Critical shoulder angle is an effective radiographic parameter that is associated with rotator cuff tears and osteoarthritis: a systematic review

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ABSTRACT

Importance The critical shoulder angle (CSA) is a relatively new radiographic parameter correlated with pathologies such as rotator cuff tears and osteoarthritis.

Objective The purpose of this systematic review was to: (1) determine the degree of correlation between the CSA and shoulder pathologies, (2) determine the reliability of measuring CSA between (intrarater reliability) and within (intrarater reliability) clinicians, (3) assess the accuracy of different imaging modalities used for measuring the CSA and (4) determine the association of CSA with patient outcomes after surgery.

Evidence review The electronic databases MEDLINE, EMBASE and PubMed were searched in March 2018 for relevant studies. The results are presented in a narrative summary.

Findings A total of 26 studies and 4563 patients satisfied the inclusion criteria. The majority of CSAs were measured using radiographs (98.2%) in neutral rotation (72.9%). Significant associations (p<0.05) were found between lower CSAs (<30°) and osteoarthritis, and higher CSAs (>35°) with primary rotator cuff tears and the risk of re-tear following a repair. The CSA has excellent intrarater (intraclass correlation coefficient (ICC) 0.903 to 0.996) and inter-rater reliability (ICC 0.869 to 0.980) when measured with radiographs. High variability in measurements was found when using MRI. The CSA, however, is not a significant independent predictor (p>0.05) of outcomes after the surgical management of shoulder pathologies.

Conclusions and relevance The CSA is an effective radiographic parameter that is associated with rotator cuff tears and osteoarthritis. Lower CSAs (<30°) are associated with osteoarthritis, whereas higher CSAs (>35°) are associated with primary rotator cuff tears and re-tear after arthroscopic repair. Currently, there is a limited predictive value of the CSA in patient-reported outcomes after rotator cuff repair. The CSA is measured with high intrarater and inter-rater reliability for both plain radiographs and CT scans. Measuring the CSA using radiographs with the arm in the neutral rotation is currently recommended. Future studies are required to further investigate how best use the CSA to guide patient management and its predictive value.

Level of evidence IV.

INTRODUCTION

Rotator cuff tears and glenohumeral (GH) osteoarthritis are multifactorial shoulder pathologies associated with risk factors such as male sex, trauma, dominant arm and age. Studies have reported prevalence rates of up to 20.7% and 16.1% for rotator cuff tears and GH osteoarthritis, respectively. Rotator cuff tears and osteoarthritis often cause pain and disability (ie, weakness and decreased range of motion) and are more common among the elderly.

Various radiographic parameters associated with rotator cuff tears and osteoarthritis exist. First, the acromial index (AI) is the ratio between the distance from the glenoid plane to the lateral edge of the acromion, and the distance from the plane of the glenoid to the lateral edge of the humeral head. Smaller and larger AI values have been associated with osteoarthritis and rotator cuff tears, respectively. A small AI increases the compressive force component of the deltoid muscle force, thus, causing an increased load to be placed onto the GH joint. A large AI, on the other hand, increases the elevation component of the deltoid force, resulting in subacromial impingement and degenerative changes of the supraspinatus (SSP) tendon. Meanwhile, the glenoid inclination (GI) is the measure of superior tilt of the glenoid articular surface and has also been associated with rotator cuff tears and the risk of re-tear after repair.

What is already known

► The critical shoulder angle (CSA) is a relatively new radiographic parameter correlated with pathologies such as rotator cuff tears and osteoarthritis at abnormal values.

