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Coracoacromial Morphology: A Contributor to Recurrent Traumatic Anterior Glenohumeral Instability?

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Abstract

Background: While scapular morphology contributes to glenohumeral osteoarthritis and rotator cuff disease, its role in traumatic glenohumeral instability remains unknown. We hypothesized that coracoacromial and glenoid morphology would differ between healthy subjects and those with recurrent traumatic anterior shoulder instability.

Methods: Computed tomographic scans of 31 cadaveric control scapulae and 54 scapulae of patients with recurrent traumatic anterior shoulder instability and Hill-Sachs lesions were three-dimensionally reconstructed. Statistical shape modelling identified the modes of variation between the scapulae of both groups. Corresponding measurements quantified these modes in relation to the glenoid center (linear offset measures), defined by the best-fit circle of the inferior glenoid, or glenoid center plane (angles), which bisects the glenoid longitudinally. Distances were normalized for glenoid size.

Results: As compared to controls, the unstable coracoids were shorter ($p=0.004$), with a more superior and medial offset of the tip (mean difference [MD]: 7 and 3 mm, respectively; $p<0.001$), and an origin closer to the 12 o'clock position (MD: 6°; $p<0.001$). The unstable scapular spines

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originated closer to the 9 o'clock position (MD: 4°; $p=0.012$), and the unstable acromion were more vertically oriented (MD: 6°; $p<0.001$). The unstable glenoids had an increased height-width index (MD: 0.04; $p=0.021$), had a flatter anterior-posterior radius of curvature (MD 77 mm; $p<0.001$), and were more anteriorly tilted (MD: 5°; $p=0.005$).

Conclusions: Coracoacromial and glenoid anatomy differ between those with and without recurrent traumatic anterior shoulder instability. This pathologic anatomy is not addressed by current soft tissue stabilization procedures and may contribute to instability recurrence.

Level of Evidence: Level III; Case-Control Design; Prognosis Study

Keywords

shoulder instability; Hill-Sachs; scapular morphology; acromion morphology; coracoid morphology; glenoid morphology; shape modeling; 3D reconstruction

The glenohumeral joint (GHJ) is the most frequently dislocated joint in the body.²⁴ The majority of GHJ dislocations are traumatic anterior dislocations.³² Glenohumeral instability is frequently recurrent (up to 85% within 5-years in young males), leads to functional impairment, and can cause degenerative changes.^{8, 35} Traumatic anterior shoulder dislocations are associated with capsulolabroligamentous tears, glenoid rim fractures, and posterosuperior humeral head compression fractures.³² The risk factors for recurrence with operative and non-operative treatment have been well described and include defects of the anterior glenoid rim,^{6, 28, 30, 37} large humeral-sided bony lesions called Hill-Sachs lesions,¹⁸ and combinations thereof.^{34, 36}

However, few studies have addressed osseous morphologic factors that may contribute to recurrent traumatic anterior shoulder instability beyond anteroinferior glenoid rim lesions and posterosuperior humeral head lesions. For instance, a taller, narrower, and flatter glenoid may be associated with recurrence.^{29, 31, 33} Glenoid version has been debated: Hohmann et al¹⁷ and Aygün et al³ found increased anteversion whereas Moroder et al²⁹ and Peltz et al³³ found no difference in glenoid version when comparing those with recurrent traumatic instability and healthy subjects.

The anatomy of the coracoacromial arch may also contribute to the etiology of recurrent traumatic anterior glenohumeral instability. Owens et al³¹ identified the coracohumeral distance as an independent risk factor for traumatic anterior instability, with a 20% increased risk of instability for every 1-mm increase in coracohumeral distance. Anatomical differences between those with and without recurrent traumatic anterior glenohumeral instability have implications for understanding the etiology, risk factors, possible preventions for, and mechanisms for treatment of recurrent traumatic anterior glenohumeral instability.

The aim of this study was to quantify and compare glenoid and periarticular scapular morphology between healthy shoulders and those with recurrent traumatic anterior shoulder instability. It was hypothesized that both glenoid morphology and periarticular scapular anatomy would be different between healthy subjects and those with recurrent anterior shoulder instability.

