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Morphological Determination of Glenohumeral Joint and Acromioclavicular Joint with Computed Tomography

Determinación Morfológica de la Articulación Glenohumeral y la Articulación Acromioclavicular con Tomografía Computarizada

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SUMMARY: Although acute and chronic pathologies of the glenohumeral and acromioclavicular joints are frequently encountered in the population, the anatomy and morphometry are not fully known. The aim of this study is to determine the measurements of morphometric parameters according to age groups and sex in a large series of Turkish population. Nine hundred and forty-one shoulders computed tomography (CT) images were screened and those of subjects with healthy anatomical structure were included. Humeral head diameter (HDD) was measured on CT images. Measurements were made using 3D-CT images of: width (GW) and height (GH) of the glenoid cavity; width (CW) and height (CH) of the distal clavicular joint surface; and width (AW) and height (AH) of the acromial joint surface. Data were compared, stratified by age and sex. Images of 223 patients (118 men, 105 women) were analyzed. The following mean measurements were determined: HDD, 41.77±3.77 mm; GH, 34.66±3.26 mm; GW, 25.50±2.90 mm; CW, 14.85±3.51 mm; CH, 8.49±2.27 mm; AW, 12.97±2.94 mm; AH, 7.01±1.77 mm. When startified by sex, HDD ($p<0.001$), GH ($p<0.001$), GW ($p<0.001$), CW ($p<0.001$), CH ($p=0.002$), AW ($p<0.001$) and AH ($p<0.001$) measurements were significantly different and mean values were greater in men. Similarly for age, significant differences were found for GH ($p=0.028$), CW ($p<0.001$), AW ($p<0.001$), AH ($p<0.001$). The parametric values we have obtained in the Turkish population we measure differ from the measurements made in different populations according to age groups and sex. Knowing these features will contribute to treatment planning, implant and prosthesis applications.

KEY WORDS: Acromion; Computed tomography; Glenoid; Humeral head; Shoulder joint.

INTRODUCTION

Both the glenohumeral joint and acromioclavicular joint are important structures in the shoulder area that allow the upper limb to move freely (Moore *et al*., 2014). The shoulder region is frequently exposed to trauma and injuries. The glenohumeral joint has been reported to suffer the most dislocations of any joint in the body (Ozan & Bora, 2010). Acromioclavicular joint is present in 9 % of injuries to the shoulder area, especially in the young population engaged in active sports (Mazzocca *et al*., 2007). The rotator cuff muscles, which act as part of the stabilizing structures for the glenohumeral joint are the most common source of shoulder pain (DeCastro, 2020) due to rotator cuff injuries. This is closely related to the morphological features of acromion, one of the bony structures that make up the articulatio acromiclavicularis (Balke *et al*., 2013).

Since these joints are frequently exposed to trauma, their morphometric properties have gained great importance. This is increasingly true as the complexity of surgical procedures and applications, such as arthroscopy and arthroplasty, has increased. Physicians must be familiar with the anatomy of the region (Bockmann *et al*., 2016). In addition, knowing the morphometric differences which depend on age, sex and ethnicity is necessary for the nearest anatomical match for implant applications in order to most closely match the pre-injury joint (Cabezas *et al*., 2016).

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There is a dearth of literature concerning the morphological features of glenohumeral joint and acromioclavicular joint (Matsumura *et al*., 2014; Damas *et al*., 2016). Studies are even more limited in pathological joints. However, knowing the morphometry of the healthy joint will be of great benefit in terms of diagnosis, treatment and patient evaluation after surgery.

The aim of this study, therefore, was to increase the amount of available data on the morphometric properties of both these joints in healthy subjects, stratified by sex and age. It is hoped that this will aid clinicians in the diagnosis, treatment planning, surgical intervention, post-treatment patient evaluation and prosthesis applications for the glenohumeral joint and acromioclavicular joint. An additional aim was to evaluate these two joints, which are in close relationship with each other in terms of anatomical and functional features, and to determine the relationship between them.

