığının bilinmesi antropoloji ve bazı klinik alanlarda özellikle adli tıpta faydalı olabilir. Ancak konunun önemine rağmen omuz ekleminin kantitatif anatomisine ilişkin az sayıda çalışma bulunmaktadır. Bu çalışmanın amacı omuz eklemi ölçülerini detaylı olarak sunmaktır.

Yöntem: Toplam 107 kişiye (54 erkek, 53 kadın) ölçüm yapıldı. 6'sı humerus proksimalinde ve 12'si cavitas glenoidealis'te olmak üzere 18 ölçüm yapıldı. Ölçümlerde MR cihazı kullanıldı. Cavitas Glenoidalis'in şekli (gözyaşı damlası, armut biçimli, yuvarlak, oval, ters virgül biçimli) değerlendirildi ve yüzdeleri hesaplandı.

Bulgular: Humerus proksimalindeki tüm değerler erkeklerde daha yüksekti ($p<0.05$). Yaşa göre karşılaştırmalarda (>40 ve <40), humerus vertikal çapı ve BF uzunluğu dışındaki tüm değerler 40 yaş üzerinde daha yüksek bulundu.

Sonuç: Bu bulgular kemik antropometrisinde articulatio humeri için tekrarlanabilir bir referans noktası sağlayabilir, omuz replasman cerrahisinde değerli bir referans sunabilir ve kemikli glenohumeral instabiliteyi karakterize etmeye yardımcı olabilir.

Anahtar Kelimeler: Proksimal humerus, cavitas glenoidealis, antropometri, omuz artroplastisi

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Introduction

Few anatomical data are available to support the need for humeral hand glenoid prosthetic components in a wide range of sizes and shapes. For total shoulder arthroplasty, the widespread gold standard suggests one radius curvature for the head of the humerus and glenoid, with two humeral offsets.[1-15] This study has a twofold purpose: to develop a specific, reproducible, computerized measurement technique to define the osseous anatomy of the proximal humerus and glenoid and to describe the osseous anatomical relationships between the normal proximal humerus and glenoid regarding total shoulder arthroplasty design.

Methods

The research method of this study was approved by our institutional review board and by the ethics committee (2019/2125). Written informed consent was obtained from all individuals before the MRI examination. This study is based on a retrospective evaluation of MRI in 107 (54 males and 53 females) individuals consecutively between March 2019 and October 2019. The patients with congenital, pathological, or traumatic lesions were excluded from the study. Patients were randomly selected and informed consent was received from all patients before participating in the study.

1.5 T (Aera, Siemens, Erlangen, Germany) device was used for magnetic resonance imaging. Fat-suppressed proton density images in the axial plane, fat-suppressed T1 and T2-weighted images in the coronal oblique plane, and fat-suppressed T2-weighted images in the sagittal plane were evaluated. Anatomical measurements were made precisely at the highest magnification possible by an experienced radiologist at the Syngo via (Siemens, Healthcare, Erlangen, Germany) workstation over the existing images. Each measurement was made 3 times and these measurements were averaged (Figure 1-4). The intra-observer agreement values for repeated measurements were found between 0.894 and 0.983 which showed a higher agreement level. The anthropometric measurements of the proximal humerus and the glenoid cavity were shown in Figures 1- 4. In the figures, it can also be followed the abbreviations of the measured parts of the proximal humerus and the glenoid cavity.

Statistical Analysis

SPSS 20.0 (IBM Inc., Chicago, IL, USA) software was used in order to analyze the study. Descriptive statistics were presented as frequencies and percentages for categorical variables and mean±SD and percentile values for numerical variables. Student t-test was used for two independent samples, and a one-way analysis of variance was used for several independent samples. Pearson correlation coefficients were calculated between measurements and gestational age. The Intraclass Correlation Coefficient (ICC) analysis was performed for agreement of repeated measurements. $P<0.05$ was considered statistically significant as a 5% type-I error.

Results

The data obtained from measurements on art. humeri were statistically evaluated. The calculations of Mean±SD and *P* values of these parameters were performed according to gender (male-female) and lateralization (right-left) and presented in tables. There were 54 males and 53 females (nearly half of the total individuals) enrolled in the study. The mean age of females was 49.67±12.57 years and 46.87±14.53 years for males.

A significant difference was identified in values of each proximal humerus between genders except for AB ($p<0.05$) (Table 1). All values were observed to be significantly higher in males.