Methods

Study Population

In this retrospective anatomic case-control study (University of Utah IRB 17182, 92668), a retrospective review of patients that underwent procedures for anterior shoulder instability between 2008 and 2016 was performed. Skeletally mature patients with recurrent traumatic anterior shoulder instability (≥ 2 dislocation events) and an osseous Hill-Sachs lesion visible on Computed Tomography (CT) scans without contrast were included. The presence of an osseous Hill-Sachs lesion provided proof of a definite anterior shoulder dislocation. Exclusion criteria were the presence of concomitant lesions, instability secondary to seizures or hyperlaxity, degenerative changes of the GHJ, and poor quality CT scans. A retrospective review of electronic medical records and surgery reports identified the preoperative baseline demographics of the subjects, mechanism of the first dislocation (traumatic vs. atraumatic), number of dislocations, preoperative clinical and radiographic findings, intraoperative findings, and performed procedures. This study group was labeled as “unstable group”. The control group included cadaveric scapulae from an existing database, verified to be free of any shoulder pathology as seen by an orthopedic surgeon during dissection, and on a CT scan.

Imaging Protocol

Instability patients and the cadaver controls underwent a CT scan acquired using Siemens Somatom (Siemens Medical, Malvern, PA, USA) CT scanner (130 kV, 512×512 matrix, 2.0-mm [unstable group] or 1.0-mm [control group] slice thickness, 0.75 pitch, 170-mAs current). Clinical CT datasets were upsampled to axial slice thicknesses of 1.0-mm to improve resolution. All images were exported to DICOM (Digital Imaging and Communications in Medicine) format and reconstructed into 3D surfaces using semi-automatic segmentation techniques (Mimics; Materialise, Leuven, Belgium).

Statistical Shape Modeling

Computationally derived Statistical Shape Modeling (SSM) approaches are useful to objectively quantify population-level shape variation and anatomical differences, independent of size differences between subjects.^{2, 16} In particular, point-based correspondence models are the computational extension of manual landmarking that enable the automatic dense placement of homologous landmarks on 3D models of anatomy, offering more detailed anatomical geometric representations and capturing more subtle shape variations than traditional landmark-based approaches. In this regard, the validated SSM software ShapeWorks⁹ was used to identify the modes of variation and to detect differences between the mean shape of the control and pathologic scapulae, without idealizing underlying geometry. Without relying on any surface parameterization, ShapeWorks computes a statistically optimal representation of the population variability by choosing landmark positions (i.e. correspondence points) that minimize the overall information content of the model while maintaining a good sampling of surface geometry.

During preprocessing, left scapulae were mirrored to a right and all 3D surfaces were aligned to a glenoid-based coordinate system (3-matic; Materialise, Leuven, Belgium)

(Figure 1).²⁰ To focus the analysis on the periarticular anatomy of the scapula and concentrate placement of correspondence points on the region of interest, a cutting plane was defined through the scapular notch parallel to the best-fit circle of the inferior glenoid. A total of 2048 correspondence points were hierarchically placed on the region of interest and used to generate the mean shape of both groups. The difference between mean shapes provided a mode-based and visual assessment that guided the selection of morphometric measurements for analysis (Figure 2, Video Supplement).

Morphometrics

To quantify the morphologic differences between groups, each scapula was imported into 3-matic (Materialise, Leuven, Belgium) and measurements focused on the regions highlighted by the modes of variation (Figure 3). The center of the best-fit circle of the inferior glenoid and the glenoid center plane were used as a reference for offset and angle measurements, respectively. Angles were measured in the plane of the glenoid unless noted otherwise. Absolute distances between landmarks were assessed, and also normalized to the radius of the glenoid circle to compensate for differences in absolute size between scapulae.

Periarticular measures included the anterior, superior and lateral offset of the apex and the base of the coracoid process as defined by Chahla et al.¹⁰ The apex and the base of the coracoid determined the coracoid length and the coracoid deviation angle, measured in the transverse plane. The coracoid pillar angle was acquired using the best-fit plane through the middle of the pillar. Similarly, the best-fit plane through the middle of the base of the acromion determined the scapular spine angle. The orientation of the best-fit plane of the acromion undersurface defined acromial tilting. The coracoacromial (CA) relationship was acquired by assessing the distance between the coracoid apex and the anterolateral corner of the acromion (CA arch length) as well as the posterolateral corner of the acromion (CA base length). These two line segments further defined the CA arch angle and CA base angle.

Glenoid measures involved the anterior-posterior (AP) radius of curvature (ROC) of the posterior segment of the articular surface, the superior-inferior (SI) ROC of the articular surface, the H-W index of the glenoid face and the calculation of glenoid bone loss as described by Bhatia et al.⁵ The defect chord in relation to the glenoid center plane determined glenoid defect orientation.

