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Three-dimensional glenohumeral relationship in cuff tear arthropathy and its correlation with the type of cuff tear

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Level of evidence: Anatomy Study; Imaging

Objective: The main purpose of this study is to evaluate 1) the three-dimensional (3D) glenohumeral relationship in cuff tear arthropathy (CTA) and 2) the correlation between different types of rotator cuff tears (RCTs) and the 3D glenohumeral relationship.

Method: A total of 124 patients with CTA and 60 control patients were included in this study. 3D models of computed tomography images of the shoulder were reconstructed to evaluate the position of the humerus in relation to the scapula using a Cartesian coordinate system. The glenohumeral relationship of the CTA group is compared to the control group (group N). Next, the CTA group is divided into three subgroups depending on the (im)balance of the transverse force couple (TFC): a balanced RCT group (group B, n = 50), a group with an imbalance of the TFC to anterior (group A, n = 30), and a group with an imbalance of the TFC to posterior (group P, n = 44). The glenohumeral relationship of the RCT group is compared to a control group of 60 patients without RCT (group N).

Results: The CTA group (96° ± 1°) was significant ($P < .05$) and more superiorly subluxated than the control group (88° ± 1°). There was no significant difference in the superior subluxation between the three subgroups: group A (98° ± 3°), group P (96° ± 3°), and group B (97° ± 2°). Group A (88° ± 2°) showed significantly more anterior subluxation compared to group P (92° ± 1°).

Conclusion: All patients with CTA have a significantly superior position of the humerus compared to the control group. If the TFC is unbalanced, a significantly more anterior or posterior translation of the humerus is observed depending on the direction of the imbalance.

The glenohumeral joint is a ball-and-socket joint with very little bony congruity, allowing all joints the greatest range of motion. Several static and dynamic mechanisms are needed to achieve the intricate balance between shoulder mobility and stability.[12,13] The rotator cuff muscles play an important role in the dynamic stability of the shoulder. Because of their unique anatomic location close to the joint, they provide stability to a dynamic fulcrum during shoulder abduction.[12,13] They help to centralize the humeral head in the glenoid concavity (concavity compression) and decrease shear forces.[14] In patients with rotator cuff tears (RCT), shoulder balance is potentially at risk.[7,14]

Burkhart et al[2] state that the location of the tear is a critical element of shoulder kinematics. The most important factors to retain stability are preserving the coronal force couple (deltoid and supraspinatus versus inferior cuff) and the transverse force couple (TFC) (anterior cuff; subscapularis versus posterior cuff; infraspinatus and teres minor). Patients with an unbalanced force couple can have an instability that can cause humeral head migration and eventually cuff tear arthropathy (CTA).[7,13,14] Different classifications evaluating the glenohumeral relationship in patients with CTA have been described: the Hamada, the Favard, the Viskotsky-Seebauer, the Sirvaux, and the Walch classification.[1,6,8,11,15,18,19] However, all these classifications are based on two-dimensional (2D) radiographic images. To our knowledge, no study evaluated the three-dimensional (3D) glenohumeral relationship in patients with CTA.

The aim of this study is 1) to evaluate the 3D glenohumeral relationship and patients with CTA and 2) to evaluate if there is a correlation between the type of rotator cuff tear and the glenohumeral relationship. A better understanding of the glenohumeral relationship can potentially help for a more individual treatment in the future.

This study was approved by 'Commissie voor medische ethiek' (number: 2017/0929 and 2019/1177).