Table 1. Distribution of the morphometric measurements of the proximal humerus by gender (in cm)

Parameters	N	Male Mean±SD	N	Female Mean±SD	p
AB	54	9.31±2.08	53	9.12±1.93	0.612
BD	54	14.97±2.42	53	13.13±2.31	0.001*
BF	54	43.67±3.96	53	38.16±3.14	<0.001*
EF	54	30.04±4.44	53	27.62±3.84	0.003*
VC	54	40.66±3.56	53	36.37±3.21	<0.001*
TC	54	49.70±3.87	53	44.24±3.06	<0.001*

*Significant at 0.05 level according to Student t-test

Comparison results of right and left proximal humerus measurements were given. Except for BF, EF all measurements were found higher on the right side than on the left side (Table 2-4).

Table 2. Distribution of morphometric measurements of proximal humerus by lateralization (in cm)

Parameters	N	Right Mean ± SD	N	Left Mean ± SD	p
AB	50	9.25±2.00	57	9.12±2.02	0.884
BD	50	15.11±2.70	57	13.14±1.97	<0.001*
BF	50	40.50±4.09	57	41.33±4.85	0.342
EF	50	28.26±4.11	57	29.35±4.45	0.192
VC	50	48.68±4.10	57	45.52±4.20	0.001*
TC	50	38.13±3.84	57	38.89±4.15	0.326

*Significant at 0.05 level according to Student t-test

For Cavitas glenoidalis, AB, AC, CD, DM, and IJ averages were found to be higher in males (Table 5) and the right side values were smaller than the left side (Table 6). All measurements except for JL, IJ, and KL in Cavitas glenoidealis were significantly different between the sides of each gender (Tablo 7). Most of the measurements did not differ between the age groups of 40 years (Table 8). 65.05% of Cavitas glenoidalis were pear-shaped, 24.27% were oval-shaped and 10.68% were reversed comma-shaped. All abbreviations stated in the results were shown in Figure 1-4.

Table 3. Distribution of measurements made in the anteroposterior view of proximal humerus by gender and lateralization (right: 50, left: 57) (in cm)

	Male			Female		
	Right	Left		Right	Left	
Parameters	**Mean ± SD**	**Mean ± SD**	**p**	**Mean ± SD**	**Mean ± SD**	**p**
AB	9.24±2.18	9.39±2.04	0,841	9.26±1.85	8.99±2.03	0.597
BD	16.13±2.59	13.99±1.77	0,823	14.11±2.47	12.26±1.80	0.725
BF	26.26±3.49	44.07±3.98	0,008*	37.79±1.79	38.50±4.00	0.913
EF	29.26±3.49	30.73±5.10	0,765	27.27±4.51	27.93±3.19	0.620
VC	51.63±3.14	48.05±3.71	0,653	45.74±2.53	42.90±2.92	0.586
TC	40.47±3.88	40.84±3.34	0,992	35.80±1.93	36.89±3.99	0.538

*Significant at 0.05 level according to Student t-test

Table 4. Distribution of morphometric measurements of proximal humerus by age (in cm)

Parameters	**N**	**>40 years Mean ± SD**	**N**	**<40 years Mean ± SD**	**p**
AB	77	9.47±2.03	30	8.56±1.80	0.028*
BD	77	14.27±2.55	30	13.53±2.42	0.162
BF	77	40.57±4.41	30	41.88±4.68	0.193
EF	77	29.00±4.12	30	28.42±4.83	0.564
VC	77	47.22±4.36	30	46.43±4.63	0.423
TC	77	38.50±4.30	30	38.62±3.17	0.872

*Significant at 0.05 level according to Student t-test

Table 5. Distribution of morphometric measurements in Cavitas Glenoidealis by gender (male, female) (in cm)

Parameters	**N**	**Male Mean ± SD**	**N**	**Female Mean ± SDd**	**p**
AB	54	32.38±5.18	53	29.31±4.96	0.002*
AC	54	16.56±3.60	53	14.16±2.69	<0.001*
BC	54	15.69±2.83	53	15.12±3.19	0.338
CD	54	3.70±1.59	53	3.00±1.42	0.018*
EF	54	24.87±6.44	53	22.58±5.59	0.051
GH	54	34.50±9.89	53	31.18±7.79	0.056
AI	54	11.16±1.22	52	11.11±1.24	0.828
IG	54	11.03±1.03	52	11.01±1.51	0.907
BF	54	11.84±1.65	52	11.59±1.20	0.382
FH	54	10.29±1.04	52	10.29±1.84	0.981
DI	53	34.29±5.76	52	30.93±4.03	<0.001*
IJ	54	17.69±5.36	52	13.60±2.44	<0.001*
GH	54	12.80±17.83	52	7.62±2.24	0.039