The scapular axis, defined by the point where the scapular spine intersects the medial border of the scapula at the trigonum scapulae and the center of the glenoid circle, and the scapular plane, defined by the scapular axis and the most inferior point of the inferior angle of the scapula, were used to determine the glenoid relationship to the scapula. Glenoid version was defined as 90° minus the angle between the scapular plane and the glenoid circle, with a negative value representing a retroversion. The angle between the scapular plane and the glenoid center plane defined glenoid anterior tilting. The angle between the scapular axis and the line connecting the most lateral point of the superior and inferior glenoid pole in the coronal plane provided glenoid inclination.

Statistical Analysis

Data normality was verified by the Shapiro-Wilk test. A two-tailed Student's t-test and Mann-Whitney U test were used for comparison, as appropriate. To determine the reliability of the measurements, two investigators (M.J., S.E.B.) assessed each measurement independently on 15 control and 15 pathologic scapulae. One investigator (M.J.) repeated all measurements at a minimum time interval of two weeks. Reliability was quantified using intra-class correlation coefficient (ICC) and typical error of measurement (TEM). The interpretation of ICCs was as follows: 0.40, poor; 0.401 to 0.600, fair; 0.601 to 0.750, good; 0.751 to 1.000, excellent.¹² Statistical tests were conducted at a significance level of $p = 0.05$. Analyses were performed with SPSS Statistics, version 24.0 (SPSS Inc., Armonk, NY, USA).

Results

Between 2008 and 2016, 307 patients underwent procedures for anterior shoulder instability at our institution. A total of 74 patients met the inclusion criteria. Ten patients were excluded because of instability secondary to seizures, four had a CT scan with poor quality, two had degenerative changes, one had laxity, and three had a concomitant lesion. This left a final study population in the unstable group of 54 shoulders (19 right, 35 left) in 54 patients (46 male, 8 female) with an average age of 28 years (range, 18 – 50). Twenty-six underwent an anterior capsulolabral repair, of which three got an additional remplissage procedure. A Latarjet procedure was performed on 28 subjects. The control group consisted of 31 shoulders (16 right, 15 left) in 31 cadavers (16 male, 15 female) with an average age of 60 (range, 40 – 78).

When comparing morphology differences between mean shapes, qualitative observation demonstrated a large shape variation around the periarticular anatomy and the anterior-inferior glenoid (Figure 2, Video). With qualitative observation, the orientation of the scapular spine and acromion differed the most with a more posteriorly rotated scapular spine, approximating the 9 o'clock position, and a more vertical acromion in the unstable group. The mean shape of the coracoid process of the unstable group was more medially and superiorly oriented with a posteriorly rotated coracoid pillar closer to the 12 o'clock position than the 3 o'clock position. The glenoid of the unstable group was larger at the inferior pole with a shape variation at the anterior glenoid rim corresponding with the glenoid defect.

The quantitative morphometric analysis revealed that the unstable group had a larger superior and medial offset of the apex of the coracoid process (mean difference: 7 and 3 mm, respectively; $p < 0.001$) (Table I, Figure 4). The base of the coracoid was more medial and posteriorly oriented in the unstable group (mean difference: 3 mm for both measures; $p < 0.001$). Although the absolute measure didn't differ, the normalized measurement revealed a more inferior orientation of the coracoid base in the pathologic group ($p = 0.857$ and $p = 0.029$, respectively). This led to a larger coracoid deviation angle (mean difference: 3° ; $p = 0.013$) (Table II), and a shorter normalized coracoid length in patients with anterior instability ($p = 0.004$). As compared to controls, the unstable group had a more posteriorly rotated coracoid pillar and scapular spine with a more vertical acromial tilt (mean difference: 6° , 4° and 6° , respectively; $p < 0.001$, $p = 0.012$ and $p < 0.001$, respectively). These differences

around the coracoid and acromion led to a more horizontal orientation of the CA arch and more vertical orientation of the CA base (mean difference: 9°; $p < 0.001$). The larger absolute CA arch and base length of the pathologic group did not correspond to a difference in normalized length ($p = 0.036$ vs. $p = 0.945$ and $p < 0.001$ vs. $p = 0.543$, respectively).