MATERIAL AND METHOD

Computed tomography (CT) images, taken between 2010 and 2019, in the Department of Radiology, including CT scans of the shoulder region, performed for any indication in the 20-79 year-old age group were used. In total 941 CT images of the shoulder region were identified. Exclusion criteria included images that prevented the measurement of morphometric parameters for indications such as dislocation, fracture, Hill-Sach lesion, Bankart lesion, degeneration, advanced osteoarthritis, tumor or for technical reasons. Images were divided by age group of the individual into three age groups: Group 1- 20 to 39 years; Group 2- 40 to 59 years; and Group 3- 60 to 79 years.

Images were obtained with the Toshiba Aquilion 64 and Toshiba Activion 16 Multislice CT devices (Toshiba Medical Systems, Otawara, Japan). Images were evaluated using the Kocaeli University Picture Archiving and Communication system (PACS) and Sectra Workstation IDS7 (Sectra AB, Linköping, Sweden), version 20.2.11.3398, software was used for measurements. Each measurement was made twice and averaged.

The study was approved by Kocaeli University Non-Interventional Ethics Committee with the decision number KÜ GOKAEK 2019/03.16 and project number 2019/49.

Morphometric measurements were made as follows:

· Humeral head diameter (HHD): The cross section in which the caput humeri was widest in the coronal plane was determined and measured as the widest diameter of the caput humeri (Bockmann *et al*., 2016) (Fig. 1.a).

· Glenoid cavity height (GH): The anteroposterior length of the cavitas glenoidalis was measured in the coronal plane in the 3-D reconstructed image (Matsumura *et al*., 2016) (Fig. 1.b).

· Glenoid cavity width (GW): In the 3-D reconstructed image, the anteroposterior length of the cavitas glenoidalis in the axial plane was measured (Matsumura *et al*., 2016) (Fig. 1.b).

· Distal clavicular joint surface height (CH): The longest craniocaudal distance of the face articulating with the acromion in the lateral view was measured (Bulkmans *et al*., 2020) (Fig. 1.c).

· Distal clavicular joint surface width (CW): The longest anteroposterior distance of the face articulating with the acromion in lateral view was measured (Bulkmans *et al*., 2020) (Fig. 1.c).

· Acromial joint surface height (AH): The longest craniocaudal distance of the articulating face with the clavicula in the lateral view was measured (Bulkmans *et al*., 2020) (Fig. 1.d).

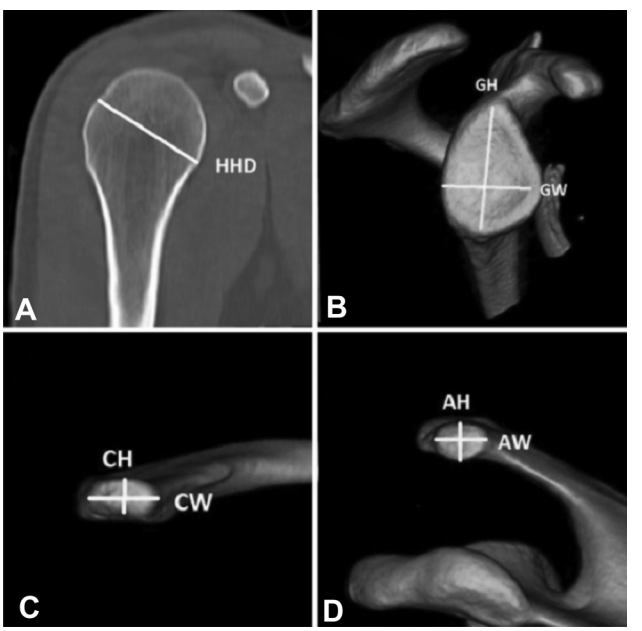

Fig. 1. Measurement of parameters. a) HHD, humeral head diameter. b) GH, height of glenoid cavity; GW, width of glenoid cavity; c) CW, width of the distal clavicular joint surface; CH, height of the distal clavicular joint surface d) AW, width of the acromial joint surface; AH, height of the acromial joint surface.