*Significant at 0.05 level according to Student t-test

Table 6. Distribution of measurements in the shoulder joint, cavitas glenoidealis by lateralization (right, left) (in cm)

Parameters	N	Right Mean ± SD	N	Left Mean ± SD	p
AB	50	35.36±3.44	55	26.84±2.91	<0.001*
AC	49	17.90±2.99	55	13.12±1.83	<0.001*
BC	50	17.32±2.65	55	13.71±2.25	<0.001*
CD	50	4.69±1.09	55	2.19±0.74	<0.001*
EF	50	20.81±3.41	55	26.46±6.84	<0.001*
GH	50	27.42±2.63	55	38.01±9.88	<0.001*
AE	49	10.42±0.57	55	11.73±1.31	<0.001*
IG	49	10.30±0.24	55	11.65±1.50	<0.001*
BF	49	10.75±0.49	55	12.53±1.50	<0.001*
FH	49	10.65±1.05	55	9.97±1.73	0.017*
DI	49	30.28±4.56	54	34.75±5.03	<0.001*
IJ	55	16.95±3.60	55	14.51±5.22	0.006*
GH	49	12.72±18.79	55	8.13±2.37	0.096

*Significant at 0.05 level according to Student t-test

Table 7. Distribution of morphometric measurements in Cavitas glenoidealis by gender and lateralization (right, left) (in cm)

	Male			Female		
Parameters	Right Mean ± SD	Left Mean ± SD	p	Right Mean ± SD	Left Mean ± SD	p
AB	37.05±3.38	28.33±2.23	<0.001*	33.68±2.63	25.41±2.80	<0.001*
AC	19.62±2.55	13.99±2.10	<0.001*	16.25±2.44	12.,30±1.01	<0.001*
BC	17.26±3.08	14.34±1.78	<0.001*	17.39±2.21	13.11±2.52	<0.001*
CD	5.06±1.23	2.56±0.73	<0.001*	4.32±0.80	1.83±0.56	<0.001*
EF	21.63±3.73	28.11±7.00	<0.001*	20.01±2.92	24.88±6.41	<0.001*
GH	28.86±2.55	40.30±11.11	<0.001*	25.98±1.82	35.82±8.16	<0.001*
AE	10.48±0.70	11.72±1.28	<0.001*	10.38±0.42	11.74±1.37	<0.001*
EG	10.33±0.26	11.67±1.11	<0.001*	10.27±0.24	11.64±1.83	<0.001*
BF	10.72±0.46	12.78±1.76	<0.001*	10.79±0.53	12.29±1.19	<0.001*
FH	10.58±0.88	10.05±1.12	0.527	10.74±1.22	9.91±2.20	0.603
DE	31.61±5.11	36.99±5.40	<.0001*	28.90±3.51	32.67±3.67	<0.001*
EF	19.00±3.70	16.55±6.50	0.836	14.83±1.87	12.55±2.40	0.920
GH	16.67±2.85	9.53±2.10	0.312	8.61±2.36	6.78±1.79	0.293

*Significant at 0.05 level according to Student t-test

Table 8. Distribution of morphometric measurements in Cavitas glenoidealis by age (in cm)

Parameters	N	>40 years Mean ± SD	N	<40 years Mean ± SD	p
AB	77	31.65±5.22	30	28.84±4.95	0.012*
AC	76	15.70±3.34	30	14.50±3.41	0.108
BC	77	15.82±3.09	30	14.34±2.53	0.013*
CD	77	3.56±1.61	30	2.84±1.22	0.015*
EF	77	23.98±6.42	30	23.12±5.30	0.483
GH	77	33.10±9.08	30	32.24±9.01	0.660
AE	76	11.03±1.01	30	11.42±1.62	0.228
EG	76	11.04±1.41	30	10.97±0.89	0.780
BF	76	11.61±1.40	30	11.99±1.54	0.253
JH	76	10.41±1.56	30	9.98±1.23	0.136
DI	76	32.17±5.18	30	33.82±5.30	0.157
IJ	76	15.74±3.58	30	15.54±6.71	0.879
GH	76	10.76±15.28	30	9.00±2.90	0.340