Compared with the control subjects, the glenoid of the pathologic group had an increased estimated H-W index (1.40 vs. 1.44; $p = 0.021$), and was flatter in the AP direction (AP ROC: 58 mm vs. 135 mm; $p < 0.001$) (Table III). No differences in SI ROC, glenoid version and inclination was found (35 mm vs. 37 mm; $p = 0.069$, 1° vs. 2°; $p = 0.114$ and 84° vs. 86°; $p = 0.155$, respectively). The glenoid was more anteriorly tilted in the pathologic group (mean difference: 5°; $p = 0.005$). Mean glenoid bone loss was $14 \pm 7\%$ with a mean defect orientation of $1 \pm 8^\circ$.

Reliability of the measurements for both inter- and intra-rater observations were good to excellent (Table IV, online supplement).

Discussion

Our hypothesis was confirmed as qualitative SSM-based analysis and quantitative morphometric analyses revealed that coracoid, acromial, and glenoid morphology differ between those with and without recurrent traumatic anterior shoulder instability. Specifically, recurrent traumatic anterior shoulder instability was associated with (1) a shorter coracoid process angled more superomedially with a more posterior origin on the glenoid closer to the 12 o'clock position than the 3 o'clock position, (2) a more vertically oriented acromion from a scapular spine with a more posterior origin on the glenoid closer to the 9 o'clock position than the 12 o'clock position, and (3) a more anteriorly tilted glenoid that was flatter in the anteroposterior direction with a shape rather approximating an ellipse than a pear. Overall these morphologic differences demonstrate that traumatic anterior shoulder instability was associated with a more posterior rotation of the CA arch and base. These differences suggest that the CA anatomy may play a potentially important and previously unknown role in glenohumeral stability.

With regards to the coracoid, the present study showed increased superomedial offset to both the base and tip of the coracoid, which was shorter and originated more posteriorly on the glenoid. These findings confirm those of Owens et al,³¹ who demonstrates that an increasing coracohumeral distance was a risk factor for anterior instability. The importance of the coracoid and its soft tissue is further emphasized by recurrent anterior instability sometimes seen in patients with isolated coracoid fractures.^{11, 21, 39} Coracoid anatomical differences may play a role in glenohumeral instability for multiple reasons. The coracoid and its soft tissue attachments might act as an anterior buttress to prevent humeral head displacement in the anterior direction. The conjoint tendon might act as a seatbelt, catching the humeral head at the level of the greater tuberosity during anterior shoulder dislocation motions. Also, the pathologic position of the coracoid might also alter the line-of-pull of the subscapularis, which is an important shoulder stabilizer.^{1, 25, 40} Hereby, the contact between the conjoint tendon and the subscapularis might be reduced in the low range of motion, leading to an altered line of action of the subscapularis. As a result, glenohumeral compression might be

converted into a shear force in a similar but more discrete fashion as seen when transferring the pectoralis major tendon above instead of underneath the conjoined tendon in subscapularis-deficient shoulders.²³ This pathologic anatomy is not addressed by current soft tissue stabilization procedures and may contribute to recurrence after traumatic anterior shoulder instability in the absence of traditionally defined glenohumeral bone loss. This pathologic anatomy may partially explain the success of the Latarjet procedure, which addresses the pathologic position of the coracoid.¹⁴ However, this non-anatomical procedure over-corrects beyond normal anatomy to obtain a stable shoulder. Our findings with regards to the coracoid suggest that there might be a place for more subtle changes of the periarticular structures. A directional osteotomy of the coracoid seems to be the most feasible immediate correction (e.g. the Trillat procedure). Adding a coracoid osteotomy to an anatomical procedure such as a capsulolabral repair or a bone block procedure, potentially better addresses all anatomical lesions associated with glenohumeral instability and may thus increase the success rate of these anatomic procedures. Given that a coracoid osteotomy would be required to correct in multiple directions simultaneously, a free hand technique would likely lack the required precision. Advanced techniques like guiding devices, patient-specific instrumentation, and intraoperative navigation may be required to provide the needed accuracy.

With regards to the acromion, the present study showed a posterior origin for the scapular spine and a more vertically oriented acromion. As far as we know, acromial morphology associated with GHJ instability has only been investigated in patients with atraumatic instability.²² In combination with the altered coracoid morphology, these acromial differences will lead to a more horizontal orientation of the CA ligament. Since the CA ligament has a proven stabilizing function^{15, 26, 38}, acromial differences might also influence shoulder stability. There are multiple potential implications for alterations in acromial and scapular spine anatomy. A more vertically oriented acromion could result in a greater percentage of deltoid muscle posterior to the glenoid center, and thus less of the deltoid to resist anterior humeral translation. Similarly, a more posterior origin for the scapula spine could result in a greater percentage of the supraspinatus posterior to the glenoid or a more posterior line-of-pull for the infraspinatus and teres minor. The pathologic anatomy of the acromion is not addressed by any current stabilization procedures and may contribute to recurrence.

