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Impact of critical shoulder angle in shoulder pathology: a current concepts review

Akinola E. Oladimeji, MD, Kelms Amoo-Achampong, MD, Gabriella E. Ode, MD*

Sports Medicine and Shoulder Surgery Division, Hospital for Special Surgery, New York, NY, USA

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Background: This review aims to describe the origin and development of critical shoulder angle (CSA) and its correlation with different shoulder pathologies. Current literature is inconclusive in characterizing the role of CSA in predicting pathology and surgical outcomes.
Methods: A literature search of both historical and more contemporary research articles on CSA was conducted to compare data points on the impact of CSA on shoulder pathology and postoperative clinical outcomes. This compilation of studies ranges from retrospective reviews to case series as well as cadaveric imaging studies.
Results: The CSA is a reliable radiographic measure in predicting shoulder pathology in correctly oriented radiographs. Surgically modifying the CSA with arthroscopic lateral acromioplasty and results has largely shown improved recovery of strength postoperatively as with no increase in postsurgical complication rates. However, it remains unclear whether surgical alteration of CSA has a role in preventing clinical failure after arthroscopic procedures such as acromioplasty and rotator cuff repair as well as following shoulder arthroplasty.
Discussion: Stronger conclusions regarding the prognostic utility of CSA are limited by the fact that most studies evaluating CSA are smaller retrospective cohorts. Moving forward, randomized controlled trials being conducted may offer greater insight as to how CSA can improve patient-reported outcomes postoperatively.

In recent years, there has been increased effort in identifying radiographic measures that better predict pathology and guide clinical decision making. The critical shoulder angle (CSA) has been proposed as a useful tool for in-office orthopedic diagnosis and treatment. The CSA is defined as the angle between the glenoid plane and the plane spanning from the lateral acromion border to the inferior glenoid pole.[52]

Early investigation into this metric have found association of CSA values <30° with glenohumeral osteoarthritis (GHOA) and CSA values >35° suggestive of rotator cuff injury.[33] These relationships have been both accepted and challenged with much controversy surrounding its utility as a prognostic tool for patient outcomes. It additionally remains unclear whether surgical modification of this metric is impactful on postsurgical clinical outcomes.

In this review, we aim to provide historical context behind the development of the CSA, to describe ranges found in both normal and pathologic populations, and to illustrate its relationship with previously developed measures of scapular morphology. We additionally describe the development of this measure, to summarize correlation with shoulder pathology, and to evaluate its utility in evaluating outcomes following surgical intervention.

Development of critical shoulder angle measurement and reported intraobserver/interobserver reliability

Early investigation into the relationship between acromial morphology and shoulder injury has largely focused on rotator cuff degenerative changes. In 1931, Meyer[32] first published their description of the extrinsic theory of rotator cuff disease, suggesting that the acromion caused mechanical attrition of the supraspinatus aponeurosis.[34] Armstrong and Neer later proposed impingement syndrome, the mechanical contact between the anterior acromion and rotator cuff, as a potential cause of bursal-sided lesions in 1949 and 1972, respectively.[2,23,35] In a cadaveric study, Bigliani et al later described 3 different types of acromial shapes which were believed to progressively decrease the supraspinatus outlet leading to increased pressure and friction predisposing to degenerative rotator cuff wear. They reported a higher

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*Corresponding author: Gabriella E. Ode, MD, Sports and Shoulder Surgery, Hospital for Special Surgery, 523 E. 72nd St, Ground Floor, New York, NY 10021, USA.

E-mail address: gabriellaode@gmail.com (G.E. Ode).