· Acromial joint surface width (AW): The longest anteroposterior distance of the articulating face with the clavicula in the lateral view was measured (Bulkmans *et al*., 2020) (Fig. 1.d).

Descriptive statistics were assessed. For continuous variables mean, standard deviation, median, and minimum-maximum values are shown. For categorical data, numbers and percentages are presented. The compliance of continuous data to normal distribution was evaluated by Kolmogorov-Smirnov and Shapiro-Wilk tests. The t-test was used to compare two independent groups with parametric distribution and the Mann-Whitney U test was used to compare two independent groups with non-parametric features. Analysis of Variance in Independent Groups (ANOVA) was used for comparing more than two groups with parametric features, and Kruskal Wallis test was used for comparing more than two groups with non-parametric features. Post-hoc analysis was conducted to determine from which group the significance originated. After ANOVA the Tukey test was used to determine which groups were significantly different. Pearson's correlation analysis was used to compare numerical variables with parametric features, and Spearman correlation analysis was used to compare numerical variables that were non-parametric. For statistical significance, $p<0.05$ in 95 % Confidence Interval were considered significant. For statistical analyses, 21.0 version of the Statistical Package for the Social Sciences (SPSS), version 21.0, (IBM Inc., Chicago, IL, USA) program was used.

RESULTS

In this study, 223 individuals (118 men; 52.9 %) who met the criteria and were considered to have a healthy shoulder structure were included in the analysis. While the average age of men in the whole cohort was 43.95±17.7, the average age of women was older at 51.5±17.6 (Table I). In Group 1 the number of men and women (mean±SD age in years) was 59 (29.2±5.5), and 28 (28.6 ± 6.8), respectively. Similarly for Group 2 the number of men and women was 31 (48.2±6.2) and 39 (50.8±5.4). In Group 3 this was 28 men (70.3±3.4) and 38 women (69.2±6.2).

The measured parameters of 223 individuals were evaluated. Overall measurements for the whole cohort are shown in Table II. When comparison was made between the sexes the mean measurements for HHD, GH, GW, CW, CH, AW, and AH were found to be greater in men. A significant difference was found between men and women for all these parameters (Table III).

When the patients were evaluated according to age groups, but without stratification by sex, there was a significant statistical difference across the age groupings for GH, CW, CH, AW and AH, although no difference was identified for the parameters HHD and GW (Table IV). Each of the parameters with an overall significant difference by age was investigated in a pairwise-fashion for all age groups.

Table I. Distribution of individuals by age and sex.

				Age			
		n	%	Mean	SD	Min.	Max.
Group 1	Male	59	67.8	29.20	5.52	20.00	39.00
20-39 years	Female	28	32.2	28.57	6.82	20.00	39.00
Group 2	Male	31	44.3	48.19	6.22	40.00	59.00
40-59 years	Female	39	55.7	50.79	5.36	40.00	59.00
Group 3	Male	28	42.4	70.32	5.34	62.00	79.00
60-79 years	Female	38	57.6	69.16	6.24	60.00	79.00
All males		118	52.9	43.95	17.68	20.00	79.00
All females		105	47.1	51.51	17.6	20.00	79.00
Whole cohort		223	100	47.51	17.72	20.00	70.00

SD, standard deviation; Min, minimum; Max, maximum.

Table II. Descriptive statistics of morphometric variables for the whole cohort.

n=223	Mean	SD	Median	Min.	Max.
HHD (mm)	41.77	3.72	42.00	31.00	50.00
GH (mm)	34.66	3.26	34.50	26.70	45.20
GW (mm)	25.50	2.90	25.00	19.20	34.00
CW (mm)	14.85	3.51	14.40	7.00	25.00
CH (mm)	8.49	2.27	8.40	4.00	18.00
AW (mm)	12.97	2.94	12.20	6.50	21.50
AH (mm)	7.01	1.77	7.00	3.80	13.00

SD, standard deviation; Min, minimum; Max, maximum; HHD, humeral head diameter; GH, height of glenoid cavity; GW, width of glenoid cavity; CW, width of the distal clavicular joint surface; CH, height of the distal clavicular joint surface; AW, width of the acromial joint surface; AH, height of the acromial joint surface.