What are the new findings

► The CSA is measured with both intrarater/inter-rater reliability for both plain radiographs and CT scans.
► The CSA is associated with rotator cuff tears and osteoarthritis.
► Lower CSAs (<30°) are associated with osteoarthritis, whereas higher CSAs (>35°) are associated with primary rotator cuff tears and re-tear after arthroscopic repair.
► The CSA is not a significant independent predictor of outcomes after the management (ie, both non-operative and operative) of shoulder pathologies.
The critical shoulder angle (CSA) was first described in 2013 by Moor et al. It was hypothesised that the CSA would correlate with the wear of either the rotator cuff tendons or articular cartilage of the GH joint. Since its inception, the interest in CSA has been rapidly rising each year (figure 1). The CSA, which accounts for both the GI and the AI, is defined as the angle between the plane of the glenoid and the most inferolateral portion of the acromion (figure 2). Moor et al hypothesised that patients with an abnormal CSA would be correlated with the wear of either rotator cuff or the articular cartilage of the GH joint (osteoarthritis). Since then, studies have reported the association of CSA angles with biomechanical/morphological changes to the shoulder. One study determined an increased SSP load in individuals with a CSA of >38° compared with those with a CSA of 33°. With an increased CSA, there are substantial alterations in forces acting across the shoulder joint, namely decreased compressive forces and increased shear forces. Consequently, an SSP overload is induced, thus increasing the risk for rotator cuff tears.

Though studies have demonstrated a correlation between various CSAs and shoulder pathologies, no review exists confirming these preliminary results or determining whether this radiographic parameter is reliably measured among clinicians. Moreover, an apparent variation in imaging modality used to measure the CSA exists, with studies using either plain radiographs, CT scans or MRI. Hence, the purpose of this systematic review was to (1) determine the degree of correlation between the CSA and shoulder pathologies, (2) determine the reliability of measuring CSA between (inter-rater reliability) and within (intrarater reliability) clinicians, (3) assess the accuracy of different imaging modalities used for measuring the CSA and (4) determine the association of CSA with patient outcomes after surgery. It was hypothesised that (1) shoulder pathology would be more prevalent in those with smaller/larger CSAs than what is considered the normal range (30°–35°), (2) the CSA would be measured with high intra/inter-rater reliability, (3) the CSA would be most accurately and consistently measured via radiographs and (4) poorer clinical outcomes would be associated with these pathological CSAs.

METHODS

Search strategy and eligibility

One reviewer (NH) searched three online databases (PubMed, Embase and MEDLINE) for literature on the CSA from database inception to 7 March 2018. Broad search terms included ‘Critical’, ‘Shoulder’, ‘Angle’, ‘Acromion index’ and similar phrases (online supplementary appendix table 1). The search terms were also entered into Google Scholar, a search engine for scholarly literature from various disciplines and sources (eg, articles, theses, books and so on), to help ensure that relevant articles were not missed. References of included studies were also screened using the same systematic approach. The research question and inclusion and exclusion criteria were established a priori. Inclusion criteria were: (1) levels I–IV evidence; (2) male and female patients of all ages; (3) papers published in English; (4) studies on humans and at least one of the following: (1) studies reporting on the accuracy or prevalence of shoulder pathology in relation to the CSA; (2) studies reporting on inter-rater agreement of the CSA; and/or (3) studies comparing CSA measurements using different imaging modalities. The exclusion criteria were: (1) cadaveric/non-human studies and (2) studies where the outcomes for the exact same patient population were reported in multiple articles. In these cases, the most recent article was included and the study with the larger patient population was included.

Screening

Systematic screening in accordance with PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) was done in duplicate by two independent reviewers (GK and AS) from title to full-text screening stages. Discrepancies at the title and abstract stages were resolved by automatic inclusion to ensure that all relevant papers were not missed.

Data extraction

Two reviewers (GK and AS) abstracted data from included studies and recorded the results onto an Excel Spreadsheet designed a priori (Version 2007, Microsoft Co., Redmond, Washington, USA). Recorded data included demographics (eg, author, year of publication and study design), inter-rater agreement, imaging...
modality used and the association of the CSA with shoulder pathologies.

**Study quality assessment**

The Methodological Index for Non-Randomised Studies (MINORS) appraisal tool was used to assess the quality of the included, non-randomised studies (eg, case reports, case series, cohorts, etc.) by two reviewers (GK and AS). A score of 0, 1 or 2 is given for each of the 12 items on the MINORS checklist with a maximum score of 16 for non-comparative studies and 24 for comparative studies. To the authors’ knowledge, there is no evidence to categorise the MINORS score. Thus, methodological quality was categorised a priori as follows: a score of 0–8 or 0–12 was considered poor quality, 9–12 or 13–18 was considered fair quality, and 13–16 or 19–24 was considered excellent quality, for non-comparative and comparative studies, respectively.