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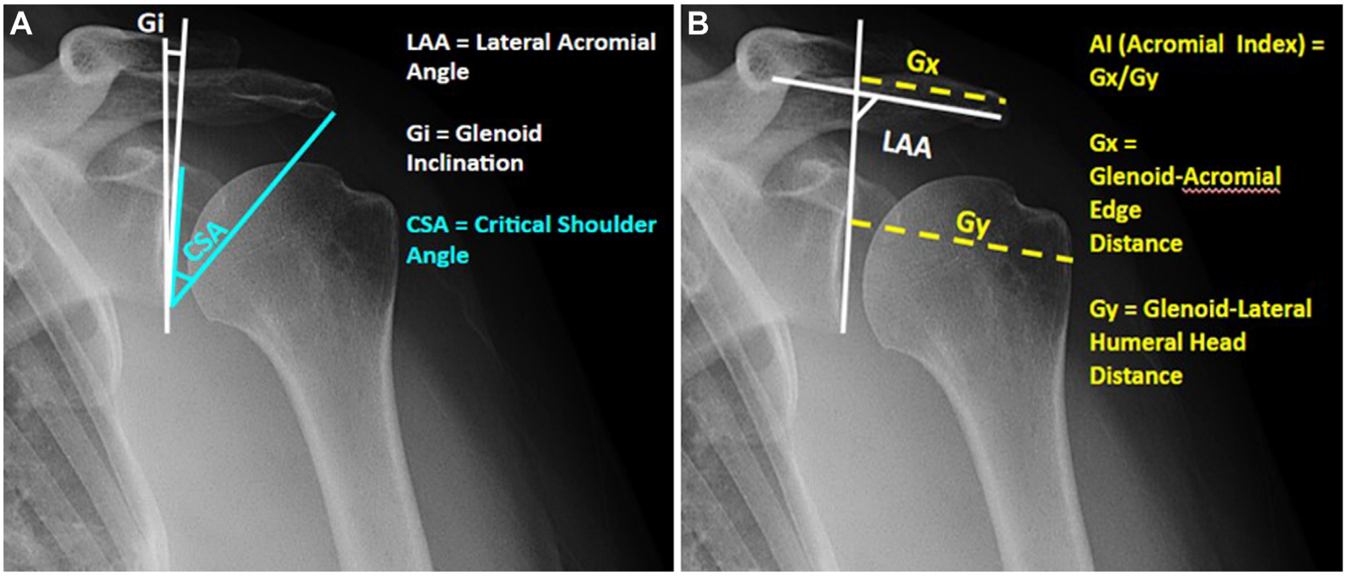

Figure 1 Radiographic shoulder measurements on Anterior-Posterior (AP) oblique Grashey view. (**A**) Critical shoulder angle (CSA), lateral acromial angle (LAA), and glenoid inclination (GI) measurements. (**B**) Acromial index (AI) measurement; Gx = glenoid-acromial edge distance; Gy = glenoid-lateral humeral head distance.

incidence of rotator tears (RCTs) in type III (hooked) acromion compared to that of type I (flat) or type II (curved) acromion.[4] This was further supported by another cadaveric study by Aoki et al[1] suggesting correlation between flattened acromial slope in the scapular plane and degenerative wear of the greater tuberosity of the humeral head.

This initial work led to the development of radiographic parameters to evaluate these relationships more quantitatively. Banas et al[3] first explored the correlation between the frontal plane slope of the acromion with rotator cuff disease using magnetic resonance imaging (MRI). They first described the lateral acromion angle (LAA), defined as the slope of the inferior acromion drawn relative to the glenoid face on a select oblique coronal MRI image (Fig. 1, *A*). Eight percent of shoulders (n = 100) with angles less than or equal to 70° had full-thickness RCTs, and a statistically significant increase in RCTs correlated with decreasing LAA. Subsequent literature also proposed glenoid morphology as a risk factor for RCTs. Nyffeler et al[36] developed the acromion index (AI) (Fig. 1, *B*), described as the distance from the glenoid plane to the lateral edge of the acromion divided by the distance from the glenoid plane to the lateral aspect of the humeral head on true anteroposterior radiographs. In age and gender-matched comparisons of 102 patients, average AI was significantly higher in shoulders with full-thickness supraspinatus tears (0.73 ± 0.06) compared to those with intact rotator cuffs (0.64 ± 0.06, $P < .0001$). Additionally, the smallest AI values were reported in osteoarthritic shoulders with intact rotator cuffs (0.60 ± 0.08). Authors concluded that the increased vertical middle deltoid force vectors led to a net ascending force relative to the glenoid plane in individuals with higher AI values. Moreover, they proposed that smaller AI values led to a net compressive force resulting in increased glenohumeral wear and degenerative changes.

While the acromial index (AI) relies on glenohumeral relationships relative to the glenoid plane, its ability to distinguish disease states is limited in cases of advanced glenohumeral erosion. To address this issue, Moor et al[33] introduced the CSA in 2013, which quantified acromial lateralization while including glenoid inclination (GI) in a single radiographic parameter that was independent of degenerative changes observed in GHOA. This was defined as the angle measured between a line connecting the inferior and superior border of the glenoid fossa and an intersecting line connecting the inferior border of the glenoid with the most inferolateral aspect of the acromion (Fig. 1, *A*). Results of their retrospective review (n = 298 shoulders) suggested that patients near 65 years of age with healthy shoulders had CSAs between 30° and 35°. Additionally, CSA >35° were associated with prevalence of RCTs while CSA <30° was more frequently seen in osteoarthritic shoulders. Like Nyfeller et al,[36] they concluded that these findings were reflective of mechanical load imbalances present in the unhealthy shoulder.