With regards to the glenoid, the glenoid shape in the unstable group was flatter in the AP direction, had a larger height to width index, and was more anteriorly rotated. These findings confirm those of prior studies.^{31, 33} Hohmann et al¹⁷ and Aygün et al³ found increased anteversion in the unstable group using measurements on conventional CT scans. However, Peltz et al³³ and Moroder et al²⁹ found no difference in glenoid version between patients with traumatic anterior shoulder instability and controls using a 3D CT scan and multiplanar CT reconstruction in the glenoid center plane, respectively. The differences in glenoid tilt identified here explains the discrepancy in the current literature, as version measurements in an anteriorly rotated glenoid will be different in conventional CT scans with 2D measurements.²⁷ This highlights the need for standardized measurements on 3D or multiplanar corrected scans, as measurements are then made in predefined planes defined by osseous landmarks.

Directional osteotomies around the acromion and/or glenoid might be of biomechanical interest, yet less feasible and more invasive with a lower potential degree of achieved correction compared to an osteotomy of the coracoid.

Limitations

This study is limited by its retrospective design and the fact that CT scan evaluation is not standard of care for patients with anterior shoulder instability at our institution. This represents a selection bias and explains the relatively small sample size with a high rate of patients with large defects undergoing a Latarjet procedure. Yet, this retrospective design can be justified since performing a standard CT scan in this young population might raise ethical questions. Although the comparison of several subgroups of instability is of interest, this study was designed to focus on one well defined subgroup to explore if unknown morphologic differences would be found. Our results provide support to conduct further prospective morphology studies on all types of shoulder instability using CT scans. In addition, the control group was composed of cadaveric shoulders. The average age of this cohort is inherently older than the mean age of patients with traumatic anterior shoulder instability. To be able to match the controls with the pathologic cohort, a younger group of healthy patients should have been acquired. However, this would not exclude potential future shoulder pathology in the control group. An age-matching would include young patients in the control group that still might suffer a first-time dislocation later in life during adulthood, as the typical demography for a first-time dislocation exceed one decade. Also, other shoulder pathology including osteoarthritis and rotator cuff tear arthropathy (RCTA) has been related to predisposing scapular shape variation, in particular around the acromion, with acromial measures differing at least 5° and 5 mm between both groups.⁴ Although these subjects are asymptomatic at a young age, deterioration toward a pathology later in life is plausible, with the predisposing morphology biasing the analysis substantially. The information provided by donor summaries, dissection and CT analysis provided us the certainty that the control group had no history of shoulder instability, osteoarthritis or RCTA. On the other hand, the bone morphology of the cadavers might have been influenced by the aging process. Yet, prior studies have only found no to small differences in periarticular anatomy between young and old age groups when comparing corresponding measurements, including glenoid version, lateral offset of the apex of the coracoid process, coracoid deviation angle and acromial tilt.^{7, 13, 41} In our study, all measures with significant differences between control and pathologic groups had a larger morphologic difference than those found between different age groups, so that we are confident that the revealed differences did not solely rely on an aging process.

Conclusion

Coracoid, acromial, and glenoid anatomy differ between those with and without recurrent traumatic anterior shoulder instability. This pathologic anatomy is not addressed by current soft tissue stabilization procedures and may contribute to recurrence after traumatic anterior shoulder instability in the absence of traditionally defined glenohumeral bone loss. While these findings may be difficult to translate to the clinic immediately, they highlight areas to focus research relating instability to morphology. The clock face representation commonly

used in shoulder arthroplasty was used as a first step toward clinical application of some measures. More advanced techniques like navigated surgery and patient-specific instrumentation could also benefit as these 3D measures are integrated into the existing software platforms.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure 1:

Illustration of the computational flowchart to generate mean shapes of the control and unstable groups in order to evaluate for shape differences. **(A)** CT scans were semi-automatically segmented and three-dimensionally (3D) reconstructed. All left scapulae were mirrored to a right. **(B)** 3D surfaces were aligned to a glenoid-based coordinate system with the center of the best-fit circle to the inferior glenoid as the origin, the glenoid circle defining the XY-plane, and the YZ-plane (glenoid center plane) defined as the plane perpendicular to the glenoid circle, containing the center of the glenoid circle and the

supraglenoid tubercle (ST). **(C)** To focus the analysis on the periarticular anatomy, a cutting plane was created through the scapular notch, parallel to the glenoid circle. **(D)** 2048 correspondence points were hierarchically placed on the region of interest. **(E)** Statistical shape modelling created the mean shapes of both groups.