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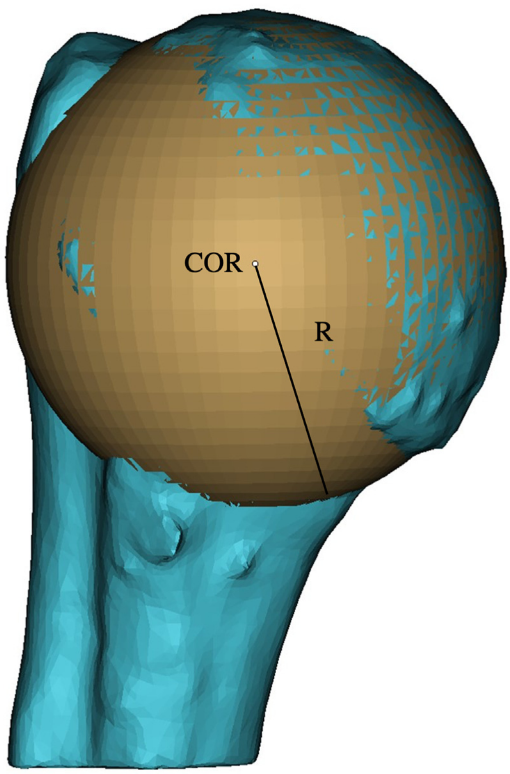

Figure 1 R

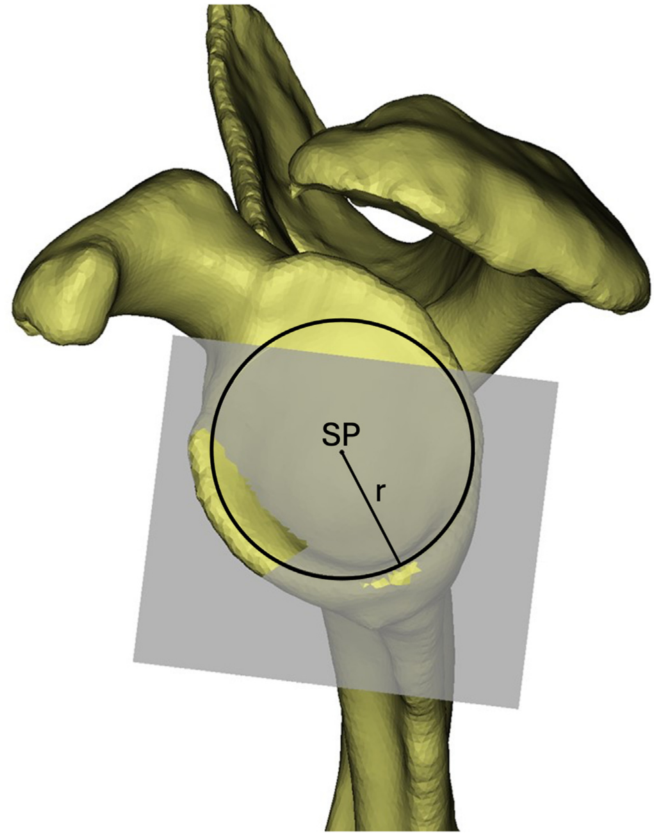

Figure 2 r

Methods

This retrospective case-control/cohort design study includes 124 shoulders with CTA and 60 shoulders with no signs of cuff or cartilage lesions. All patients included in this study are diagnosed with CTA based on the Hamada classification grade 2 or more. The data were collected at the beginning of 2022 in the University Hospital of Ghent. The computed tomography (CT) scans of patients who underwent a reverse shoulder arthroplasty between January 2017 and December 2021 were included. The measurements were performed by S.D.B., B.I. and R.C. When there was no agreement, a check was performed with A.V.T. and L.D.W. until a consensus was reached. The CT scans used for this study were made in the context of shoulder pathology. Thus, the patients did not receive any additional radiation for this study. All patients with radiological suspicion of primary osteoarthritis, rheumatoid arthritis, avascular necrosis, a fracture, or a previous intervention were not included in this study. For segmentation purposes, all arthrography was excluded as well. A Somatom Volume Zoom–Siemens CT (Siemens, Erlangen, Germany) with a matrix set to 512 x 512, kV: 140/eff. mAs: 350 was used to perform these scans. Using a standardized technique, the patients were positioned in the CT gantry in dorsal recumbency. The CT files were imported into Mimics (Materialize, Leuven, Belgium), a medical image processing software. Using this software, a 3D model could be reconstructed of the shoulders concerned with semiautomatic segmentation techniques. This model was then exported to 3-Matic (Materialise, Leuven, Belgium) for measurement purposes.[10,16,17]