*Significant at 0.05 level according to Student t-test

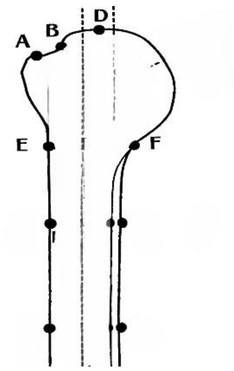

Figure 1. Proximal humerus for morphometric measurements (anterior view) (*Adapted from McPherson et al., 1997).*

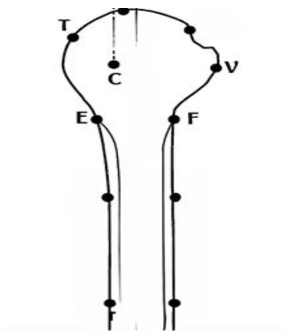

Figure 2. Proximal humerus for morphometric measurements (lateral view). (TD: Transverse diameter, VD: Vertical diameter) (*Adapted from McPherson et al., 1997*)

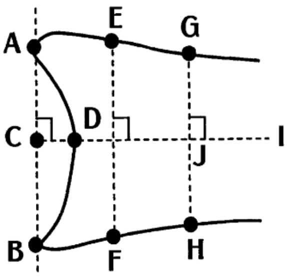

Figure 3. Glenoid fossa for morphometric measurement (anterior view) (*Adapted from McPherson et al., 1997*)

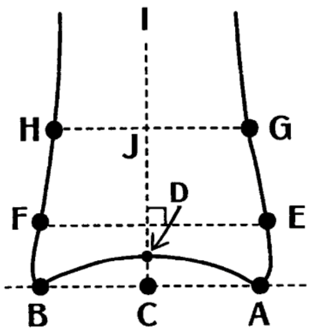

Figure 4. Glenoid fossa for morphometric measurement (lateral view) (*Adapted from McPherson et al., 1997*)

Discussion

The importance of precise reconstruction of the normal three-dimensional anatomy has been stressed by newly introduced designs for prosthetic replacement of the proximal part of the humerus. However, so far, the external three-dimensional anatomy of the proximal part of the humerus has been reported in only a few studies. As far as we know, no researchers have directly measured intramedullary proximal humeral morphology or associated it with extramedullary morphology.

The glenoid version describes the orientation of the glenoid cavity with respect to a plane perpendicular to the scapular body. The glenoid version is between 2^0 of anteversion and 9^0 of retroversion on normal shoulders.[16-20] Since version abnormalities have been correlated with glenohumeral instability [21,22], osteoarthritis[23,24], rheumatoid arthritis[18], and subcoracoid impingement[19], knowledge of glenoid version is fundamental. The glenoid version may also serve a function in shoulder replacement surgery. The latest studies have indicated that excessive glenoid component version is linked with abnormal loading of a glenoid component[25] and with poor clinical results.[26]

The modern era of shoulder arthroplasty began in 1951 with the introduction of Kruger's vitallium humeral head replacement and Neerer's similar humeral head implant.[27-29] Since then, a wide range of prosthetic designs have been developed, and clinically implanted and various successful results have been obtained.[30-33] These prosthetic systems consist of designs ranging from minimally constrained such as the Neer prosthesis to constrained or fixed fulcrum devices such as the Bickel, Jefferson, Reeves, Leeds, and Stanmore.

The efficacy of a minimally or nonconstrained shoulder design should be dependent on recreating the exact and complicated mechanical connections between the proximal humerus and glenoid fossa. The following is essential for the creation of a durable total shoulder prosthesis tolerating the functional ranges of the normal human shoulder:

(1) Knowledge of glenohumeral kinematics and the mechanical forces that interact at the shoulders within the functional range of motion. This information has been rigorously researched and carefully defined and explained in the literature.[34-40]

(2) Knowledge of the properties and performance of biomaterials present for the use of total shoulder arthroplasty in humans. These data have been obtained from extensive studies of total hip and knee implants.[41-42]

(3) Knowledge of the accurate osseous anatomy and anatomical relationships of the normal proximal humerus and glenoid.[43-46]

