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The influence of radiographic viewing perspective and demographics on the Critical Shoulder Angle

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Abstract

Background—Accurate assessment of the critical shoulder angle (CSA) is important in clinical evaluation of degenerative rotator cuff tears. This study analyzed the influence of radiographic viewing perspective on the CSA, developed a classification system to identify malpositioned radiographs, and assessed the relationship between the CSA and demographic factors.

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Methods—Glenoid height, width and retroversion were measured on 3D CT reconstructions of 68 cadaver scapulae. A digitally reconstructed radiograph was aligned perpendicular to the scapular plane, and retroversion was corrected to obtain a true antero-posterior (AP) view. In 10 scapulae, incremental anteversion/retroversion and flexion/extension views were generated. The CSA was measured and a clinically applicable classification system was developed to detect views with $>2^\circ$ change in CSA versus true AP.

Results—The average CSA was $33\pm4^\circ$. Intra- and inter-observer reliability was high (ICC 0.81) but decreased with increasing viewing angle. Views beyond 5° anteversion, 8° retroversion, 15° flexion and 26° extension resulted in $>2^\circ$ deviation of the CSA compared to true AP. The classification system was capable of detecting aberrant viewing perspectives with sensitivity of 95% and specificity of 53%. Correlations between glenoid size and CSA were small ($R=0.3$), and CSA did not vary by gender ($p=0.426$) or side ($p=0.821$).

Conclusions—The CSA was most susceptible to malposition in ante/retroversion. Deviations as little as 5° in anteversion resulted in a CSA $>2^\circ$ from true AP. A new classification system refines the ability to collect true AP radiographs of the scapula. The CSA was unaffected by demographic factors.

Keywords

Critical shoulder angle; computed tomography (CT); digitally reconstructed radiograph; viewing perspective; demographics; reproducibility

Introduction

The etiology of degenerative rotator cuff (RC) tears and osteoarthritis (OA) is multifactorial and remains poorly understood. Several radiographic parameters have been described to evaluate the shape of the acromion, and the tilt and version of the glenoid, in these degenerative pathologies.^{1-3,18,21,34,41,48} Both massive RC tears and/or progressive OA of the glenohumeral joint may lead to changes in acromion, glenoid or humeral morphology, and therefore modify radiological parameters in pathologic versus non-pathologic shoulders.^{2,14,31-33}

To control for changing glenohumeral morphology, Moor et al introduced the concept of the critical shoulder angle (CSA). The CSA is defined as the angle between a line connecting the superior and inferior margins of the glenoid and a line between the infero-lateral border of the acromion and the inferior margin of the glenoid on true antero-posterior (AP) view radiographs.^{28,30} Their data indicated that the glenohumeral joint of a 65 year old patient without OA or RC tears is characterized by a CSA between 30° and 35° .²⁸ The CSA combines the lateral extension of the acromion and the inclination of the glenoid as risk factors for RC tears. Conversely, a small lateral acromial extension and inferiorly tilted glenoid may lead to increased glenohumeral compression forces and glenohumeral OA. Biomechanical analyses support the concept that a high CSA can induce supraspinatus overload particularly at low degrees of active abduction, and therefore could explain the relationship between rotator cuff tears and scapular anatomy seen in these patients.¹³ Furthermore, the CSA, in combination with established risk factors like trauma and age, can

accurately predict the integrity of the postero-superior rotator cuff.²⁹ Therefore, accurate measurement of the CSA is important in the assessment of patients suffering from shoulder pain and may result not only in more purposeful use of MR arthrography, but also may be crucial in preoperative evaluation and planning in patients undergoing surgery for subacromial impingement or RC repair.

The accuracy of CSA measurement depends on the spatial relationship of the scapula relative to the x-ray beam. This relationship can vary significantly depending on patient positioning and posture, and *in situ* scapular orientation. Alterations in the projection of the glenoid margin and the lateral extension of the acromion may consequently lead to errors in CSA measurement. Moor et al documented a reproducible assessment of the CSA yielding variability 2° for malrotations up to 20° of scapular internal rotation or extension and 20° of external rotation or flexion.²⁸ However, most hospitals do not routinely take AP radiographs of the glenohumeral joint under fluoroscopic control. Therefore, precise radiographic criteria, which technicians, radiologists and orthopaedic surgeons could use to detect malpositioned scapula that will result in an inaccurate CSA are lacking. Digitally reconstructed radiographs (DRR) generated from 3D computed tomography (CT) reconstructions of the scapula allow the study of these positional errors and their influence on the CSA. The DRR has recently been validated as a surrogate for clinical radiographs that can be generated from controlled perspectives with respect to the CT image stack.¹⁵ Furthermore, little is known about how the CSA varies in populations with otherwise healthy shoulders as a function of demographic factors like glenoid size, gender, or side.