The reference system

The reference system was constructed using computer-aided design operations in 3-Matic, Materialise. In the humerus, a best-fitting sphere was made based on the marked articulating surface of the humeral head. The center of this sphere was defined as the center of rotation (COR) (Fig. 1). In the scapula, bony references of the glenoid were used to construct the inferior glenoid plane and circle as described by De Wilde et al.[4] The inferior rim of the glenoid was marked, and the best-fitting circle and plane were defined (Fig. 2). A coronal scapular plane was formed through three points as described by Verstraeten et al: a lateral scapular point in the center of the inferior glenoid circle (SP), the most medial point of the scapula (S_{med}), and the most inferior point of the scapula (S_{inf}).[16] Following the placement of the inferior glenoid circle and the coronal scapular plane, a left-handed Cartesian coordinate system was incorporated into our reference system with SP as the origin. Both the x and y axes are positioned in the glenoid plane. To determine the relationship of COR to the scapular plane, the angle of COR to both the x-axis and y-axis was measured.

To evaluate the 3D-glenohumeral relationship, the following measurements were made (Figs. 1–6).

- R = The radius of the best-fitting sphere in the caput humeri
- r = The radius of the glenoid circle
- α = The retroversion angle between the inferior glenoid plane and the coronal scapular plane
- β = The inclination angle between the perpendicular to the scapular plane, including Smed and Sp, and the inferior glenoid plane
- x = The angles between the x-axis and the y-axis, respectively, and the line from the Sp to the COR
- y = The distances between Sp and COR, normalized to the radius of the glenoid circle, and reported as a ratio between the distance and the radius.

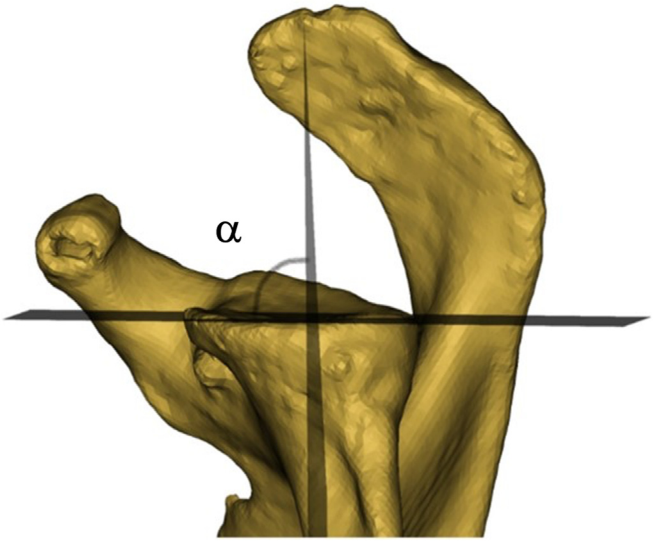

Figure 3 Alfa

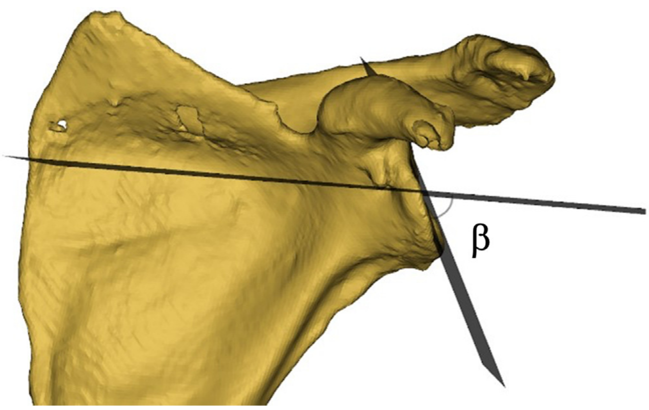

Figure 4 beta

Modified Collin classification

A total of 124 patients with CTA (Hamada classification grade 2 or more) are included and are divided into subgroups depending on the type of RCT, based on the Collin classification.[3] Collin et al describe 5 groups of RCT (see Fig. 7). For this patient population, we propose a modification of the classification, and four extra groups need to be created (see Fig. 8): patients with a tear of the upper subscapularis, supraspinatus, infraspinatus, and teres minor (type F) patients with a tear of the subscapularis, supraspinatus, and infraspinatus (type G), patients with a tear of the whole rotator cuff patients (type H) and patients with only a supraspinatus tear (type I). A total of 9 groups of RCT are redistributed into three groups depending on the (im)balance of the TFC

