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REVIEW ARTICLE

Critical shoulder angle: what do radiologists need to know?

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Abstract
The critical shoulder angle (CSA) constitutes a straightforward and highly reproducible tool. Degenerative rotator cuff tears (RCT) are associated with a significantly larger CSA. In this review, the most relevant features of the CSA are summarized: (1) the relationship between the CSA and RCT pathophysiology, (2) accurate measurement of the CSA according to various imaging modalities, (3) the contribution of the CSA in predicting the occurrence of RCT, and (4) RCT recurrence after surgical repair.

Keywords Shoulder · X-rays · MRI · Rotator cuff injuries

Introduction

Shoulder pain is a common condition, with an estimated prevalence of 4 to 26%, and rotator cuff disorders account for more than two-thirds of all cases [1]. The cause of rotator cuff tears appears to be multifactorial and is most likely a combination of functional factors, microtrauma, and age-related degeneration [2]. The quantitative individual geometry of the scapula is one of several factors associated with the occurrence of rotator cuff tears (RCT) [3, 4]. Imaging is very useful for investigation of rotator cuff disorders as it helps with the detection of risk factors and the presence of RCT. Radiographs allow assessment of the morphology and the lateral extension of the acromion [5]. Indeed, the lateral extension of the acromion appears to be associated with full-thickness tearing of the rotator cuff, as described by Nyffeler et al. in 2006 (Fig. 1) [4]. To estimate the lateral extension of the acromion, Nyffeler introduced the acromial index (AI), which is the ratio between (1) the distance from the glenoid to the lateral edge of the acromion and (2) the distance from the glenoid to the lateral edge of the greater tuberosity (Fig. 2). Radiography also allows assessment of the morphology of the scapula using the critical shoulder angle (CSA), an index introduced by Moor et al. in 2013 [6]. The CSA quantifies the extent of acromial coverage and the inclination of the glenoid, and it corresponds to the angle between the glenoid axis and the line through the inferior edge of the glenoid and the lateral edge of the acromion (Fig. 3). Unlike the AI, the CSA remains independent of the morphology of the humeral head and has the advantage of providing an assessment of the lateral extension of the acromion when considering the glenoid slope [7–9]. A recent study comparing the AI, the lateral acromial angle (LAA), the CSA, and the acromial slope concluded that the CSA was the most accurate radiographic predictor of the presence of a degenerative RCT [10]. Moreover, although the CSA was first studied in radiographs, it can be measured in all imaging modalities [11, 12]. Moor et al. concluded that a CSA greater than 35° correlates with rotator cuff tears, and a CSA of less than 30° correlates with osteoarthritis of the glenohumeral joint (Fig. 4) [6, 10]. Further studies have confirmed these findings [13, 14], although these results remain controversial in light of several studies that do not support these correlations [15, 16]. The primary aim of this work is to provide an overview of CSA measurement methods and to clarify the added value of CSA in making an RCT diagnosis and for predicting patient recovery after surgical repair.

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How should the CSA be measured?

Radiographs

The CSA equates to a line connecting the superior and inferior borders of the glenoid fossa and another line from the inferior border of the glenoid to the most lateral point of the acromion