Figure 2:

Statistical shape modelling determined the group differences between the mean control and mean pathologic unstable scapulae. The blue arrows indicate an increase and yellow arrows denote a decrease in morphologic difference between the illustrated mean control shape and the mean unstable shape, with the size of the arrow indicative of the magnitude of the difference. As compared to the mean control shape, the mean pathologic shape demonstrated a posteriorly tilted coracoid pillar and scapular spine, an anterior-superior oriented and shorter coracoid with a more vertical orientation of the acromion, and more posteriorly rotated coracoacromial arch and coracoacromial base. Additional shape variation was seen at the inferior and anterior glenoid rim. This analysis guided morphometric measurements.

Figure 3:

Morphometric measurements were assessed in relation to the center of the best-fit glenoid circle (O) (offset measures) and the glenoid center plane (black line) (angles), respectively. Absolute distances were normalized to the radius of the best-fit glenoid circle for comparison of scapulae of differing size. (A) The coracoacromial (CA) arch (a) and CA base (b) distances were determined by the apex of the coracoid process (A) and the anterolateral corner (ALC) and posterolateral corner (PLC) of the acromion, respectively. The CA arch (α) and base angle (β) determined their relationship to the glenoid center plane in the plane

of the glenoid. The line tangent to the glenoid defect (c) defined the glenoid defect orientation (γ). **(B)** The coracoid pillar angle (δ) and the scapular spine angle (ϵ) were defined by the plane through the middle of the coracoid pillar (pink plane) and scapular spine (green plane), respectively. The best-fit plane to the acromion undersurface (red transparent plane) determined acromial tilting (ζ). Glenoid tilting (η) was assessed by measuring the angle between the glenoid center plane (black line) and the scapular plane (blue plane), defined by the center of the glenoid circle (O), the point where the scapular spine intersects the medial border of the scapula (trigonum scapulae) and the most inferior point of the inferior angle of the scapula. **(C)** The glenoid height-width (H-W) index was calculated by dividing the longitudinal distance of the articular surface of the glenoid along the y-axis (H) by the glenoid circle diameter (W).³³ Glenoid defect size was calculated as the percentage represented by the missing surface segment with respect to the best-fit glenoid circle (orange segment). The equation for the calculation of a circular segment area was used, with the angle between the superior margin of the defect, the origin and the inferior margin of the defect as well as the radius of the inferior glenoid circle being the input variables.⁵ **(D)** The distance between the apex (A) and base of the coracoid (B), formed by the junction of the lateral border of the suprascapular notch with the medial border of the conoid and trapezoid tubercles, provided the coracoid length (d).¹⁰ Glenoid inclination (θ), as measured in the coronal plane, was assessed by measuring the angle between the line connecting the superior and inferior glenoid pole (blue line) and the scapular axis (green line), running through the trigonum scapulae and the center of the glenoid circle. The best-fit circle to the articular surface along the y-axis determined the superior-inferior (SI) radius of curvature (ROC).³³ **(E)** The following angles were measured in the transverse plane. Glenoid version (ν) was assessed as the angle between the plane of the glenoid (red line) and the scapular plane (blue plane) at the anterior side of the scapula in the transverse plane. Glenoid version was defined as 90° minus the angle between the scapular plane and the glenoid circle, with a negative value representing a retroversion.¹⁹ This measurement differed to most studies measuring glenoid version in that the glenoid center plane was used as the reference plane for the coordinate system whereas in general the version measurement is measured in a coordinate system referring to the scapular plane. The coracoid deviation angle was measured as the angle between d and the glenoid center plane (κ). The anterior-posterior (AP) ROC was defined by the best-fit circle to the articular segment posterior to the glenoid center plane along the x-axis.