1. Group B = balanced RCT group (n = #): type C, H, and I.
2. Group A = imbalanced TFC to anterior (n = #): type A, B, and G.
3. Group P = an imbalanced TFC to posterior (n = #): type D, E, and F
4. Group N = control group

Statistical method

For statistical analyses, the variables were analyzed with a one-way analysis of variance model followed by Tukey post hoc tests. Model assumptions were verified. Significance was set at $P < .05$ for all analyses. The analysis was performed with the glm and plm procedure of SAS (SAS 9.4, SAS Institute Inc., 2019, Cary, North Carolina).

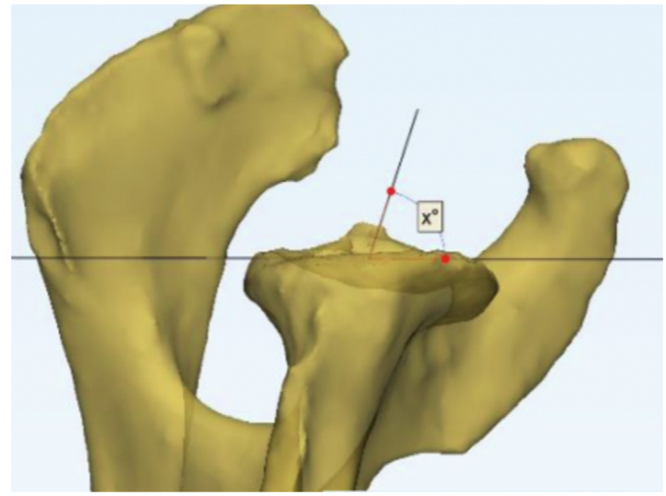

Figure 5 x

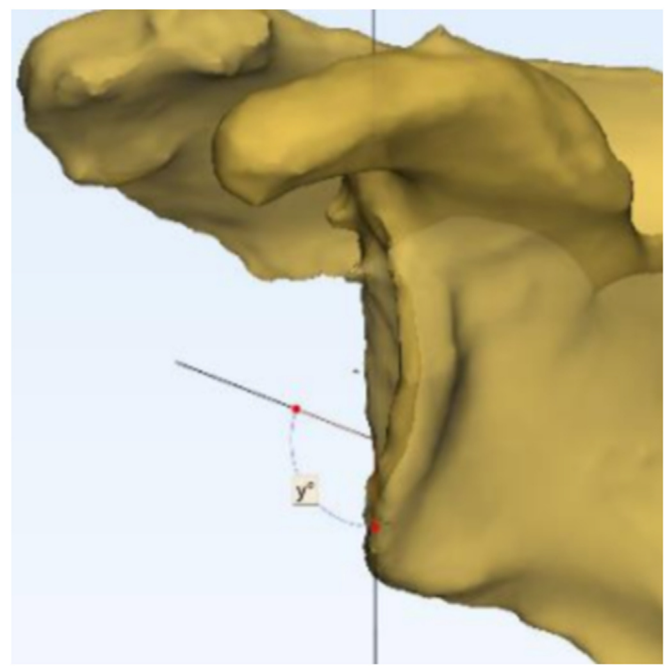

Figure 6 y

Results

Interobserver and intraobserver reliability

The measurements were performed once on all shoulders by two observers and repeated for 50 shoulders by one observer after 14 days. Subsequently, the interclass correlation coefficient was calculated to assess the intraobserver and interobserver reliability.

The interobserver and intraobserver reliability was for all measurements good to excellent (intraclass correlation coefficient ≥ 0,798).