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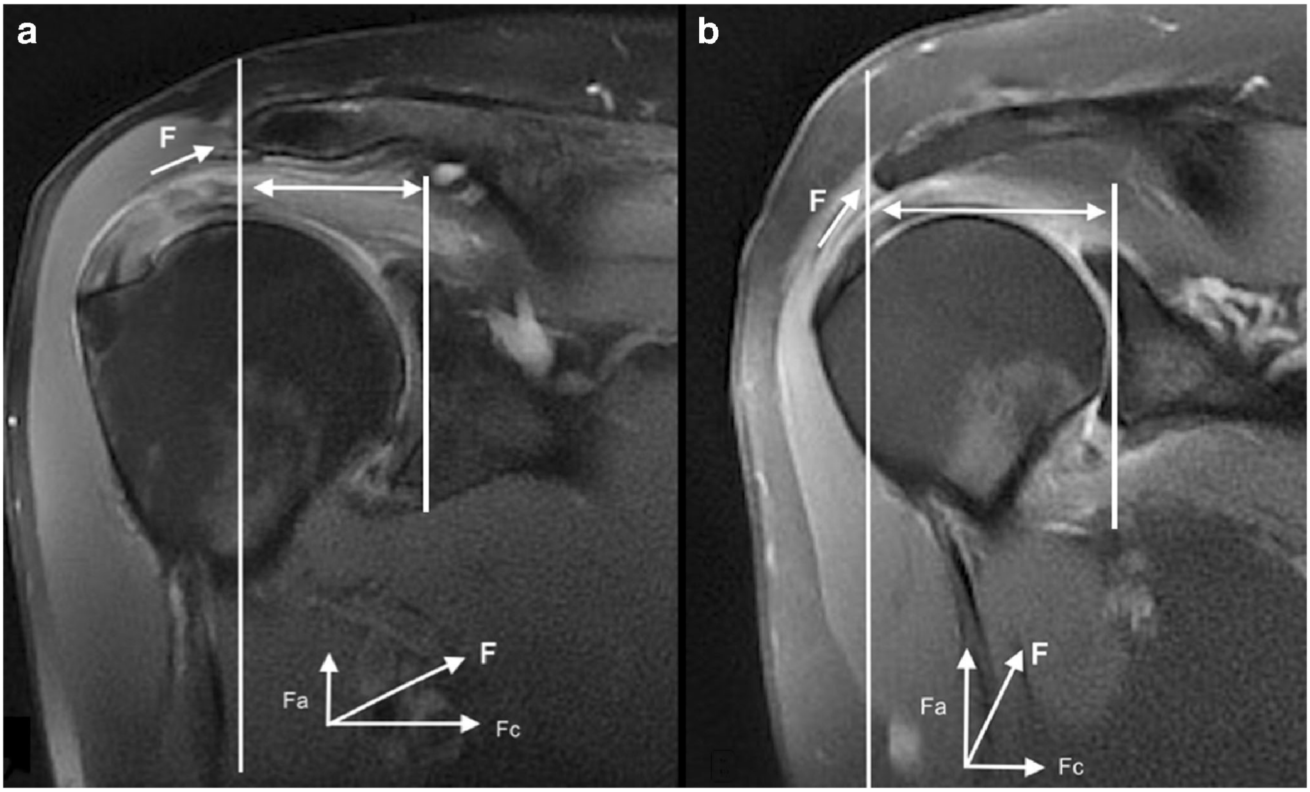

Fig. 1 The relationship between the lateral extension of the acromion and rotator cuff disease. The deltoid force vector (F) is the result of a vertical component that leads to ascension of the humeral shaft (Fa) and a horizontal component that induces compression of the humeral head against the glenoid (Fc). In case of a short acromion (**a**), a relative increase in the compression force Fc (rather than Fa) leads to osteoarthritis. In case of a long acromion (**b**), a relative increase in the ascension force Fa (rather than Fc) leads to narrowing of the subacromial space and rotator cuff disease. Adapted from Nyffeler et al. [4]

(Fig. 2). A CSA greater than 35° correlates with degenerative rotator cuff tears, while a CSA of less than 30° correlates with osteoarthritis of the glenohumeral joint [6, 10].

Measurement of the CSA is usually carried out on true anterior-posterior (AP) radiographs of the shoulder (upright position) with a visible joint space, and it is highly reproducible. CSA measurements obtained from radiographs have been shown to have excellent interobserver agreement, as indicated by the study by Spiegl et al. [12] that found inter-observer and intra-observer agreements on radiographs of 0.87 (95% CI 0.78–0.93) and 0.91 (95% CI 0.82–0.96), respectively. Additionally, Moor et al. [6] have demonstrated that measurements of the CSA are insensitive to minor malrotations of the scapula. Their experimental analysis of the dependence of the CSA on rotation showed that the CSA increased slightly with internal rotation of the scapula and that it decreased slightly with external rotation. These changes do not exceed 2° for rotation and/or flexion of up to 20°.