Therefore, the purpose of this study was to analyze the influence of non-AP viewing perspectives on the magnitude and reproducibility of the CSA as compared to the true AP view, and to develop and validate a clinical classification system to identify a malpositioned scapula that will result in an inaccurate CSA. In addition, we assessed the relationship between the CSA and glenoid size, gender and side. We hypothesized that the non-AP viewing perspectives would significantly alter the reproducibility and absolute values of the CSA as compared to true AP views, and that the CSA would increase with glenoid size. We also hypothesized that the CSA would be larger in males than in females, but would not differ between left and right shoulders.

Materials and Methods

Analysis of cadaveric scapulae

Glenohumeral joints were selected from a database of cadaver specimens with both 3D CT data and documentation of specimen dissection/condition. Shoulders were excluded if any pathology was detected during dissection. Glenoid cartilage was visually screened for degenerative changes consistent with OA, and the RC was visually assessed for degenerative full-thickness tears. All dissections were performed by a board certified orthopaedic surgeon (R.T.). A total of 68 non-pathologic cadaver shoulders were included in this study (25 pairs + 18 individual).

CT data acquisition and three-dimensional reconstruction

Each cadaver shoulder was placed in a supine anatomic position, and axial CT images were acquired using a Siemens Sensation 16 CT Scanner (130 kV tube voltage, 512×512 acquisition matrix, 1.0 mm slice thickness, 0.75 pitch, 170mAS baseline tube current). CT scans were stored in DICOM (Digital Imaging and Communications in Medicine) format for later processing. Scapulae were then semi-automatically segmented from the CT image data using Amira (v5.4, Visage Imaging, San Diego, CA) and 3D reconstructions of the bony surfaces were generated.^{15,16} Previous validation studies verified that accurate and reproducible 3D models of excised and *in situ* scapulae can be created from segmentation of CT scans.^{5,17,22}

Morphometric measurements on 3D reconstructions

The 3D reconstructions of the scapulae were imported into LS-PrePost (Livermore Software Technology Corporation, Livermore, CA, USA) and visualized by two independent observers to determine the bony landmarks, axes and planes in each scapula (Fig. 1). First, the glenoid height was measured between the most superior (S) and inferior points (I) of the contour of the articular surface of the glenoid. Next, anterior (A) and posterior points (P) were selected at the glenoid rim such that both points were perpendicular to the supero-inferior axis. The glenoid width was measured as the distance between point A and P.^{11,45} There is no consensus as to which landmarks provide the best native glenoid plane, but points A and P, as part of the inferior circular plane, were previously described as the plane with the smallest variability.^{42,43} The plane of the scapula was defined by three points: the most distal point of the inferior scapular angle (IS), the center of the glenoid fossa (C), and the point where the scapular spine intersects the medial border of the scapula (MS).^{4,6-8,22,35-38} A Cartesian coordinate system was generated with the z-axis (+ lateral) defined by the line MS-C, and the x-axis (+ anterior) normal to the plane created by points IS-C-MS. The y-axis (+ superior) was then defined by the cross product of the z- and x-axes. The glenoid version angle α was defined as the angle subtended by a line A-P and the x-axis.^{7,11} Anteversion of the glenoid surface with respect to the scapular plane was defined (+), and retroversion was defined (-).

Generation and alignment of Digitally Reconstructed Radiographs (DRR)

DRRs were used to simulate 21 different radiographic viewing perspectives (one true AP view, 20 altered orientations). The terms “viewing angle” or “viewing perspective” now refer to any position away from a true AP view centered on the glenohumeral joint. The DRRs were generated from CT data using ray casting to produce an image similar to a clinical radiograph. This allowed for controlled viewing perspectives to be generated with respect to the CT image stack, thereby eliminating inconsistencies in inter-subject positioning. A recent validation study demonstrated that DRRs could serve as a surrogate for clinical radiographs.¹⁵ True AP view DRRs were generated in Amira for all 68 scapulae as follows: Using the Cartesian coordinate system developed from bony landmarks (Fig. 1), the 3D model was transformed to align with the Amira local coordinate system. This provided a viewing perspective normal to the scapular plane. Each scapula was then rotated about the y-

axis by its respective glenoid version (α). This rotation corrected for the individual glenoid ante/retroversion, providing a true AP view aligned parallel to the face of the glenoid.