Table III. Comparison of morphometric variables by sex, excluding age grouping.

	MALE (n=118)		FEMALE (n=105)		
	Mean	SD	Mean	SD	p-value
HHD (mm)	44.22	2.54	39.01	2.81	<0.001*
GH (mm)	36.60	2.55	32.48	2.52	<0.001*
GW (mm)	27.19	2.46	23.59	2.06	<0.001
CW (mm)	15.85	3.41	13.74	3.30	<0.001
CH (mm)	8.96	2.35	7.95	2.05	0.002
AW (mm)	13.73	2.97	12.11	2.66	<0.001
AH (mm)	7.55	1.79	6.42	1.55	<0.001

Mann Whitney-U test was used; * t test used.
SD, standard deviation; HHD, humeral head diameter; GH, height of glenoid cavity; GW, width of glenoid cavity; CW, width of the distal clavicular joint surface; CH, height of the distal clavicular joint surface; AW, width of the acromial joint surface; AH, height of the acromial joint surface.

There was a significant difference between Groups 1 and 3 for the height value of glenoid cavity (p=0.026). A significant difference was found between Groups 1 and 2 (p=0.010), between Groups 1 and 3 (p<0.001), and between Groups 2 and 3 (p=0.011) for the width of the distal clavicular joint surface. A significant difference was found between Groups 1 and 2 (p<0.001) and between Groups 1 and 3 (p<0.001) for the height of the distal clavicular joint surface. There was also a significant difference between the youngest and oldest groups for the mean measurements of the width of the acromial joint surface and the height of the acromial joint surface (both p<0.001). Correlation analysis was undertaken for all of the mophometric parameters being investigated (Table V). This showed a significant correlation between all the parameters under study.

Table IV. Comparison between age groupings excluding sex. Kruskal Wallis test was used.

	Group 1 Mean ± SD	Group 2 Mean ± SD	Group 3 Mean ± SD	*All groups p*	Pairwise comparison
HHD (mm)	42.30 ± 3.61	40.82 ± 4.01	42.07± 3.41	0.094	Not significant
GH (mm)	34.48 ± 3.31	34.07± 3.18	35.52± 3.16	0.028*	Groups 1-3 *p*=0.026
GW (mm)	25.25 ± 2.85	25.18± 2.79	26.16± 3.02	0.186	Not significant
CW (mm)	13.41±3.01	15.01± 3.54	16.58± 3.30	<0.001	Groups 1-2 *p*=0.010 Groups 1-3 *p*<0.001 Groups 2-3 *p*=0.011
CH (mm)	7.52±2.04	9.02± 2.54	9.20± 1.77	<0.001	Groups 1-2 *p*<0.001 Groups 1-3 *p*<0.001
AW (mm)	12.12±2.84	12.92± 2.62	14.14± 3.02	<0.001	Groups 1-3 *p*<0.001
AH (mm)	6.46±1.48	6.93± 1.54	7.84± 2.05	<0.001	Groups 1-3 *p*<0.001

* Analysis of variance (ANOVA) was used in independent groups. SD, standard deviation; HHD, humeral head diameter; GH, height of glenoid cavity; GW, width of glenoid cavity; CW, width of the distal clavicular joint surface; CH, height of the distal clavicular joint surface; AW, width of the acromial joint surface; AH, height of the acromial joint surface.

DISCUSSION

It is known that the morphometry of the structures that make up the shoulder joint varies according to age and sex (Piponov *et al*., 2016). In addition, studies evaluating the bone tissues that make up the joint have shown that ethnic differences change bone morphometry (Cabezas *et al*., 2016). The glenohumeral joint and acromioclavicular joint morphometers remain uncertain as studies have been conducted in a limited number of series and have focused mainly on pathological joints.