**Statistical analysis**

A meta-analysis was not performed as there was high statistical and methodological heterogeneity among the studies and thus, results are summarised descriptively with no pooling of data. Descriptive statistics such as mean, range and measures of variance (eg, SD, 95% CIs)) are presented where applicable. A kappa (κ) statistic was used to evaluate inter-reviewer agreement at all screening stages. An intraclass correlation coefficient (ICC) was calculated for the quality assessment using the MINORS criteria. Agreement was categorised a priori as follows: κ/ICC of 0.81–0.99 was considered as excellent agreement; κ/ICC of 0.61 to 0.80 was substantial agreement; κ/ICC of 0.41–0.60 was moderate agreement; κ/ICC of 0.21–0.40 fair agreement, and a κ/ICC value of ≤0.20 was considered slight agreement.

**RESULTS**

**Eligibility**

The initial search yielded 500 studies of which 21 full-text articles met the inclusion criteria (figure 3). On reviewing references of included studies and a search on Google Scholar, 5 additional studies were retrieved from the references and included in the review for a total of 26 studies. Of the 26 included studies published between 2013 and 2018, there were 6 prospective cohorts, 7 retrospective cohorts, 6 case-controls, 3 cross-sectional studies and 4 case series (table 1).

**Study quality**

Majority of studies in this systematic review were of level III evidence (n=18; 69.2%) (table 1). There was excellent agreement
## Table 1  Study characteristics

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<th>Primary author</th>
<th>Year</th>
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*0–16 for non-comparative studies, 0–24 for comparative studies. LOE, level of evidence; NR, not reported.
between reviewers at the title (k=0.86; 95%CI 0.78 to 0.94) and the abstract (k=0.81; 95%CI 0.66 to 0.97) screening stages and perfect agreement at the full-text screening stage. The Mean MINORS score for non-comparative and comparative studies were 12.0±0.8 and 16.4±1.6, respectively, which indicates a fair quality of evidence for non-randomised studies. Overall, 28 studies had a clearly stated aim and endpoints appropriate to the aim of the study. However, only four studies reported the unbiased assessment of the study endpoint. There was an excellent agreement among the reviewers for the quality assessment using the MINORS criteria (ICC=0.980; 95%CI 0.955 to 0.991).

Patient characteristics
A total of 4563 patients (4640 shoulders) were included in this study. The mean total sample size per included study was 175.5 patients (range 30–724). Of these included participants, 38.7% were men, and had a mean age of 62.5±6.1; six studies did not specify sex distribution,19–24 whereas two studies did not report mean age for their patients.19–22 The CSA was assessed using plain radiographs (98.2%; n=4556), CT scans (3.1%; n=143) and MRI (0.6%; n=30) (table 1). Arm position during imaging assessments included neutral rotation (72.9%; n=3383), not reported (27.1%; n=1257), external rotation (2.3%; n=106), internal rotation (2.3%; n=106) and adduction (1.8%; n=84).

The CSAs association with shoulder pathologies and outcomes
Rotator cuff tears
A total of 13 studies (n=2796) determined that those with rotator cuff tears had significantly higher CSAs (p<0.05) compared with those with intact rotator cuff.8 14 22 23 25–33 Two studies (n=400) found a strong association between a CSA >35° and the presence of rotator cuff tears.8 30 Moreover, two studies (n=179) found a significant association between high CSAs (>38°) and the risk of re-tear following a rotator cuff repair (p<0.03).12 34 One study (n=46) determined that those without a satisfactory result postrotator cuff repair with latissimus dorsi transfer had a significantly higher CSA (p=0.005) than those with a satisfactory outcome.24 Similarly, in another study (n=307), those with a CSA <35° had significantly greater (p=0.04) pain reduction compared with those with a CSA >35° 1 month after subacromial injections19 (online supplementary appendix table 2).