In 10 randomly selected scapulae (non-paired), DRRs were generated for incremental anteversion, retroversion, flexion and extension viewing perspectives using the true AP DRR as the baseline. When rotated about the y-axis, positive rotation corresponded to anteversion and negative rotation corresponded to retroversion. By rotating about the z-axis, positive rotation corresponded to flexion and negative rotation corresponded to extension. DRRs were created for each scapula at 5°, 10°, 15° and 30° for each perspective. In addition, four 15° compound rotations (e.g. 15° anteversion + 15° flexion) were generated for each scapula. In total, 20 altered perspective DRRs were generated for each scapula for a total of 268 DRRs (200 non-AP + 68 AP).

Definition and measurement of CSA

Each DRR was blinded and randomized as to its viewing perspective then evaluated by two independent board-certified orthopaedic surgeons (T.S., R.T.). All DRRs were assessed a second time by a single surgeon two weeks later. This allowed determination of both intra- and inter-rater reliability. The CSA was measured on each DRR using Image-J (<http://imagej.nih.gov/ij/>), according to Moor et al, between a line connecting the superior and inferior border of the glenoid fossa and another connecting the inferior border of the glenoid with the most infero-lateral point of the acromion (Fig. 2).^{28,30}

Development and validation of the scapular classification system

In order to rule out non-AP viewing perspectives, which could result in an erroneous measurement of the CSA, a new classification system was developed (SH, Suter-Henninger). This radiographic classification system is based on the relationships between the coracoid, acromion and glenoid in plain radiographs (Fig. 3). First, malposition in ante- or retroversion is identified by assessing the glenoid rim double contour caused by an overlap between the posterior and anterior margins of the glenoid. This phenomenon can be related to either the whole glenoid surface (Type D) or only parts of the glenoid (Type B and C). Type B and C patterns occur when glenoid version changes as a function of glenoid height.^{19,24} Second, malposition in flexion (Type 2) or extension (Type 3) is identified by determining the overlap between the coracoid process and the upper glenoid rim and the projection of the coracoid in relation to the upper glenoid rim. A flexed scapula results in a proximal projection of the coracoid process in relation to the upper glenoid rim and *vice versa*. For validation purposes, the same two observers (T.S., R.T.) independently rated the alignment of the DRRs according to the SH scapular classification system in all DRRs with altered viewing perspectives (200 non-AP) and the corresponding true AP DRR (10 AP) for a total of 210 DRRs. All DRRs were blinded to the observers during the validation.

Statistical analysis

Statistical analyses were carried out by biostatisticians at the Study Design and Biostatistics Center in the University of Utah Study Design & Biostatistics Center at the University of Utah. Descriptive statistics were calculated, and linear mixed-effect models were used to compare the differences in CSA with respect to viewing perspectives, gender and side,

respectively. Linear mixed-effect model took into account the correlation among the repeated measurements on the same shoulder and correlation between the paired shoulders by introducing random effect component.²⁵ Therefore, it allowed modeling repeated CSA measurements on the same shoulder at various viewing perspectives and modeling both independent and paired shoulders together. Age was adjusted in all models. The intra-class correlation coefficient (ICC) was used to measure the absolute agreement and assess the intra- and inter-observer reliability in the measurement of glenoid size, version and CSA measurements for each viewing perspective. Each ICC was rated according to the classification of Landis: 0.01 poor, 0.01 to 0.2 slight, 0.21 to 0.4 fair, 0.41 to 0.6 moderate, 0.61 to 0.8 substantial, 0.81 to 1.00 almost perfect.²³ Pearson correlation coefficients were calculated to analyze the relationship between CSA and glenoid size (height, width and height/width ratio) and version. They were categorized according to Dancey and Reidy: 0 zero, 0.1 to 0.3 weak, 0.4 to 0.6 moderate, 0.7 to 0.9 strong, 1 perfect.¹⁰ All data are presented as mean±SD (range). All statistical tests were conducted at a significance level 0.05. All these analyses were performed using SAS 9.4 (SAS Institute Inc., Cary, NC, USA) and the R statistical packages.⁴⁰

Results

CT scans of 68 non-pathologic cadaveric shoulders (36 female, 32 male, 35 left, 33 right) with an age of 60±10 years (26 to 73) were included in the study. The average CSA in true AP views of 68 shoulders was 33±4° (23° to 44°).