However, as shown by Suter et al. [17], the CSA is highly sensitive to radiographic alignment of the scapula in anteversion and retroversion, in which a 5–8° change in the viewing angle can result in a 2° change in the CSA. According to Suter's observations, and to limit potential bias related to different viewing perspectives, Blonna et al. also proposed to define a radiograph with an acceptable quality as an image with ≤ 5 mm of overlap between the anterior and the posterior margins of the glenoid [13] (Fig. 5).

For comparison of pre- and post-operative CSA, the exact orientation of the X-ray and the spatial orientation of the scapula should be as similar as possible [18]. Finally, the CSA is not affected by demographic factors [17]. Indeed, the CSA and the glenoid version did not differ between right and left shoulders in true AP images, and the CSA and the glenoid version did not differ based on gender ($p \geq 0.064$).

CT scans

The measurements can also be performed on CT scans, and there is a high degree of reliability between AP radiographs and CT scans [11]. The CSA should be measured on a defined plane with multiplanar reconstruction (MPR) in three-dimensional reconstruction. The plane is defined by three points: the superior border of the glenoid, the inferior border of the glenoid, and the most lateral point of the acromial extension (Fig. 6). The cut must include the largest visible distance between the superior and inferior border of the glenoid and the most lateral point of the acromion.

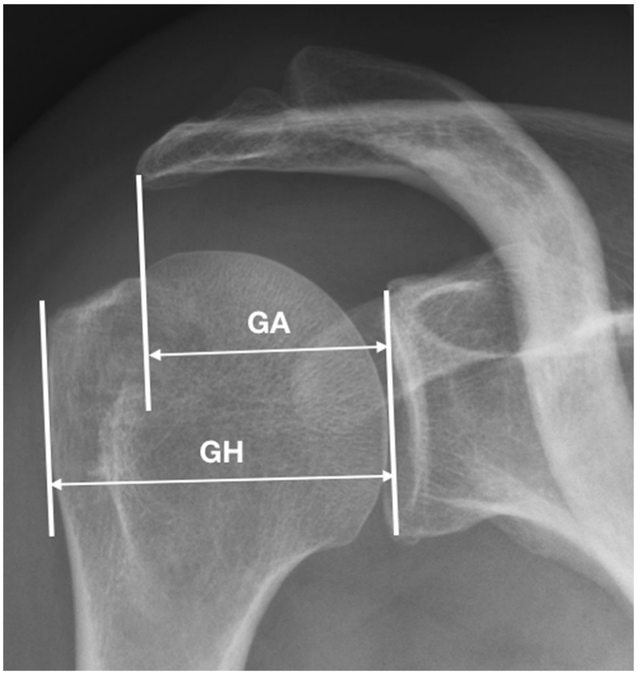

Fig. 2 Anteroposterior radiograph of the shoulder. The acromial index (AI) is the ratio between the distance from the glenoid (G) and the lateral edge of the acromion (A) and the distance from the glenoid and the lateral edge of the greater tuberosity (H)

In their study, Bouaicha et al. found a very strong intermethod correlation for the value of the CSA between the CSA measured on radiographs and CT scans (Spearman's rho = 0.974). The mean CSA measured by the two readers were 33.2° (SD ± 5.9°) and 33.1° (SD ± 5.9°) on radiographs. The mean CSA measured on CT scans were 33.3° (SD ± 5.7°) and 33.0° (SD ± 5.6°).

The inter-reader reliability was estimated to be 0.989 for CT scans, whereas it was 0.993 for radiographs. Images should be taken in a supine position with both arms in neutral rotation.

MRI

The CSA measured by MRI exhibits greater variability and less correlation than radiographs [12] due to limitations of MRI in bone imaging and the glenohumeral joint morphology (Fig. 7). Especially in cases of osteoarthritis, the upper and lower osseous boundaries of the glenoid are difficult to define due to degeneration including osteophytes.

Moreover, evaluation of the CSA by MRI is also dependent on the image quality and the technique, including the MRI slice orientation and patient positioning. With MRI, the inferior glenoid margin and the lateral acromial margin required for measurement of the CSA are typically on different slices. By contrast, in AP radiographs, the inferior glenoid and lateral acromial margin are both fixed in the same projection. Evaluation of the CSA by different obliquely oriented MRI slices compared with a single AP projection radiograph is hence subject to greater inter- and intra-observer variability [12]. Nevertheless, isotropic 3D gradient imaging which allows to depict bony surfaces better than with conventional fast spin echo sequences may be more accurate to assess CSA.