In the original Moor et al[33] study, CSA demonstrated excellent interobserver reliability (0°, range; ±2°). Additionally, there was good intraobserver reliability (−0.21°, standard deviation 1.1, limits of agreement −2° to 2°) between 2 readers in the study.[33] Subsequent studies have corroborated the relationship of CSA with GHOA and rotator cuff pathology with high intraobserver and interobserver reproducibility of 96.7% and 95.5%, respectively.[8,52] Alternatively, a number of studies have reported skepticism about CSA correlation with rotator cuff and GHOA pathology and have emphasized the importance of high-quality true anteroposterior radiographs for precise measurement of the CSA.[5,7] Other investigators have also questioned whether acromial changes characterized by these CSA are the consequence or cause of their associated pathology.[19,25,53]

Furthermore, debates persist today regarding even the existence or significance of subacromial impingement, many decades after it was first characterized. Therefore, the role of treatment methods to address acromial morphology such as acromioplasty are still not clearly defined or universally accepted in current literature.[26]

Epidemiology: range of CSA in normal and pathologic shoulder populations

Literature suggests a range of CSA values in both normal and pathologic populations. Moor et al[33] reported a mean CSA of 33.1° (26.8°-38.6°) in 94 healthy shoulders compared to 38.0° (29.5°-43.5°) in 102 shoulders with RCTs and 28.1° (18.6°-35.8°) in 102 osteoarthritic shoulders. Additionally, 84% of patients with rotator cuff pathology had CSA values of >35° while 93% of patients with GHOA demonstrated CSA values of <30°.[33] Gumina et al[16] further characterized CSA in a population of healthy shoulders by surveying over 2000 radiographs in patients over age 15. They found a similar mean CSA of 33.6° (range: 24°-50°, standard deviation: 3.9°) in normal shoulders. Additionally, no significant differences were identified in gender or laterality, which they concluded argued against heavy workload playing a major role in modifying acromial morphology or GI. Linear regression analysis also demonstrated a small (0.04°) increase with each year of age that was not found to be significantly different between each decade, suggesting genetic determination of CSA which may remain stable throughout life.[16]

In a retrospective review of longitudinally collected data, Chalmers et al[7] sought to identify reliability of CSA as well as assess its correlation with RCT progression. Like Moor et al,[33] CSA was higher in RCT patients compared to healthy controls (34° ± 4° vs. 32° ± 4°; 95% confidence interval [CI], 0.7°-3.2°; P = .003). There were no differences in CSA between patients with stable RCTs and tears that progressed at mean 3-year radiographic follow-up. Despite these findings, Chalmers et al[7] acknowledged that only 21% of eligible radiographs were of adequate quality for study inclusion and that measurement differences were small enough to be influenced by measurement errors. The Suter-Henninger criterion, published in 2019, has been proposed to predict CSA on radiographs with an 89% probability of accuracy within 2° utilizing their exclusion criteria for malrotated images.[49]

Correlation of CSA with other radiographic shoulder measures

The CSA, AI, GI, and lateral acromial angle (LAA) are among the most frequently published radiographic measures used to characterize scapular morphology. Like the LAA and AI, the CSA remains independent of sagittal morphology, described by the Bigliani classification.[4] Hence, these parameters remain relatively static following standard anterolateral acromioplasty. A 2019 meta-analysis including 30 unique titles published by Zaid et al[55] demonstrated that all 4 measures were consistently correlated with the presence of degenerative shoulder pathology. Both elevated CSA >35° and AI >0.74 were correlated with rotator cuff pathology and conversely, decreased values were associated with GHOA compared to healthy control patients. In contrast to CSA and AI, lower LAA values were found to consistently correlate to degenerative RCTs. The authors concluded that the relationship between GI and degenerative shoulder pathology remains inconclusive.[55] Results from a prediction model study additionally reported superior performance of CSA in predicting degenerative shoulder pathology over AI and LAA measurements, most notably between GHOA and rotator cuff pathology.[18]

Clinical and radiographic correlation of CSA with clinical outcomes of pathologic shoulder conditions

Lateral acromial extension and GI, both components of CSA, have been implicated in the development of RCTs and GHOA, respectively.[22,35] These quantitative measures may be suggestive of biomechanics that predispose to degenerative conditions.[33,45] Follow-up studies have supported this association as well as demonstrated high interobserver and intraobserver agreement on plain radiographs, potentially serving as a predictive diagnostic tool for degenerative shoulder conditions.[47] These findings spurred further investigation into the correlation of CSA with pathology and function.