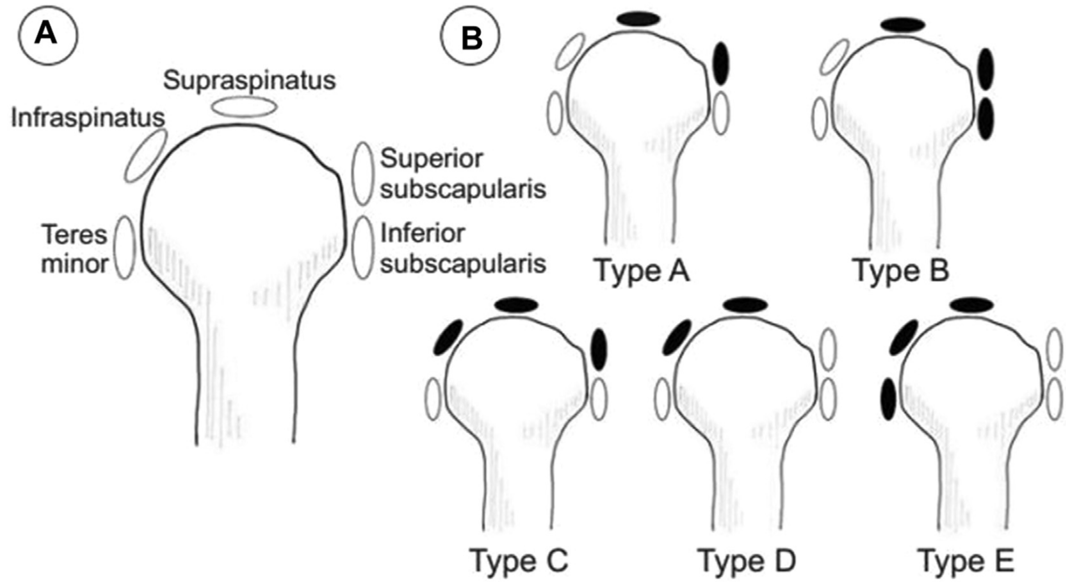

Figure 7 Collin P et al Relationship between massive chronic rotator cuff tear pattern and active shoulder range of motion loss. J Shoulder Elbow Surg 2014; 23:1195–1202).

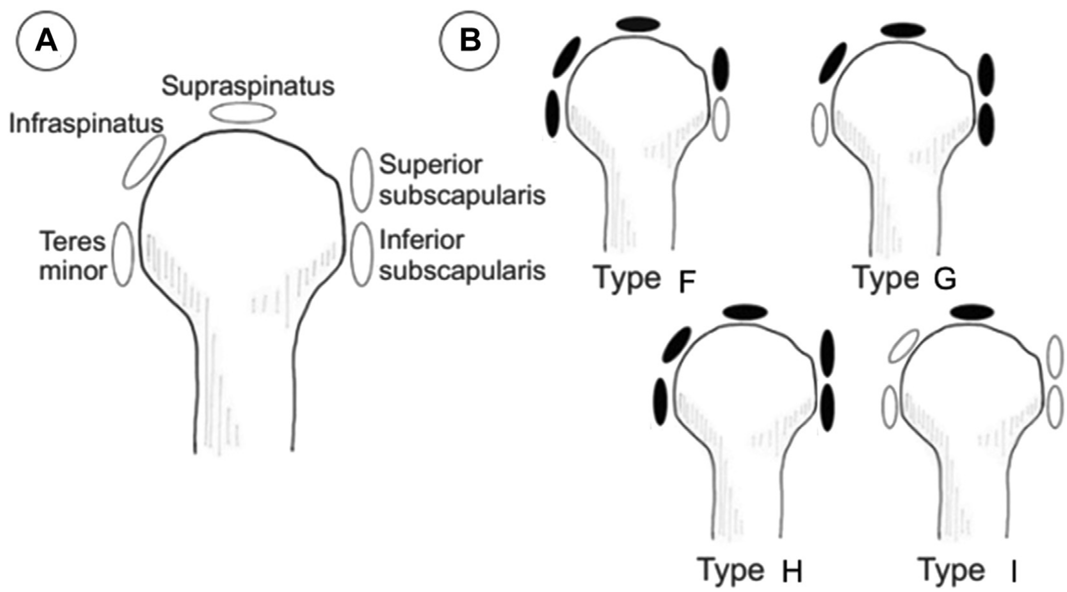

Figure 8 Extension of the Collin classification.