What does the CSA predict?

The CSA combines assessment of the lateral extent of the acromion and the glenoid inclination. These factors are involved in the pathogenesis of RCT and OA [4, 19], whereby the deltoid has either a greater upward force resulting in RCT or a greater compressive force leading to OA. Several studies, published subsequent to the study by Moor et al. in 2013 [6], support that the notion that high CSA values are significantly correlated with full-thickness RCT while small CSA values are significantly correlated with OA [12, 20, 21].

Some authors have indicated that the CSA may help to predict the pathology for patients with shoulder pain [12, 22]. Moreover, in a population with OA, the CSA measurement can be of use to determine the need for magnetic resonance imaging for assessment of rotator cuff integrity [20].

These results remain controversial, however, as suggested by the study of Bjarnison et al., which did not find any association between the CSA and RCT, although it did show an

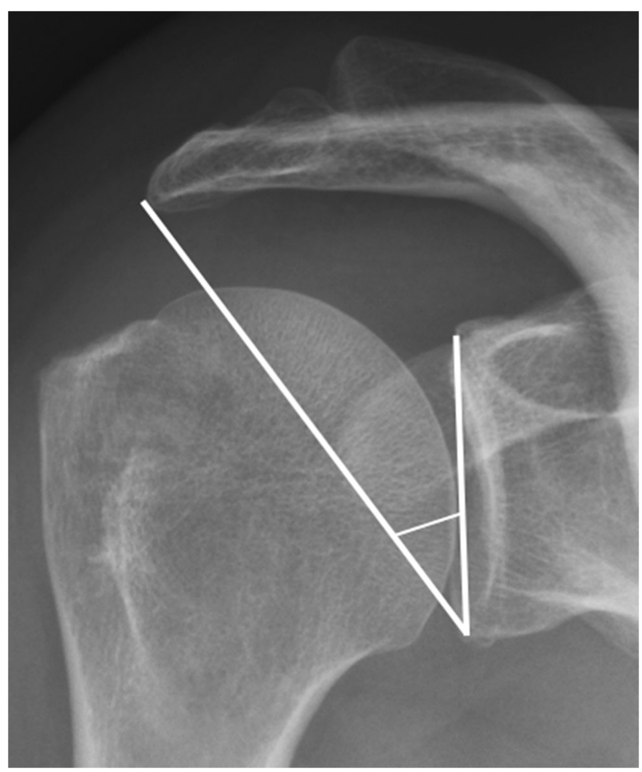

Fig. 3 Anteroposterior radiograph of the shoulder. The critical shoulder angle (CSA) is the angle between the glenoid axis and the line through the inferior edge of the glenoid and the lateral extremity of the acromion

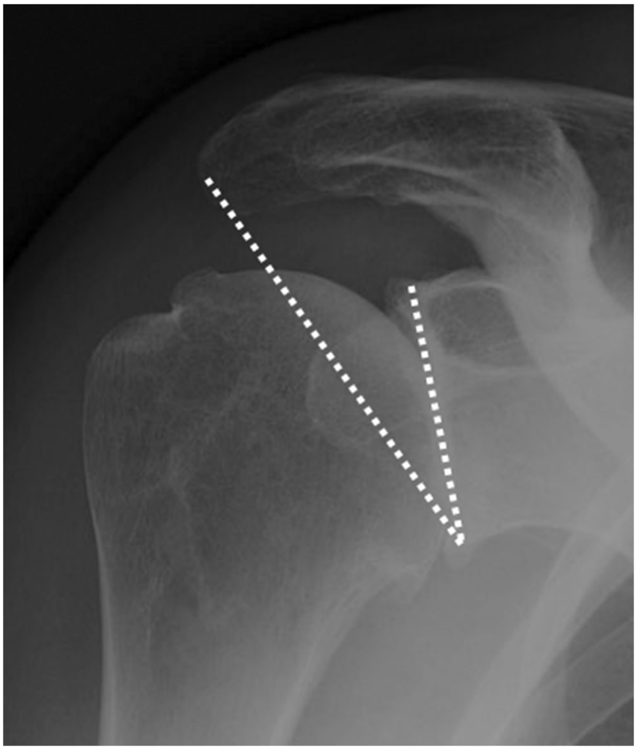

Fig. 4 Anteroposterior radiograph of the shoulder. Low CSA is associated with higher risk of shoulder osteoarthritis