As prior investigations have supported higher susceptibility to tensile loads on the articular side of the rotator cuff,[20,40] a biomechanical study by Gerber et al[15] identified increased humeral head stabilization force requirements in scapula with higher CSAs. Clinical studies have also suggested CSA may distinguish articular-sided from bursal-sided injury, the latter of which may occur secondary to extrinsic mechanisms of tendinopathy. A retrospective review examined 1069 patients over a 5-year span and compared CSA between healthy controls, patients with articular-sided and bursal-sided partial thickness RCTs, and patients with full-thickness RCTs. Mean CSA of articular-sided partial tears (34.2° ± 4.7°) and full-thickness RCTs (34.7° ± 4.4°) were significantly higher than both control group (32.3° ± 4.8°) (P = .001 and P < .001 respectively) and bursal-sided partial tears (31.5° ± 4.6°), (both P < .001).[42] While average CSA values were found to be lower than originally expected, their results support the theory that CSA could identify tears with increased likelihood of progression, and thus tears that are more likely to require surgical intervention.

While the incidence of concurrent GHOA and RCTs is reported as low as 8%,[13] studies also identified higher CSAs in these patients compared to patients with isolated GHOA. In a case series (n = 31) from a 2-surgeon arthroplasty registry, a significantly higher mean CSA of 35° was found in patients with concurrent pathology compared to 30° in patients with GHOA alone (P < .0001) with excellent interobserver reliability (k = 0.89, P = .95) and specificity (90%).[31] As a result, it was proposed that MRI should be ordered in these instances for further evaluation of rotator cuff deficiency when considering surgical management for GHOA with arthroplasty.

As CSA has been shown to correlate, and perhaps differentiate, between types of shoulder pathology, others have sought to evaluate the role of CSA on functional compensation in the setting of rotator cuff arthropathy. A retrospective review by Lu et al[30] (n = 93, mean age 73.8 ± 8.0 years) demonstrated a higher mean CSA in patients who could perform forward elevation greater than 90° (33.7° ± 3.9°) compared to patients with pseudoparalysis (inability to perform forward elevation greater than 90°, 37.1° ± 6.3°). They concluded that functional compensation observed in patients with smaller CSAs was reflective of a more medialized acromion decreasing the upward vertical shear force of the deltoid. Other studies have suggested that this restores the fulcrum provided by the downward and compressive forces of the rotator cuff allowing for arm elevation.[36]

Impact of CSA on clinical outcomes following surgical intervention

Rotator cuff repair

Studies have recently evaluated the role of CSA as a prognostic indicator of outcomes after rotator cuff repair (RCR). Garcia et al[12] retrospectively reviewed 76 RCRs (mean age 69 years) with postoperative ultrasound at mean 7.6-month follow-up. They identified a higher mean CSA (38.6° ± 3.5°) in patients with full thickness retears compared to patients without retears (34.5 ° ± 2.9°, P < .01). Additionally, CSA >38° was found to be associated with a 15-fold increased risk of retear (OR 14.8, P < .01) and poorer American Shoulder and Elbow Surgeons scores. As recurrent tendon defects have been found to occur between 12 and 24 years after double-row repair, it has been proposed that MRI imaging at 2-year postop may more accurately identify recurrent tears.[48] Consequently, additional retrospective MRI studies found correlation between mean CSA >38° and increased repair failure rates at mid-term follow-up.[28,41] These outcomes may lend credence to consideration of CSA as a risk-stratification tool for surgical decision making.