Table V. Correlation of morphometric variables.

n=223		HHD	GH	GW	CW	CH	AW	AH
HHD	r	1.000	0.69	0.68	0.38	0.30	0.315	0.36
	p		**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
GH	r		1.000	0.73	0.43	0.365	0.38	0.42
	p			**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
GW	r			1.000	0.415	0.32	0.37	0.33
	p				**<0.001**	**<0.001**	**<0.001**	**<0.001**
CW	r				1.000	0.67	0.535	0.52
CH	r					1.000	0.445	0.54
	p						**<0.001**	**<0.001**
AW	r						1.000	0.63
	p							**<0.001**
AH	r							1.000
	p							

Spearman correlation analysis was performed; p, p-value; r, correlation coefficient. HHD, humeral head diameter; GH, height of glenoid cavity; GW, width of glenoid cavity; CW, width of the distal clavicular joint surface; CH, height of the distal clavicular joint surface; AW, width of the acromial joint surface; AH, height of the acromial joint surface.

The glenoid cavity is the region of the scapula that articulates with the humeral head. Rajput *et al*. (2012) found that the height of glenoid cavity was 34.76 mm and the width was 23.31 mm in their study with 43 right-hand dry bone scapulae in India. Peltz *et al*. (2015) determined the height of glenoid cavity to be 33.3 mm and the width to be 25.3 mm in their study on 11 healty volunteers in USA. Matsumura *et al*. (2016) found that the height of glenoid cavity was 31.5 mm and the width was 21.3 mm in their study on 160 individuals in Japan. The results from the present study are consistent with this literature. We found that the height of glenoid cavity increased significantly with age, but the width of glenoid cavity did not differ between the age groups. We suggest that the reason for this may be that the cummulative effects of the force applied to the superior and inferior parts of glenoid cavity is significant over time whereas the force applied to the anterior and posterior regions does not result in a change in dimensions over time.

The caput humeri is an important component of the glenohumeral joint morphometry and is of great importance for anatomical reconstruction of the joint (Matsumura *et al*., 2014). Knowles *et al*. (2016) determined the width of the humeral head to be 47.1 mm in their study which included 50 individuals in Canada. In contrast, Bockmann *et al*. (2016) determined the width of humeral head to be 43 mm in their study of 210 patients in Germany. Harrold & Wigderowitz (2013) determined the width of humeral head to be 48.8 mm in their study of 24 bone samples (14 female and 10 male) in Scotland. In our study, a significant difference was found between the sexes for humeral head diameter while there was no significant difference between age groups. The overall mean width of the humeral head in our cohort (41.77 mm) was smaller than these earlier reports, with an additional significant difference between the sexes of more than 5 mm for the mean measurements. The mean measurement for the males in our cohort would be in line with the mean measurement in the Bockmann *et al*. (2016) study, but still below that of the studies of Knowles *et al*. (2016) and Harrold & Wigderowitz (2013).

The acromioclavicular joint is frequently injured by direct or indirect traumas (Crönlein *et al*., 2018). Approximately 40-50 % of shoulder injuries in athletes occur in this joint (Cerciello *et al*., 2019). Morphometry of the acromion and clavicula has gained importance for the safe placement of implants applied in acromioclavicular joint surgery (Kim *et al*., 2015), clavicular fractures (Sinha *et al*., 2011) and ligamentum coracoclavicular repair (Xue *et al*., 2013). Bulkmans *et al*. (2020) performed a 3D-CT examination on 84 claviculae and examined the distal clavicula and acromion joint faces. These authors reported the height of the distal clavicular joint surface as 10 mm in males and 9 mm in females while the joint face width was 9 mm in men and 8 mm in women. They also reported the acromial joint surface height as 15 mm in males and 13 mm in females while the joint face width was 15 mm in men and 13 mm in women. In our study, the mean height of the distal clavicular joint surface was 8.96 mm in men and 7.95 mm in women and the mean joint face width was 15.85 mm in men and 13.74 mm in women. The acromial joint surface

height was 13.73 mm in men and 12.11 mm in women and the joint face width as 15 mm in men and 13 mm in women (Table III). Measurements of the acromion and distal clavicular joint surfaces are in agreement in studies with either CT imaging or dry bone. In addition, in our study, we determined that joint face measurements increased significantly in males and with advance in age.