Each non-AP view showed a significant difference ($p = 0.0001$) in CSA compared to its respective true AP view. As viewing perspective increased in magnitude, more CSA values fell outside the normal threshold between 30° and 35° (Fig. 4). All incremental viewing perspectives were significantly different ($p = 0.0001$), but the CSA was most highly sensitive to anteversion and retroversion (Fig. 4). The linear mixed-effect model showed that isolated changes of the scapula position of more than 5° anteversion, 8° retroversion, 15° flexion and 26° extension, resulted in a more than 2° alteration of the CSA compared to the true AP view (Fig. 5). The area shown in green is considered a “safe zone” where the position of the scapula in the field of view should result in a CSA <2° different than in true AP.

Intra-observer reliability for all CSA measurements was almost perfect (range 0.89 to 0.99) except for one scapula position (30° anteversion, ICC = 0.80). The highest correlation coefficient (ICC = 0.99) corresponded to the true AP view, where the intra-observer difference averaged 1±0° (0° to 2°). Inter-observer reliability was almost perfect in viewing perspectives up to 15° flexion/extension, 5° retroversion to 10° anteversion, and at the 15° retroversion position (Table I). For the true AP view the average difference between the two observers was 1±1° (0 to 7).

In order to detect a 2° deviation in CSA versus true AP images using the SH scapular classification system, type B1, B2, B3 and D1, D2, D3 malposition could be predicted with a sensitivity and specificity of 95% and 53%, respectively (e.g. Fig. 6). The agreement of the two observers in identifying a malpositioned DRR was 89%. Some scapula malpositions resulted in specific visualization patterns. Type 2 patterns (Fig. 3F) could only be detected in

flexed scapulae (present in 58% of flexion views), whereas Type 3 patterns (Fig. 3G) only occurred in extended scapulae (present in 38% of extension views). A Type D1 was most commonly detected in anteversion and retroversion, where this pattern was represented in 93% and 70% of ante- and retroverted DRRs, respectively.

Glenoid height, width, height/width-ratio and version showed only a weak correlation with CSA ($R = |0.230|$). The CSA, glenoid size and version did not differ between right and left shoulders in true AP images. Whereas the CSA, glenoid version and height/width-ratio did not vary by gender ($p = 0.064$), glenoid height and width were higher for males ($p = 0.0001$) (Table II). Inter- and intra-observer reliability was almost perfect for height, width and glenoid version (0.95 to 0.99).

Discussion

The CSA is a recently developed radiographic parameter that accounts for the inclination of the glenoid and the acromion index, and is independent from degenerative changes of the humerus.²⁸ Moor *et al* considered a CSA value between 30° and 35° as normal, with a CSA <30° associated with OA and a CSA >35° associated with degenerative RC tears.²⁸ The present study is the first to show how highly sensitive the CSA is to radiograph alignment of the scapula in ante- and retro-version, where a 5-8° change in viewing perspective can affect a 2° change in CSA that could alter clinical interpretation of the radiograph. In addition, this study presented a new radiographic classification system that is highly sensitive to detecting malpositioning of the scapula in plain radiographs. Finally, the present study is the first to report on the weak correlation between CSA and gender and side in a non-pathologic population of cadaver shoulders.

The mean true AP view CSA for these cadaver scapulae was 33° (N=68), which is comparable to previous reports in asymptomatic shoulders with normal RCs and no OA.^{28,30,39} Our cadaver population had a CSA range of 23° to 44° in true AP, which is considerably higher than previous reports for non-pathologic shoulders. It should be noted that while we had no detailed medical history for the donor tissue, no acute pathology was detected during the specimen preparation. Further study is required to determine the true range of non-pathologic CSA in healthy individuals.