Osteoarthritis
Meanwhile, seven studies (n=1895) investigated the association between CSA and osteoarthritis,8 10 14 27–29 33 Three studies (n=323) found that those with osteoarthritis had a significantly lower CSA (p<0.05).14 28 29 One study (n=500) reported a trend towards significance (OR=0.87 (95%CI 0.75 to 1.01); p=0.06) for the same association.27 One study (n=298) determined that of the patients with a CSA <30°, 93% had osteoarthritis.8 One study (n=724) determined that the OR for developing osteoarthritis in those with a CSA <30° was 2.25 (p=0.002).35 Lastly, one study (n=50) found no difference in mean CSA between patients with osteoarthritis versus those with massive rotator cuff tears40 (online supplementary appendix table 2).

Other pathologies
One study (n=500) found a significant association between the CSA and other shoulder pathologies such as impingement (OR=2.38 (95% CI 1.93 to 2.93); p<0.001) and rotator cuff tear arthropathy (OR=2.62 (95% CI 2.07 to 3.31); p<0.001).20 Lastly, one study (n=58) examining the relationship between the CSA and symptomatic glenoid erosion after shoulder hemiarthroplasty, found no significant difference (p=0.05) in CSA measurements between the study (ie, symptomatic glenoid erosion after anatomic hemiarthroplasty) and control (ie, no signs of symptomatic glenoid erosion) groups regardless of arm position (ie, neutral, external or internal rotations) during measurement44 (online supplementary appendix table 2).

Outcomes
Three studies (n=302) found the CSA to not be a significant predictor of patient-reported outcomes after arthroscopic rotator cuff repair.20 21 34 Lastly, one study (n=48), found no significant differences (p>0.05) of CSA values measured in various arm positions (ie, neutral, external or internal rotation), between patients diagnosed with secondary rotator cuff insufficiency after a shoulder replacement versus those who had the same procedure and were successful.37 (online supplementary appendix table 2).

Accuracy of imaging modality
Two studies (n=89) investigated the accuracy of different imaging modalities used for measuring the CSA.14 35 One study (n=59) compared radiograph with CT scans and found the results to be highly correlated (Spearman’s rho=0.974) with negligible inter-modality differences.14 The other study (n=30) compared radiographs with MRI and determined that CSA measurements from radiographs demonstrated excellent intrarater/inter-rater agreement, 0.909 (95%CI 0.818 to 0.956) and 0.869 (95% CI 0.776 to 0.930), respectively.14 Meanwhile, the intrarater/inter-rater agreement for MRIs was moderate, 0.534 (95% CI 0.221 to 0.747) and 0.622 (95% CI 0.427 to 0.780), respectively. There were no significant differences in CSAs measured by radiograph versus MRI in the rotator cuff tear and non-rotator cuff tear/ non-osteoarthriti pathology groups (p>0.05), whereas a significant difference was observed in the osteoarthriti group (p=0.01 (online supplementary appendix table 3).

Intrarater and inter-rater reliability
A total of 10 studies (n=2392) investigated the intrarater reliability in assessing the CSA.8 14 20 21 23 25 27 29 34 35 Of these studies, seven studies (n=1839) evaluated the intrarater reliability using an ICC.14 20 21 25 27 34 35 whereas the remaining three (n=553) used Bland-Altman plots.23 29 Overall, a high intrarater reliability was found when using radiographs from seven studies (ICC range 0.903–0.996),14 20 21 23 25 27 29 34 35 and a moderate intrarater reliability was found in MRIs from one study (ICC=0.534, 95%CI 0.221 to 0.746), respectively.14 Lastly, studies evaluating intrarater reliability using Bland-Altman plots via radiographs reported agreement that was either with excellent minimal bias or equally reproducible (for both an expert and less experienced rater).23 29

Meanwhile, a total of 20 studies (n=4181) investigated the inter-rater reliability in assessing the CSA.8 14 15 19 22 23 27–31 33–38 39

Inter-rater reliability was assessed using an ICC in 16 studies (n=3021),14 15 19–22 25 27 28 30 31 34–38 Bland-Altman plots in 4 studies (n=1160),8 23 29 33 and also the κ (0.91) in 1 study (n=307).19 Overall, inter-rater reliability among radiographs (ICC range 0.869–0.980) and CT scans (ICC=0.989) was high,44 whereas inter-rater reliability with MRIs was moderate (ICC=0.622, 95% CI 0.427 to 0.780).44 Lastly, studies evaluating inter-rater reliability using Bland-Altman plots via radiographs reported agreement that was excellent with little or no bias (online supplementary appendix table 4).8 23 29 33