Although systematic reviews have reported significant correlation between increased preoperative CSA and rotator cuff retear rates, there is much variability of reported values between and within treatment groups. This is attributed to measurement errors, heterogeneity in control group definition and patient demographics.[10,44,46] Additionally, the combination of thorough medical history and physical examination demonstrates excellent predictive power for diagnosing RCTs, leading many to question routine use of CSA measurements in clinical practice.[34] Most importantly, literature has failed to demonstrate a relationship between CSA and postoperative clinical outcomes. Studies such as Gürpınar et al[17] did not find any clinically significant differences in postoperative Constant scores between cohorts of patients with CSA >35° and those with CSA <35° after RCR. As a result, some have argued against utilizing CSA as a predictive tool when considering indications for RCR.[10,44,46]

Acromioplasty

Investigators have also sought out to evaluate the ability to change CSA surgically with acromioplasty. In 2018, Gerber et al[15] retrospectively reviewed 49 consecutive patients undergoing arthroscopic RCR with lateral acromioplasty without anterior acromioplasty. The procedure was determined to be safe without cases of dehiscence, increased fatty infiltration or deltoid atrophy with mean CSA reduced from 37.5° preoperatively (95% CI, 36.7°-38.3°) to 33.9° postoperatively (95% CI, 33.3°-34.6°; $P < .001$). Furthermore, significantly larger postoperative CSA values were observed in the 7 RCR failures (14%) compared to healed repairs ($P = .026$). Healed patients with a postoperative CSA corrected to 33° or less (n = 22) had 25% more abduction strength vs. those corrected to ≥35° (n = 14, $P = .04$).[14] The ability to correct CSA with lateral acromioplasty was supported by a 2022 systematic review and meta-analysis of 9 studies, which concluded that lateral acromioplasty was superior to anterolateral acromioplasty. The studies demonstrated that lateral acromioplasty reliably reduced postoperative CSA by a mean of 2.63° without complications at short term follow-up (range 12-30 months).

Karns et al[21] further localized the critical point responsible for the acromial contribution to CSA through a cadaveric imaging study (n = 88). This critical acromion point was determined using 3-dimensional (3D) computed tomography and digitally reconstructed radiographs. The mean critical acromion point was 21% ± 10% of the anterior-posterior length measured from the anterolateral corner and easily measured fluoroscopically without any difference observed between 3D computed tomography and digitally reconstructed radiographs. A 5-mm acromial resection was found to be reliable in reducing the CSA to ≤35° in 12 of 13 specimens, supporting the notion that arthroscopic lateral acromioplasty (ALA) was effective in altering the CSA. Mathematical models have additionally corroborated this data, suggesting that the amount of resection necessary to reduce a large CSA to <34° via ALA can be planned preoperatively with a simple equation (the suggested amount (in mm) of ALA resection = −39.120 + (1.165 × Original CSA)).[22] Literature has also suggested that there is an upper limit to arthroscopic resection with less reliable CSA reduction with preoperative CSA >40°.[37]

Authors have also proposed CSA reduction within normal ranges may not be easily achievable with a standard arthroscopic anterolateral acromioplasty aimed at producing a flat acromion undersurface. In a large 2022 case series (n = 435 patients) performed by Thiesemann et al,[51] pathologic CSA values >35° were reduced, but not significantly, to values within the normal 30°-35° range. Others also questioned whether standard anterolateral acromioplasty aimed at restoring normal CSA values provides any meaningful clinical outcomes.[17]

Shoulder arthroplasty

Investigations on the impact of CSA on surgical outcomes have also extended beyond arthroscopy into complications following shoulder arthroplasty. Shoulder arthroplasty literature have looked at correlations between CSA and failed total shoulder arthroplasty (TSA) and hemiarthroplasty (HA)[6,24,50,54] as well as correlation between CSA and stress fractures 9,[24] and instability[17,27,30,38,39,43] following RSA. Filer et al[11] retrospectively reviewed 16 symptomatic patients with rotator cuff failure following HA and anatomic TSA requiring revision to reverse shoulder arthroplasty (RSA) to an age and sex-matched control group. They reported significantly higher median CSA in the study group compared to controls (32.5°, interquartile range = 29.8°-36.1° vs. 29.5°, interquartile range = 27.6°-30.4°; $P = .026$). Watling et al[54] similarly conducted a retrospective review of 61 primary TSAs, identifying a statistically significant correlation between CSA and glenoid lucency grade (OR, 1.20 per degree CSA) and lucency grade progression (OR 1.24) at mean 5.0 ± 2.2-year follow-up.

Consequently, Tabeayo et al[50] suggest consideration of primary RSA for primary GHOA in patients with preoperative CSA ≥35°. In a 1:2 matched case-control study (n = 78 patients), they reported a higher likelihood of revision after TSA in patients with CSA ≥35° (OR = 2.41, 95% CI = 1.27-4.59). Elevated CSA values were also observed in TSA cases specifically revised for glenoid loosening (OR = 4.58, 95% CI = 1.20-17.50) and RCT (OR = 2.41, 95% CI = 1.18-4.92) with odds increasing with every 5° CSA increase. Conversely, Cerciello et al[6] failed to identify a relationship between primary HA and TSA patients requiring revision to RSA for secondary rotator cuff insufficiency. They also found no significant difference in CSA values between those who had undergone successful anatomic shoulder arthroplasty and those who exhibited the same procedure with late rotator cuff failure. Given these small cohorts and heterogeneity in outcomes of TSA in patients with high CSA, definitive conclusions regarding the role of CSA in TSA failure remain unclear.