In plain radiographs the CSA is a 2D analysis of a 3D structure and, as such, is subject to errors due to the orientation of the viewing plane with respect to the scapula. Our investigation confirmed that the magnitude of the CSA depends on the viewing perspective of the x-ray beam during clinical examination. The true AP CSA was significantly altered by each incremental change in viewing perspective (Fig. 4).

The point at which error in CSA measurement becomes clinically important was suggested in the initial description of the CSA.²⁸ Moor *et al* analyzed the influence of different scapula positions on the CSA in two dried left human scapulae using a device that allowed incremental internal/external rotation and flexion/extension of the scapula. They documented a consistently reproducible assessment of the CSA yielding variability 2° for

malrotations up to 20° of internal rotation or extension and 20° of external rotation or flexion.²⁸

Our data, with a highly reproducible imaging technique, larger sample size, and mixed gender/side, further restrict the 20° tolerance for viewing perspective error initially proposed by Moor.²⁸ In the present study, the results of the linear mixed-effects model illustrates a “safe zone” where the CSA should not deviate more than 2° versus true AP views (Fig. 5, safe zone shown in green). The magnitude of the CSA did not change more than 2° within a range of 15° flexion and 26° extension, and in both cases as the viewing angle became more extreme the CSA increased (Fig. 4). To the contrary, anteversion and retroversion viewing perspectives were much more sensitive where 5° and 8°, respectively, resulted in CSA changes of >2°. As viewing angle grew, anteversion increased the CSA and retroversion decreased the CSA (Fig. 4). This is most easily explained in that ante- and retroversion alter the relationship between the most infero-lateral point of the acromion to the plane of the glenoid (Fig. 2, 5).

The differences between the present study and Moor et al may be explained by their choice of alternate neutral positions and axes for flexion/extension and anteversion/retroversion.²⁷ Furthermore, their scapula was manually set in the rotation device, which theoretically could lead to positional errors. Our DRRs were independent from these positional errors since the plane definitions and rotations were locked to anatomic landmarks, and the scapular plane has previously shown excellent intra- and inter-observer reproducibility.^{22,37}

Ultimately, the error and deviation in CSA was minimized in perspectives closest to true AP, therefore the authors recommend avoiding radiographic perspectives >5° from true AP in anteversion and retroversion, and >15° in flexion and extension. In the clinical setting, even small malalignment of the x-ray beam and scapula in anteversion and retroversion could result in substantial changes in the measured CSA (Fig. 4), and therefore may influence treatment plans. Orthopaedic surgeons, technicians and radiologists should be aware of this potential error and misguidance. Although standard protocols to obtain a true AP view are used in most hospitals to minimize the error of positioning of the scapula, achieving a true AP view can be complicated by medical comorbidities, body habitus, substantial variability of scapular dimensions/shapes among individuals^{26,44} and the scapular plane orientation, which is affected by gender and age.^{9,11,20}

With the SH scapular classification system developed herein (Fig. 3), we were able to detect a malpositioned scapula with a sensitivity of 95%. After ruling out any glenoid double contour of more than 50% of glenoid height (pattern D1, D2, D3) and inverted teardrop patterns at the upper glenoid rim (<50% of glenoid height, pattern B1, B2, B3), there was an 89% probability of assessing the CSA within 2° compared to the true AP view. That said, the SH scapular classification system cannot be used to predict a true AP view, but instead provides radiographic criteria to rule-out malpositioned scapulae. This represents a simple, useful tool for technicians, radiologists and orthopaedic surgeons to decide if the x-ray examination should be repeated in order to assess the CSA in an accurate and reliable manner.

The intra- and inter-observer reliability in the true AP view was excellent in the present study, which is consistent with previous reports, supporting the repeatability and reliability of this technique.^{30,39} However, intra- and inter-observer reliability was nearly perfect only in viewing perspectives up to 15° flexion/extension and 5° retroversion to 10° anteversion, and at the 15° retroversion position (Table I), suggesting that the reproducibility decreased as the viewing perspective increased. The source of decreased agreement arises from viewing perspectives where the anterior and posterior glenoid margin are not perfectly superimposed, resulting in a pear- or teardrop-shaped glenoid profile that made it difficult to define the upper and lower border of the glenoid rim (Fig. 3B-D).