Descriptive statistics

A total of 124 patients with CTA are included: a balanced RCT group (group B, n = 50), a group with an imbalance of the TFC to anterior (group A, n = 30), and a group with an imbalance of the TFC to posterior (group P, n = 44). The control group exists out 60 patients without RCT (group N) (Table I). There are 114 females and 70 men, without significant differences in gender between all groups (Table II). The mean age is 79.4 (min. 57 and max. 103). There were no significant differences in age distribution between the three groups (see Table III).

Evaluation of the scapulohumeral relationship

The x and y variables were analyzed with a one-way analysis of variance model followed by Tukey post hoc tests. Model assumptions were verified. The analysis was performed with the glm and plm procedure of SAS (SAS9.42019; SAS Institute Inc., Cary, NC, USA).

Inferior-superior evaluation

In shoulders with CTA, the group with anterior tears ($98^\circ \pm 3^\circ$), the group with posterior tears ($96^\circ \pm 2^\circ$), and the group with balanced tears ($97^\circ \pm 2^\circ$) were significant ($P < .05$) more superiorly subluxated compared to the control group ($88^\circ \pm 1^\circ$) (Fig. 9, Table IV).

Anterior-posterior evaluation

Shoulders with anterior tears ($88^\circ \pm 2^\circ$) showed significantly more anterior subluxation additionally compared to shoulders with posterior tears ($92^\circ \pm 1^\circ$) (Fig. 10, Table V).

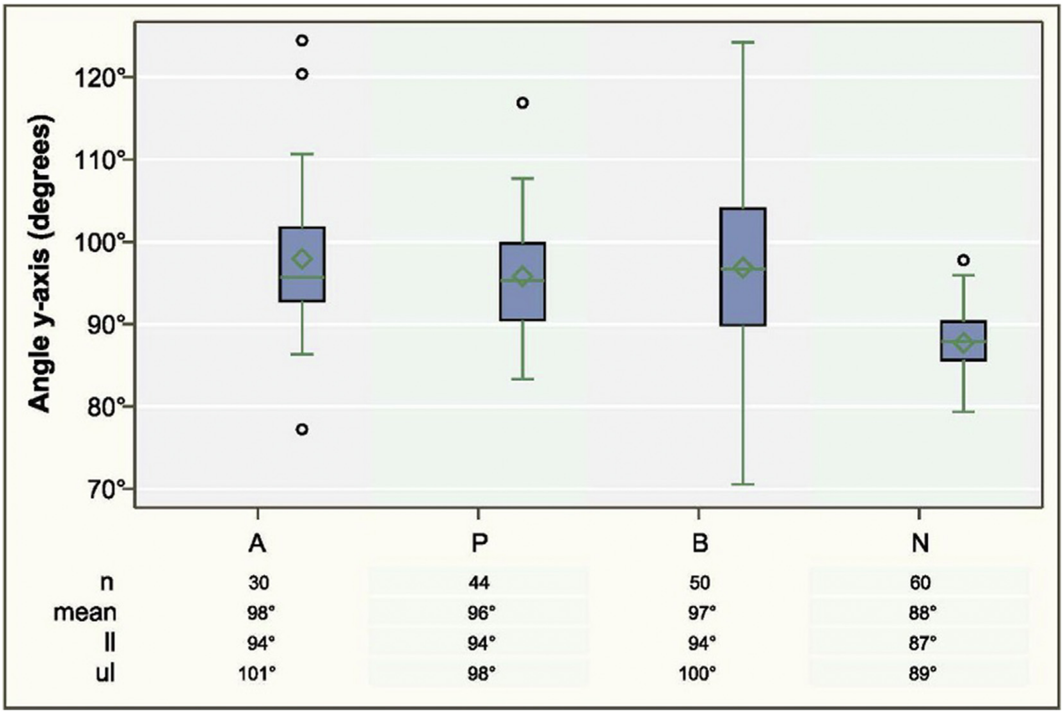

Figure 9 Boxplot inferior-superior evaluation.