association between the CSA and OA, with a 2.25 odds ratio of developing OA when the patient had a CSA of less than 30° [15]. Moreover, Chalmers et al. have suggested that the CSA is unlikely to be related with rotator cuff disease [16], because the difference between control subjects and patients with a history of degenerative cuff disease is small enough that it could be influenced by measurement errors in practice.

Does the CSA helps in predicting patient outcomes?

Comparing treatment outcomes with specific findings can help clinicians with advising patients as to what to expect from different interventions, based on their particular findings. Does determination of the CSA helps clinicians with advising their patients about interventions?

Dietrich et al. investigated the efficacy of subacromial anesthetic and long-acting corticosteroid injections. They found significantly improved outcomes at 1 week and 1 month in patients with a CSA $< 35°$, while patients with a CSA $> 35°$ had less favorable functional outcomes [23].

Also, the CSA may be useful for the prognosis of retearing after arthroscopic rotator cuff repair. Garcia et al. used ultrasound to investigate the retear rate for repaired rotator cuff tendons, and they found that a larger CSA significantly increased the risk of a full-thickness retear after rotator cuff repair. When the CSA was $> 38°$, the risk of retear after arthroscopic rotator cuff repair was 15 times higher, with an odds ratio at 14.8 ($p < 0.01$) [24]. Li et al. used postoperative MRI to study the retear rate of repaired rotator cuff, and they also found that a large CSA was associated with an increased risk of rotator cuff retearing [25]. Similar findings with the AI have not been confirmed. As demonstrated by the Garcia and the Ames studies, there does not appear to be a significant relationship between the AI and retear rates [24, 26]. These studies demonstrate that the CSA is an important radiographic marker for preoperative assessment of patients undergoing arthroscopic repair and that it may help with stratification of the risk of retear in this population.

Moreover, Beeler et al have shown that the lateral acromial roof extension is the factor that influences RCT the most. It supports the possibility of lateral acromioplasty to influence the CSA and to change the radiological CSA towards normal values and thereby reduce an overload of the rotator cuff [27]. A recent study by Gerber et al. has confirmed that arthroscopic lateral acromioplasty performed in addition to rotator cuff repair allows a large CSA to be reduced without significant complication. Moreover, they found that insufficient CSA reduction was associated either with a higher rate of non-healing or with a lower abduction strength when the tears heal [28]. This suggests that CSA reduction has to be planned and performed quantitatively, even if the ideal CSA has not yet been established. Karns et al. recently introduced the critical acromial point, which is responsible for the acromial contribution of the CSA, to guide the surgeon in regard to where and how to alter the CSA [29]. Pre- and post-operative CSA

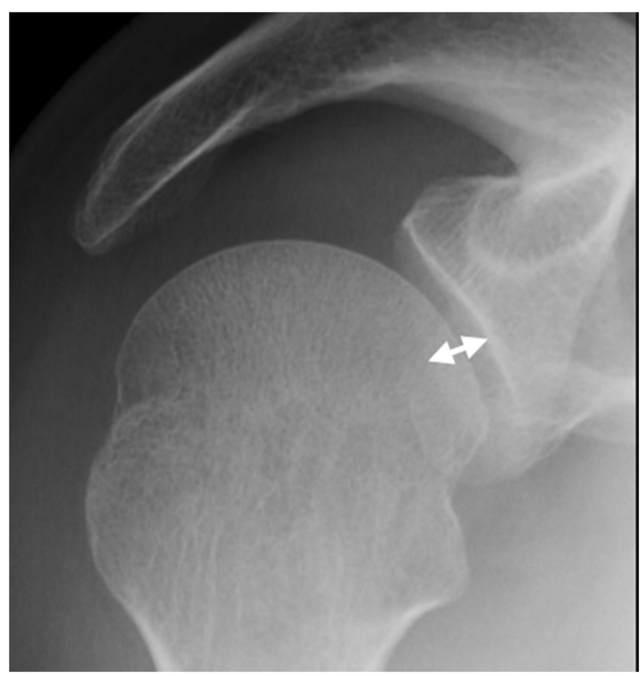

Fig. 5 Anteroposterior radiograph of the shoulder. Acceptable quality for CSA measurement is defined when overlap between the anterior and the posterior margins of the glenoid is ≤ 5 mm