DISCUSSION

Key findings

The key findings of this systematic review were that the CSA is a useful radiographic parameter that is associated with various shoulder pathologies. More specifically, CSAs of lesser magnitude are associated with osteoarthritis, whereas CSA values of greater magnitude are associated with primary rotator cuff tears and re-tears following repair. Possible CSA measurement thresholds to identify patients with rotator cuff tears and osteoarthritis are >35° and <30°, respectively. Meanwhile, the CSA has an overall high intrarater and inter-rater reliability that is sustained even when measured among patients with varying shoulder pathology (e.g., rotator cuff tears, osteoarthritis, impingement and so on) and with different imaging modalities. Radiographs and CT scans were found to produce higher intrarater and inter-rater reliability compared with MRIs. However, there were very few studies which compared these statistics among the various imaging modalities. Lastly, the CSA is not a significant predictor of outcomes after surgery.

The CSA is associated with various shoulder pathologies such as osteoarthritis and rotator cuff tears. More specifically, smaller and larger CSAs are associated with osteoarthritis and rotator cuff tears, respectively. In healthy patients, the proposed mean CSA is around 33°, in which the resulting force vector of the deltoid muscle is more balanced on the glenoid surface. However, with larger CSAs, the resulting force vector of the deltoid is directed upwards against the rotator cuff, leading to degenerative cuff tears. In contrast, smaller CSAs produce a resulting vector force of the deltoid that is unbalanced against the glenoid and thus, increasing the risk for the development of concentric osteoarthritis. Though our findings suggest that the CSA can be associated with other pathologies such as impingement and is not associated with glenoid erosion after hemiarthroplasty, further research is warranted to ascertain these results and to determine the mechanism through which they develop.

The included studies showed high agreement between raters when measuring the CSA. Moreover, high agreement was sustained across various groups of patients with pathologies such as rotator cuff tears, repaired rotator cuff tears, adhesive capsulitis, cuff tear arthropathy, impingement, tendinitis calcarea, those without rotator cuff tears and re-tears following repair. Possible CSA measurement thresholds to identify patients with rotator cuff tears and osteoarthritis, respectively, are >35° and <30°, respectively. Meanwhile, the CSA has an overall high intrarater and inter-rater reliability that is sustained even when measured among patients with varying shoulder pathology (e.g., rotator cuff tears, osteoarthritis, impingement and so on) and with different imaging modalities. Radiographs and CT scans were found to produce higher intrarater and inter-rater reliability compared with MRIs. However, there were very few studies which compared these statistics among the various imaging modalities. Lastly, the CSA is not a significant predictor of outcomes after surgery.

In this systematic review, the CSA was measured with both a high intrarater and inter-rater reliability when using radiographs and CT scans; however, the contrary was true for MRIs. Many factors exist to explain this low intrarater and inter-rater reliability of the CSA when measured by MRIs. First, Speigl et al attribute the high variabilities in inter-rater and intrarater reliabilities in measuring the CSA on MRI as a result of the landmarks required to measure the CSA (e.g., inferior glenoid margin and lateral acromial margin) being found on different slices that are oblique to each other in the anterior-to-posterior axis. Moreover, raters may find measuring the CSA in patients with osteoarthritis to be difficult as the upper and lower borders of the glenoid can be more difficult to define in such cases; however, this is not necessarily specific to MRI. Lastly, MRIs are frequently associated with displaying variations in the definitions of cartilage contours and bony edges, thus possibly leading to low reliability of measuring the CSA on MRIs. Though theoretical advantages in using CT scans over radiographs exist, such as the implementation of the third dimension, high resolution of bony structures and cross-sectional images where the exact landmarks are defined, the differences between tomography and radiographs in measuring the CSA are negligible. However, CT scans come with the disadvantages of increased cost and radiation exposure.