The morphologic measurements of the glenoid were consistent with those reported in previous studies.^{12,17,22,46,47} Glenoid height, width, height/width-ratio and version measurements were only weakly correlated with CSA. Although males typically had larger glenoid height and width, no significant difference was found for the CSA by gender. Furthermore, CSA, glenoid size and version were not found to vary between right and left shoulders. These data suggest gender and side are not strongly associated with differences in CSA and each shoulder can be considered independently based on the prior description.

There were limitations to this study. First, the CT scans were obtained from non-pathologic cadaver shoulders where a detailed medical history was not available. Dissection confirmed that no acute signs of OA and RC tears were present, but we cannot directly apply our results in patients suffering from primary OA or RC tear as alterations in their bony morphology may affect the magnitude of the findings. Second, one of the two observers was involved in the generation of the DRRs; therefore we acknowledge the potential for observer bias. However, the study design, which was randomized and blinded for measurement and included a second orthopaedic surgeon in the analysis of the DRRs, effectively limited this bias. The high ICCs calculated for all measurements reinforce the reliability of the methods. Third, the therapeutic consequences of this relative new concept of the CSA haven't yet been clearly defined. Reports showing a clinical benefit for patients undergoing anterolateral acromioplasty instead of an isolated anterior acromioplasty to address an abnormally large CSA in rotator cuff repair or impingement surgery are severely lacking. Similarly the therapeutic strategies to prevent arthrosis of the glenohumeral joint in patients with small CSA are unclear. Further investigations are needed to study if adapting new surgical techniques according to the CSA will influence patient outcomes. Finally, the SH scapular classification system may indicate patients for additional exposure to ionizing radiation if additional radiographs are required to isolate a viewing perspective which will result in a reliable and accurate CSA measurement. This exposure may be trivial if the CSA and indications for further, more invasive and expensive radiographic examinations like MR arthrography were significantly modified with a true AP view of the scapula.

Conclusion

In conclusion, accurate measurement of the CSA is most susceptible to scapula malposition in anteversion and retroversion with respect to the viewing plane, and did not vary according to gender or side. The CSA measurements showed significant differences from true AP with malposition of only 5°, illustrating the importance of correct alignment of the scapula during

x-ray examination. The CSA in 2D radiographs can be measured with less than 2° error compared to the true AP view, provided that there is no double contour of more than 50% of glenoid height or an inverted teardrop pattern at the upper glenoid rim. In a controlled viewing perspective, the CSA represents a simple, accurate and reproducible technique to assess the lateral extension of the acromion and the inclination of the glenoid.

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Figure 1.

A 3D reconstruction of a left scapula (posterolateral view). The scapular plane was defined by 3 points at the center of the glenoid (C), the inferior scapular angle (IS) and the point at the vertebral border where the scapular spine intersects the medial border of the scapula (MS). A Cartesian coordinate system was defined with the origin at point C, with the x-axis normal to the scapular plane, the z-axis connecting MS and C, and the y-axis defined by the cross product of x and z axes. Glenoid height was measured as the distance between the most superior (S) and most inferior (I) points of the glenoid rim, glenoid width as the distance between the most anterior (A) and most posterior (P) points of the glenoid rim. The glenoid version (α) was measured as the angle subtended by a line connecting points A and P and the x-axis.

Figure 2.

Examples of DRRs showing the CSA measurement which is the angle subtended by a line connecting the superior and inferior border of the glenoid fossa and another connecting the inferior border of the glenoid with the most infero-lateral point of the acromion in true AP views (left panes). Incremental increases in anteversion (upper row) and extension (lower row) are also shown. The viewing perspective altered the visualization of the most infero-lateral reference point of the acromion and consequently the CSA. Note the changing relationship between the infero-lateral acromion and tip of the coracoid process.

Figure 3.

Suter/Henninger (SH) scapular classification system to assess the viewing perspective of an AP DRR of the scapula: the glenoid rim is marked by the yellow line. (A- D) Determination of a glenoid rim double contour. (A) Type A: none. (B) Type B: inverted teardrop double contour initiated at the upper glenoid, <50% of glenoid height. (C) Type C: teardrop double contour initiated at the lower glenoid, <50% of glenoid height. (D) Type D: double contour >50% of glenoid height. (E-G) Assessment of coracoglenoid overlap and projection of the coracoid process. (E) Type 1: Overlap of the upper glenoid rim and the coracoid process, or its inferior edge aligned with the upper glenoid rim. (F) Type 2: no overlap of the upper glenoid rim and the coracoid process, coracoid process is above the upper glenoid rim. (G) Type 3: no overlap of the upper glenoid rim and the coracoid process, coracoid process is below the upper glenoid rim or its superior edge aligned with the upper glenoid rim.