The relationship between morphometric parameters of the shoulder joint according to age and sex is of importance. There are few earlier studies that investigated the relationship between these parameters. Matsumura *et al*. (2016) found a positive significant relationship between the humeral head diameter and the height and width of glenoid cavity in their study of 410 individuals from a normal Japanese population. Kircher *et al*. (2014) found a positive significant relationship between the humeral head diameter and the width of the glenoid cavity in their study of 50 individuals. Our data are compatible with this literature. In addition, a significant positive correlation was found between the humeral head diameter and the other six parameters in our study (Table V). As this strong positive correlation exists, we hypothesize that the humeral head diameter can be a guide in determining the implant size in cases where other parameters cannot be determined. The glenohumeral and acromioclavicular joints are two joints that are frequently injured in day-to-day living. Injuries to these joints may limit the movement range and cause affected individuals to consult a physician. Thus morphometry of both joints is of great importance when planning treatment. However, there is a dearth of literature concerning the normal morphometry of both joints. In addition, there are no studies evaluating the morphometric properties of these joints, which are in close relationship with each other.

In our study we evaluated seven morphometric properties of both joints using stored computed tomography images and 3-D reconstruction images. We have evaluated these morphometric properties according to sex and age groups and compared them with the data in the literature. As a result, we were able to identify significant differences between our cohort and the literature, and between between sexes and age groups within our cohort.

CONCLUSION. The parametric values we have obtained in the Turkish population we measured, differ from the measurements made in different populations. Knowing these characteristics in Turkish society according to age groups and gender will contribute to the planning of the treatment of pathological shoulder injuries, implant and prosthesis applications as close to anatomical features.

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RESUMEN: Aunque las patologías agudas y crónicas de las articulaciones glenohumeral y acromioclavicular son frecuentes en la población, la anatomía y morfometría no se conocen por completo. El objetivo de este estudio fue determinar las medidas de los parámetros morfométricos según grupos de edad y sexo en una serie de individuos de población turca. Se examinaron 941 imágenes de tomografía computarizada (TC) de hombro y se incluyeron las de sujetos con una estructura anatómica sana. El diámetro de la cabeza humeral (HDD) se midió en imágenes de TC. Las mediciones se realizaron utilizando imágenes 3D-CT de: ancho (GW) y altura (GH) de la cavidad glenoidea; anchura (CW) y altura (CH) de la superficie articular clavicular ; y anchura (AW) y altura (AH) de la superficie articular acromial. Los datos fueron comparados, estratificados por edad y sexo. Se analizaron imágenes de 223 pacientes (118 hombres, 105 mujeres). Se determinaron las siguientes medidas medias: HDD, 41,77±3,77 mm; GH, 34,66 ± 3,26 mm; GW, 25,50±2,90 mm; CW, 14,85±3,51 mm; CH, 8,49±2,27 mm; AW, 12,97±2,94 mm; AH, 7,01±1,77 mm. Cuando se inicia por sexo, HDD ($p<0,001$), GH ($p<0,001$), GW ($p<0,001$), CW ($p<0,001$), CH ($p=0,002$), AW ($p<0,001$) y AH ($p <0,001$) las mediciones fueron significativamente diferentes y los valores medios fueron mayores en los hombres. De igual forma para la edad se encontraron diferencias significativas para GH ($p=0,028$), CW ($p<0,001$), AW ($p<0,001$), AH ($p<0,001$). Los valores paramétricos que hemos obtenido en la población turca difieren de las medidas realizadas en diferentes poblaciones según grupos de edad y sexo. El conocimiento de estas características contribuirá a la planificación del tratamiento, aplicaciones de implantes y prótesis.

PALABRAS CLAVE: Acromion; Tomografía computarizada; Cavidad glenoidea; Cabeza humeral; Articulación glenohumeral.

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