Figure 4: Mean differences between the control (transparent) and unstable group (solid) of the coracoacromial (CA) measurements in relation to the glenoid center plane (black line), including the coracoid pillar (purple lines), scapular spine (green lines), acromion (red lines), CA arch (blue lines), CA base (grey lines), and apex of the coracoid process (red mark). These differences demonstrate a more superomedially oriented coracoid with a more posterior rotated coracoid origin on the glenoid closer to the 12 o'clock position than the 3 o'clock position, (2) a more vertically oriented acromion from a scapular spine with a more posterior origin on the glenoid closer to the 9 o'clock position than the 12 o'clock position, (3) and a more posteriorly rotated CA arch and base. Note that planes were translated to lines for clarification purposes.

Table I:

Offset and length measures of the coracoid and acromion

	Absolute (mm)				Normalized (radii)					
	Control Group		Unstable Group		P Value	Control Group		Unstable Group		P Value
	Mean ± SD	95% CI	Mean ± SD	95% CI		Mean ± SD	95% CI	Mean ± SD	95% CI	
Apex of the Coracoid:										
Anterior	27 ± 3	26 – 28	26 ± 4	25 – 27	0.532	2.17 ± 0.27	2.07 – 2.26	2.00 ± 0.30	1.92 – 2.08	0.055
Superior	23 ± 5	21 – 25	30 ± 4	29 – 32	< 0.001	1.85 ± 0.35	1.72 – 1.97	2.33 ± 0.37	2.23 – 2.43	<0.001
Lateral	19 ± 3	18 – 20	16 ± 4	15 – 17	< 0.001	1.56 ± 0.26	1.47 – 1.66	1.23 ± 0.38	1.13 – 1.34	<0.001
Base of the Coracoid:										
Anterior	7 ± 3	6 – 8	4 ± 3	3 – 5	< 0.001	0.60 ± 0.24	0.51 – 0.69	0.33 ± 0.21	0.27 – 0.38	<0.001
Superior	34 ± 4	33 – 36	34 ± 3	33 – 35	0.935*	2.77 ± 0.38	2.46 – 2.91	2.62 ± 0.32	2.54 – 2.71	0.047*
Lateral	–20 ± 3	–21 – –19	–23 ± 4	–24 – –22	< 0.001*	–1.60 ± 0.20	–1.67 – –1.53	1.74 ± 0.25	–1.81 – –1.67	0.002*
Coracoid Length	45 ± 4	44 – 57	45 ± 4	44 – 46	0.808	3.69 ± 0.29	3.58 – 3.79	3.46 ± 0.32	3.37 – 3.55	0.004*
CA Arch Length	40 ± 5	39 – 42	43 ± 6	41 – 44	0.036	3.28 ± 0.38	3.14 – 3.42	3.29 ± 0.46	3.16 – 3.42	0.945
CA Base Length	69 ± 6	67 – 71	74 ± 7	72 – 76	< 0.001	5.60 ± 0.46	5.42 – 5.75	5.66 ± 0.52	5.52 – 5.80	0.543

SD: standard deviation, CI: confidence interval, CA: coracoacromial

* Non-parametric Mann-Whitney U test

Table II:

Angle measurements of the coracoid and acromion

	Control Group		Unstable Group		P Value
	Mean $\pm$ SD	95% CI	Mean $\pm$ SD	95% CI	
Coracoid Deviation Angle ($^{\circ}$)	26 $\pm$ 4	25 – 28	29 $\pm$ 6	28 – 31	0.013
Coracoid Pillar Angle ($^{\circ}$)	135 $\pm$ 7	132 – 138	141 $\pm$ 7	139 – 143	< 0.001
Scapular Spine Angle ($^{\circ}$)	61 $\pm$ 6	58 – 63	65 $\pm$ 8	63 – 67	0.012
Acromial Tilting ($^{\circ}$)	49 $\pm$ 7	46 – 52	43 $\pm$ 8	41 – 45	< 0.001
CA Arch Angle ($^{\circ}$)	78 $\pm$ 7	76 – 81	87 $\pm$ 7	85 – 89	< 0.001
CA Base Angle ($^{\circ}$)	101 $\pm$ 6	99 – 104	110 $\pm$ 6	108 – 111	< 0.001*

SD: standard deviation, CI: confidence interval, CA: coracoacromial

* Non-parametric Mann-Whitney U test

Table III:

Measurements of the glenoid

	Control Group		Unstable Group		P Value
	Mean $\pm$ SD	95% CI	Mean $\pm$ SD	95% CI	
					<
AP ROC (mm)	58 $\pm$ 45	42 – 74	135 $\pm$ 207	78 – 191	<i>0.001*</i>
SI ROC (mm)	35 $\pm$ 4	34 – 37	37 $\pm$ 4	36 – 38	0.069
H-W Index	1.40 $\pm$ 0.096	1.36 – 1.43	1.44 $\pm$ 0.098	1.41 – 1.46	<i>0.021*</i>
Version (°)	1 $\pm$ 3	0 – 3	2 $\pm$ 4	1 – 3	0.114
Anterior Tilting (°)	17 $\pm$ 8	15 – 20	22 $\pm$ 6	20 – 23	<i>0.005</i>
Inclination (°)	84 $\pm$ 4	83 – 86	86 $\pm$ 4	85 – 87	0.155

SD: standard deviation, CI: confidence interval, AP: anterior-posterior, ROC: radius of curvature, SI: superior-inferior, H-W: height-width

Table IV:

Reliability of the measurements (Online Supplement)

	Inter		Intra		TEM
	ICC	95% CI	ICC	95% CI	
Absolute Offset/Length Measures					
Apex of the Coracoid:					
Anterior	0.809	0.638 – 0.904	0.810	0.639 – 0.904	0.62
Superior	0.949	0.884 – 0.976	0.984	0.968 – 0.993	0.45
Lateral	0.949	0.895 – 0.975	0.994	0.988 – 0.997	0.43
Base of the Coracoid:					
Anterior	0.875	0.756 – 0.938	0.920	0.839 – 0.961	0.51
Superior	0.642	0.272 – 0.829	0.721	0.458 – 0.862	0.79
Lateral	0.832	0.627 – 0.922	0.905	0.811 – 0.953	0.58
Coracoid Length	0.977	0.952 – 0.989	0.985	0.945 – 0.995	0.25
CA Arch Length	0.932	0.841 – 0.969	0.955	0.903 – 0.979	0.68
CA Base Length	0.941	0.880 – 0.972	0.947	0.891 – 0.974	0.64
Normalized Offset/Length Measures					
Apex of the Coracoid:					
Anterior	0.765	0.547 – 0.883	0.779	0.587 – 0.888	0.048
Superior	0.910	0.819 – 0.956	0.956	0.911 – 0.979	0.045
Lateral	0.943	0.884 – 0.972	0.992	0.983 – 0.996	0.036
Base of the Coracoid:					
Anterior	0.883	0.770 – 0.942	0.927	0.852 – 0.965	0.039
Superior	0.706	0.243 – 0.877	0.791	0.496 – 0.908	0.063
Lateral	0.751	0.528 – 0.875	0.812	0.645 – 0.906	0.048
Coracoid Length	0.879	0.763 – 0.940	0.863	0.734 – 0.932	0.045
CA Arch Length	0.895	0.702 – 0.956	0.926	0.836 – 0.965	0.053
CA Base Length	0.891	0.772 – 0.948	0.912	0.823 – 0.957	0.071
Periarticular Angle Measures					
Coracoid Deviation Angle	0.826	0.663 – 0.913	0.966	0.925 – 0.984	0.99
Coracoid Pillar Angle	0.778	0.587 – 0.888	0.878	0.763 – 0.940	1.38
Scapular Spine Angle	0.921	0.838 – 0.962	0.969	0.936 – 0.985	1.04
Acromial Tilting	0.904	0.647 – 0.964	0.991	0.980 – 0.996	1.02
CA Arch Angle	0.938	0.875 – 0.970	0.984	0.966 – 0.992	0.87
CA Base Angle	0.953	0.905 – 0.977	0.997	0.994 – 0.999	0.61
Glenoid Measures					
APROC	0.866	0.740 – 0.934	0.924	0.849 – 0.963	4.20
SI ROC	0.874	0.668 – 0.946	0.919	0.791 – 0.965	0.66
H-W Index	0.817	0.622 – 0.912	0.775	0.579 – 0.886	0.017
Version	0.902	0.806 – 0.952	0.950	0.897 – 0.976	0.50
Anterior Tilting	0.971	0.939 – 0.986	0.980	0.957 – 0.990	0.48
Inclination	0.944	0.887 – 0.973	0.980	0.934 – 0.992	0.45

AP: anterior-posterior, CA: coracoacromial, CI: confidence interval, H-W: height-width, ICC: intra-class correlation coefficient, ROC: radius of curvature, SI: superior-inferior, TEM: typical error of measurement

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