Figure 4.

CSA measured for 10 scapulae in extension/flexion (top) and anteversion/retroversion (middle) viewing perspectives. The grey lines indicate the normal range of CSA from Moor et al.³⁰ The standard deviation of CSA typically increased as the viewing perspective increased, with more CSA values outside the normal threshold. There were significant differences in CSA between non-AP and true AP views. In flexion/extension the CSA increased with viewing angle. In anteversion the CSA increased with viewing angle, whereas the CSA decreased with increased retroversion. The difference between the non-AP and true AP CSA at different viewing perspectives (bottom). The CSA was relatively insensitive to flexion/extension (black bars), where only 30° viewing angles had mean differences outside the $\pm 2^\circ$ window. Beyond a 5° viewing angle versus true AP, anteversion and retroversion (shaded bars) resulted in more than 2° alteration of the CSA compared to the true AP view.

Figure 5. Results of the linear mixed-effects model showing the “safe zone” (green) where scapula malposition may result in a CSA within 2° of the true AP view. 3D reconstructions of scapulae are shown to indicate the representative viewing perspective in each quadrant of the graph.

Figure 6.

Application of the scapular classification system and CSA measurement in (A-B) two different malpositioned DRRs and one (C) corresponding true AP view of the same scapula, respectively. (A) Example of an unacceptable DRR according to our classification system showing a type D1 scapula (double contour >50% of glenoid height, coracoglenoid overlap). This scapula was malpositioned in a 15° anteverted position in respect to the true AP view resulting in a difference of 4° compared to the true AP view, which would represent an overestimation of the CSA. (B) Example of an acceptable DRR with a type A2 scapula (no double contour of the glenoid rim, no coracoglenoid overlap with the coracoid process above the upper glenoid rim) which according to the classification system should result with less than 2° error compared to the true AP view (in this example the error added up to 0°).

Table I

Inter-observer intra-class correlation coefficients (ICC) for CSA with scapular malposition in retro-/anteversion and flexion/extension

Characteristics	ICC	Interpretation	Characteristics	ICC	Interpretation
30° retroversion	0.68	substantial	30° flexion	0.20	slight
15° retroversion	0.92	almost perfect	15° flexion	0.90	almost perfect
10° retroversion	0.77	substantial	10° flexion	0.89	almost perfect
5° retroversion	0.95	almost perfect	5° flexion	0.91	almost perfect
True AP view	0.91	almost perfect	True AP view	0.91	almost perfect
5° anteversion	0.91	almost perfect	5° extension	0.85	almost perfect
10° anteversion	0.82	almost perfect	10° extension	0.92	almost perfect
15° anteversion	0.76	substantial	15° extension	0.86	almost perfect
30° anteversion	0.17	slight	30° extension	0.45	moderate

Table IIAnatomic and CSA[‡] measurements for 68 non-pathologic scapulae (SD; range)

Characteristics	Total (n = 68)		Female (n = 36)		Male (n = 32)		p-value
Glenoid height (mm)	34.0	(3.7; 26.8 to 43.8)	31.4	(2.3; 26.8 to 36.6)	36.9	(2.7; 31.4 to 43.8)	< 0.0001
Glenoid width (mm)	25.4	(3.3; 18.1 to 33.3)	23.1	(2.0; 18.1 to 27.2)	27.9	(2.5; 23.0 to 33.3)	< 0.0001
Height/Width ratio	1.3	(0.1; 1.1 to 1.7)	1.4	(0.1; 1.1 to 1.7)	1.3	(0.1; 1.1 to 1.6)	0.064
Glenoid version* (°)	−6	(5; −17 to 10)	−7	(4; −15 to 0)	−5	(5; −17 to 10)	0.525
CSA [‡] (°)	33	(4; 23 to 44)	32	(3; 23 to 39)	33	(4; 25 to 44)	0.426

[‡]CSA, Critical shoulder angle.

* Anteversion of the glenoid surface with respect to the plane of the scapula: anteversion (+), retroversion (−)