Results are also mixed regarding the relationship between CSA and rates of acromial stress reactions (ASR) and acromial stress fractures (ASF) following RSA. Kriechling et al[24] published a 5.4% rate and 5.2% rate of ASF and ASR, respectively, in a retrospective case-control study of 854 RSAs. In addition to center of rotation lateralization, both preoperative and postoperative CSA were identified as a predictor of ASF and ASR in both groups compared to controls at mean 31.6-month year follow-up. Contrastingly, Cho et al[9] retrospectively reviewed 61 patients undergoing RSA for primary GHOA and found no association between preoperative CSA (37.2± vs. 36.0, $P = .160$) and ASF at mean 10.0 months.

Further, current literature has yet to establish the relationship between CSA and shoulder stability following RSA with equivocal results regarding its association with postoperative clinical outcomes.[25,38,39,43] Using a 3D biomechanical study design of 19 cadaveric shoulder specimens, Pastor et al[38] investigated the relationship between bony anatomy and anterior dislocation forces in RSA. While the distance between the coracoid tip and glenoid in 2 planes had significant negative correlation with anterior stability of RSA, no relationship was identified with CSA. Lädermann et al[27] additionally used 3D modeling to evaluate computed tomography scans of 12 patients with CSAs of 25°, 30°, 25°, and 40° at variable neck-shaft angles, different degrees of lateralization and several standardized movements. The CSA was not found to influence range of motion in any of the models. Clinical studies have also yielded mixed results regarding range of motion and patient outcomes at mean 2-year follow-up, Roberson et al[39] additionally retrospectively reviewed 108 patients (mean age 69 ± 8 years) who underwent RSA and found that postoperative CSA <25° correlated with improved forward elevation compared to patients with CSA ≥25° (131° vs. 112°, $P = .02$). Shah et al[43] also sought out to identify the impact of preoperative variables on patient outcomes following RSA for cuff tear arthropathy. At minimum 2-year follow-up (n = 79 patients; mean age 69.9 ± 7.7 years), neither preoperative Hamada[18] or Seebauer[53] rotator cuff arthropathy grades nor preoperative scapular geometric measures including CSA were found to be associated with postoperative American Shoulder and Elbow Surgeons scores.

Discussion

Despite extensive inquiry into the utility of CSA for clinical decision making, previous investigations have largely been limited to retrospective studies. Future focus on randomized controlled trials would further establish understanding of how CSA could affect surgical indications and whether alteration of CSA may improve patient outcomes. Currently, 1 prospective study[29] is evaluating the impact of acromioplasty on CSA reduction in patients indicated for arthroscopic RCR with preoperative CSA $\geq 33^{\circ}$. Patients will be allocated to 1 of 3 treatment groups (anterolateral acromioplasty, lateral acromioplasty or precise acromioplasty) with planned clinical follow-up maintained up through 1 year with follow-up postoperative CSA measurements and shoulder function scores. Longer-term follow-up may further elucidate the effect of acromioplasty on revision and retear rates following prior arthroscopic RCR. As the availability of adequate preoperative films has also been a major limitation of prior studies, prospective study designs with standardized preoperative imaging would allow for further determination of the relationship between CSA and shoulder pathology.

Conclusion

The CSA is a reliable radiographic measure in predicting shoulder pathology in correctly oriented radiographs. There has been extensive inquiry into CSA as a prognostic indicator of treatment outcomes. Specifically, several investigators have evaluated the impact of surgically modifying the CSA with ALA and results have largely shown improved recovery of strength postoperatively as with no increase in postsurgical complication rates. Additionally, investigation into the impact of CSA on surgical outcomes regarding shoulder arthroplasty has shown a correlation between increased CSA values and revision rates. Stronger conclusions regarding the prognostic utility of CSA are limited by the fact that most studies evaluating CSA are smaller retrospective cohorts. Moving forward, randomized controlled trials being conducted may offer greater insight as to how CSA can improve patient-reported outcomes postoperatively.

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