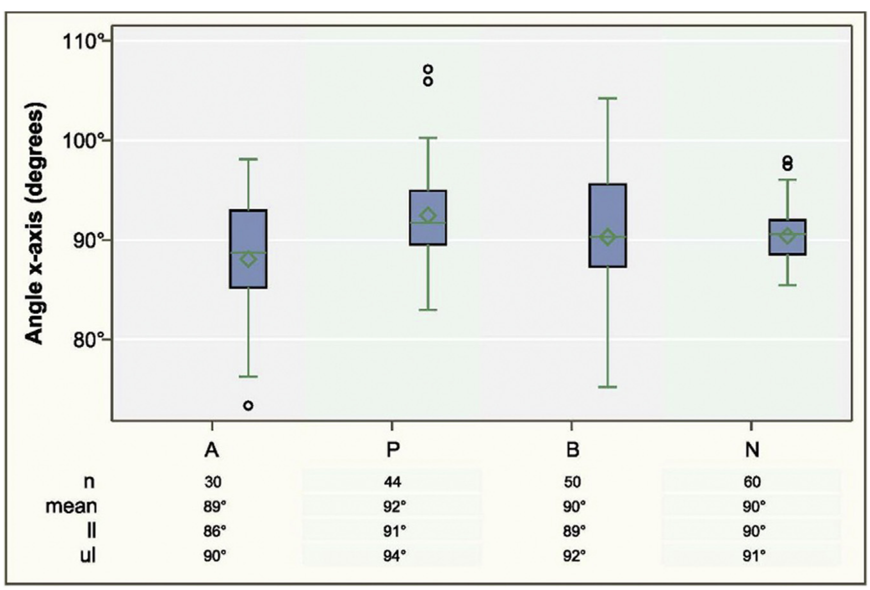

Figure 10 Boxplot anterior-posterior evaluation.

Table I
Descriptive statistics.

		Y-axis		X-axis	
ForceType	N	Estimate	Lower-upper 95% CL	Estimate	Lower-upper 95% CL
A	30	98°	95° − 101°	88°	86° - 90°
B	50	97°	95 °− 99°	90°	89° - 92°
N	60	88°	86° −90°	90°	89° − 92°
P	44	96°	94° − 98°	92°	91° − 94°

CL, confidence level.

Table II
Gender.

Group	Frequency	Percent
A		
F	22	73.3
M	8	26.7
Total	30	100.0
B		
F	33	66.0
M	17	34.0
Total	50	100.0
N		
F	28	46.7
M	32	53.3
Total	60	100.0
P		
F	31	70.5
M	13	29.5
Total	44	100.0

CL, confidence level.

Table III
Age.

Group	N	Minimum	Maximum	Mean	Standard deviation
A	30	57	97	81.57	10.47
B	50	57	103	78.12	8.53
P	44	62	93	79.23	9.48

CL, confidence level.

Table IV
Inferior-superior evaluation.

ForceType	_ForceType	Estimate	Tukey adjusted lower 95% CL	Tukey adjusted upper 95% CL	Tukey adjusted p value
A	B	1.04	−3.51	5.60	9.34E-01
A	N	10.20	5.79	14.61	6.21E-08
A	P	2.10	−2.57	6.78	6.48E-01
B	N	9.16	5.38	12.94	1.11E-08
B	P	1.06	−3.02	5.14	9.07E-01
N	P	−8.10	−12.01	−4.18	1.50E-06

CL, confidence level.

Evaluation retroversion and inclination

There is no significant difference in glenoid retroversion ($P = .4576$) or glenoid inclination ($P = .8319$) (Tables VI and VII).