Fig. 6 CT with MPR reconstruction in a coronal oblique plane shows the CSA measurement

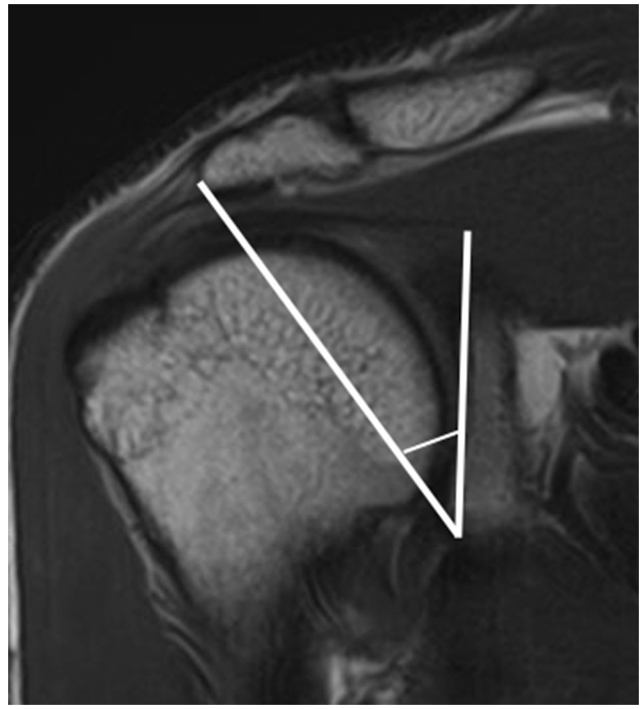

Fig. 7 MRI with T2-weighted sequence in a coronal oblique plane. Note that inferior glenoid margin and lateral acromial margin required for measurement of the CSA are on different slices

measurements in AP radiographs exhibited better effect sizes than in adjusted CT.

In terms of functional outcomes, the literature is controversial. Garcia et al. found that an increasing CSA correlated with worse postoperative outcomes, as indicated by worsening American Shoulder and Elbow Surgeons scores [24]. However, Kirsch et al. investigated the association between the CSA and functional scores at 24 months after arthroscopic rotator cuff repair, and they found that the CSA did not appear to be a significant predictor of patient-reported outcomes [30]. The study by Li et al. also indicates that the CSA does not appear to influence postoperative functional outcomes [25]. These findings suggest that the CSA is not the only predictive factor for patient outcomes after arthroscopic rotator cuff repair. Other anatomical factors may be involved, such as the greater tuberosity angle recently introduced by Cunningham et al. [31].

Conclusion

Multiple studies have shown that the radiologically visible lateral extension of the acromion is a relevant predictor for the development of either osteoarthritis or RCT. The critical shoulder angle quantifies the extent of acromial cover and the inclination of the glenoid, integrating both risk factors of RCT into one biomechanical parameter. The CSA is hence a valuable, simple, and highly reproducible parameter to discriminate between OA and RCT. X-rays are a sufficient tool to assess CSA whereas CT scans have the same diagnostic performance but is limited by the increased radiation dose and may not be used to measure it. Even if MRI is the method of choice for rotator cuff injuries, it should not be used to measure CSA. For patients with RCT undergoing arthroscopic repair, a pre-operative large CSA is associated with a higher risk of retear. Some studies tend to indicate that an elevated CSA could be surgically modified during rotator cuff repair with concomitant arthroscopic lateral acromioplasty. Pre- and post-operative CSA measurements are a useful tool for assessment of the retear risk. However, the relationship between the CSA and functional outcomes is less clear, thus suggesting that other anatomical factors may be involved, such as the greater tuberosity angle.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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