Unlike the hip and knee, few anthropometric data are available highlighting the osseous anatomy of the human shoulder.[30,32,40,44,45] When using minimally constrained shoulder implants, it is essential to recreate normal anatomical relationships. Unlike the hip joint, where the osseous anatomy resembles a ball-and-socket providing inherent stability, glenohumeral articular stability depends primarily on the surrounding musculotendinous soft-tissue unit acting in a smooth synchronous pattern to provide a resultant stabilizing force towards the glenohumeral joint.[31,34-36,38-40] The osseous anatomy and normal anatomical relationships of the glenohumeral joint need to be reconstructed in every individual undergoing minimally restricted resurfacing shoulder arthroplasty in order to enable the complex movements of the 17 muscles surrounding the shoulder joint to function properly. Furthermore, when an uncemented procedure is used, a close match between the bone and the implant is essential. This is supported by histological data suggesting that before bone ingrowth occurs on porous impaled surfaces the relative motion between an implant and bone must be decreased to 50 µm or less.[47] In addition, the strength and rigidity of cancellous bone increase significantly within 2 to 5 mm of the cortical Wall.[48] Therefore, it is only possible to directly support the humeral component with the strongest available bone if instruments and implants closely representing endosteal geometry are designed.

The anatomic parameters described and measured in this study provided an accurate reference for proximal humerus and glenoid implant designs. In general, the anthropometric data obtained in this study are in line with the latest results of Lannotti et al.[44] and Maki and Gruen.[45] The anatomic relationships discussed in this study also provide further insight into human glenohumeral geometry.

If the purpose of prosthetic replacement of the proximal part of the humerus is to reconstruct normal anatomy, it is crucial to provide a three-dimensional understanding of normal extramedullary and intramedullary humeral morphology. Prosthetic sizing, positioning, and design may be influenced by this information. Extramedullary anatomy may affect fixation and the position of the articular surface. In order to properly approximate normal anatomy with proximal humeral arthroplasty, this relation between the two anatomical considerations requires concurrent knowledge of both extramedullary and intramedullary morphology. A review of the literature on the morphological and morphometric properties of the glenoid cavity reveals the incredible variety of existing forms and parameters.[49-54] It appears that the morphology of the scapula and the glenoid cavity is extremely diverse. There is, however, a consensus on the role of the glenoid cavity that an osseous base is provided for the stability of the glenohumeral joint both sagittally and vertically.[51] The most significant factor that contributes to this stability was recently identified by Itoi et al.[55] indicating that a bone loss of more than %21 of the superior-inferior glenoid length would lead to instability in spite of correct soft-tissue recovery.[54] This was confirmed by Burkhart et al.[56], who clarified the definition of bone loss: assuming that the inferior glenoid is in the form of a circle to the anterior rim of less than 6mm (loss of %25) would be the sign for a bony surgical stabilizing procedure. Anatomists describe the shapes of the glenoid cavity as teardrop, pear-shaped, round, ovoid, or inverted comma shape. The anteroposterior (AP) width of the upper half of the glenoid cavity in this shape is less than the lower half. In addition, the supero-inferior (SI) diameter is greater than the largest AP diameter.[57-60] Normal variations in the anatomical dimensions of the glenohumeral surfaces should be known for the design and selection of prosthetic components for shoulder arthroplasty.[59] Reestablishment of normal glenohumeral relationships is achieved by restoring normal skeletal anatomy, selecting appropriate size prostheses, and their correct placement.[59] When Cavitas glenoidalis measurements were compared between genders, a significant difference was observed. This feature was mentioned in the studies of both Von Schroeder et al.[57] and Mallon et al. In their study on cavitas glenoidalis, Prescher and Klümpen[58] stated in their citation from Acsadi Nemesceri (1970) that the main bones used in gender determination were pelvis and skull bones, and they also investigated whether the use of cavitas glenoidalis is appropriate. The surface area of cavitas glenoidalis was reported as 9.87 ± 1.23cm² in males and 7.18 ± 0.89 cm² in females. He also indicated that this area is associated with the maximum length and width of the scapula. Nevertheless, the same researcher stated that 60% of men and 36% of women can be correctly detected by cavitas glenoidalis and it can thus only be used as an aid in the presence of other bones.[58]

Conclusion

1. A precise/reproducible system has been developed for the comprehensive examination of the osseous anatomy of the human shoulder.
2. Many osseous parameters have been identified by a meticulous anthropometric study of the glenoid and proximal humerus, which can be used to fit the prosthesis to the anatomical geometry of a patient.
3. Anatomical relationships of the humeral head and glenoid have been described as conformity, constraint, and canal flore useful to understand the geometry of the glenohumeral joint.
4. Correlations that are beneficial for the design and sizing of prosthetic components exist between many parameters.

Compliance with Ethical Standards

Ethics committee approval for the study was obtained from the University of Necmettin Erbakan Research Ethics Committee (2019/2125).

Conflict of Interest

There is no conflict of interest between the authors.

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