Discussion

A great number of classifications have been described for CTA. However, all the well-known classifications are based on 2D (radiographic) images. De Wilde et al[5] were the first to study the normal 3D glenohumeral relationship. Jacxsens et al[9] investigated the 3D scapulohumeral relationship between nonpathological shoulders and those with primary osteoarthritis. Evidence was found that shoulders classified as type A and B according to the Walch classification (centered or posteriorly subluxated) show a posterior and inferior translation of the humeral head. This shows the possible advantage of 3D studies over 2D studies. This study used CT images to construct 3D models of CTA patients. Compared to the 2D studies, we analyzed both the superoinferior and anteroposterior positions of the humeral head in relation to the glenoid. This study confirmed a superior subluxation of the humeral head for all patients with RCT. Additionally, a significantly more anterior respectively posterior position is found in patients with an imbalance of the TFC to anterior resp. posterior.

Table V
Anterior-posterior evaluation.

ForceType	_ForceType	Estimate	Tukey adjusted lower 95% CL	Tukey adjusted upper 95% CL	Tukey adjusted pvalue
A	E	−2.24	−5.26	0.78	2.23E-01
A	N	−2.35	−5.28	0.57	1.61E-01
A	P	−4.40	−7.50	−1.30	1.70E-03
E	N	−0.12	−2.62	2.39	9.99E-01
E	P	−2.16	−4.87	0.54	1.65E-01
N	P	−2.05	−4.64	0.55	1.75E-01

CL, confidence level.

Table VI
Glenoid retroversion.

Glenoid retroversion	Estimate	Lower 95% CL	Upper 95% CL
A	87°	85°	90°
B	87°	85°	88°
N	87°	86°	89°
P	86°	84°	87°

CL, confidence level.

Table VII
Glenoid inclination.

Glenoid inclination	Estimate	Lower 95% CL	Upper 95% CL
A	71°	69°	73°
B	71°	69°	72°
N	70°	68°	71°
P	71°	69°	72°

CL, confidence level.

Next, the correlation between the 3D glenohumeral relationship and the type of RCT was evaluated. Therefore, patients needed to be divided into groups depending on the type of RCT. A well-known classification to do this is the Collin classification.[3] Collin investigated the effect of the tear's location and size on the shoulder's active movement in patients with massive RCT. To do this, he divides RCTs into five groups (see Fig. 7). This study concludes that dysfunction of the entire subscapularis and supraspinatus or three rotator cuff muscles is a risk factor for pseudoparalysis. It was impossible to divide the 124 patients included in this study using this classification. Four extra groups needed to be created (see Fig. 8). Because the sample sizes were too small, when patients were divided into nine groups, patients were redistributed into three groups. Patients were divided into three groups depending on the (im)balance of the TFC. By dividing the patients depending on the (im)balance of the force, a significantly more anterior position of the humerus is seen in group A (imbalance of TFC to anterior) compared to group P (imbalance of TFC to posterior). We only investigated the difference of glenohumeral relationship between the three different groups depending on (im)balance of TFC. We believe the TFC has the greatest impact on the anterior-posterior translation and other subdivisions of RCTs are less relevant to investigate.

This study showed no significant difference in the glenoid retroversion of the three groups compared to the control group. However, the posterior escape in patients with an imbalanced TFC to posterior (group P) does result in more glenoid retroversion. We also evaluated the glenoid inclination in the three groups compared to the control group and found no significant difference. This can be explained by the inferior glenoid circle determining the glenoid inclination. Further research could be done to evaluate the glenoid inclination based on the supraglenoid tubercle.

In the boxplot which describes the inferior-superior relationship, we notice a large scatter in the figure in the balanced group. This is mainly due to the determination of glenoidal plane which is based on inferior circle. In some patients, we see osteophyte formation which makes the angle smaller. And not because of more inferior migration of the humeral head.

Conclusion

In patients with RCT, the force couples of the shoulder are imbalanced**.** This is the first 3D study to confirm a superior escape of the humerus in all patients with RCTs because of disruption of the coronal force couple. In addition, this study proves that the type of RCT influences the direction of the humeral escape. RCT with an imbalance of the TFC to anterior or posterior results in a significantly more anterior resp. posterior translation of the humerus. A better understanding of the glenohumeral relationship and the importance of the TFC can potentially help for a more individual treatment in the future.

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