In addition to the specific imaging tool used to measure the CSA, the specific radiographic view and the positioning of the scapula are also important. In the original study first introducing the concept of the CSA, authors reported variability of ≤2° in measuring the CSA with malrotations of the scapula of up to 20° of internal rotation or extension and 20° of external rotation or flexion. In a biomechanical study of 68 non-pathological cadaver shoulders, the authors found that the radiographic alignment of the scapula in anteversion and retroversion can yield highly inaccurate measurements of the CSA. More specifically, a 5°–8° change in viewing perspective can result in a 2° change in CSA. Henceforth, given the small range of non-pathological CSA values (30°–35°), clinicians must be careful to have appropriate shoulder/scapula positioning in order to avoid significant miscalculations of the CSA.

Based off of the results, the authors of this review recommend using the CSA as a diagnostic tool measured through radiographs to accurately detect the presence of shoulder pathologies, such as osteoarthritis and rotator cuff tears. We recommend the use of plain radiographs to measure the CSA over CT scans due to their decreased radiation exposure and cost. Although the majority of patients were measured for their CSA while having their arm in the neutral rotation, it is difficult to recommend its routine use given the lack of comparative studies with large sample sizes to ascertain these preliminary findings. Moreover, we recommend the thresholds of >35° and <30° to identify patients with rotator cuff tears and osteoarthritis, respectively. This suggestion should be taken with caution given the limited available evidence to classify these pathologies under certain CSA thresholds. The threshold of 38° can also be used to determine the risk of re-tear after rotator cuff repair. The CSA alone, however, cannot be used as a predictor of patient-reported outcomes after arthroscopic repair based on preliminary evidence. Though less favourable outcomes after arthroscopic rotator cuff repair are predicted in patients with larger CSAs due to the increased force placed onto the rotator cuff and the superior translation of the humeral head, the findings of this review are inconclusive of this notion based off of the included studies (mean follow-up 46.2±87.0 months).

Lastly, surgeons opting to perform an arthroscopic rotator cuff repair on patients with high CSAs may consider the use of a lateral acromioplasty in the future as studies verify that a higher CSA (>38°) is significantly associated with the risk of re-tear. In a prospective study of 49 patients (mean age 56 years, mean follow-up 30 months), it was found that reported improvements in patient-reported outcomes have no effects on the deltoid muscle origin, after arthroscopic alteration of the CSA. A biomechanical study has identified that with a smaller CSA, the load from the SSP is transferred to the deltoid, thus theoretically
protecting the SSP and generating increased abduction power with the more effective use of the deltoid.\textsuperscript{41} It is also suggested that the risk of primary rotator cuff tears or even re-tears after rotator cuff repair can potentially be reduced when combining an arthroscopic anterolateral acromioplasty with an arthroscopic lateral acromion resection to significantly reduce the CSA, the favourable range of 30° to 35°.\textsuperscript{41} Though there are theoretical advantages, studies investigating the use of an anterolateral acromioplasty have demonstrated that there are no differences in clinical outcomes after rotator cuff repair with or without this adjunct procedure.\textsuperscript{42,41}

**Strengths**

The strengths of this systematic review stem from the rigorous methodology employed throughout its preparation. First, a systematic screening approach was employed in duplicate minimised reviewer bias. There was also excellent agreement between the two reviewers at all screening stages and quality assessment. Moreover, an expansive search strategy and inclusion criteria ensured that all relevant articles were included in this review. Lastly, this systematic review consisted of numerous studies with moderate to large sample sizes, resulting in an overall large sample size.

**Limitations**

This review was primarily limited by the quality of evidence available. The majority of included studies were level III evidence. Moreover, the high statistical and methodological heterogeneity among included studies precluded a meta-analysis. Characteristics of the studies contributing to this heterogeneity included variations in study design, sample size, reporting of outcomes and included patient populations/controls. Also, there was an inconsistent use/reporting of outcomes across included studies, thus limiting the ability to determine the effectiveness of the CSA to accurately predict patient-important outcomes.

**Future directions**

Future studies should be directed towards gaining a better understanding on how to use the CSA to guide management and possibly the screening of patients with shoulder pathologies. Possible elements for further investigation are arm position during radiographic assessment and determining the association of various CSA values with patient-reported outcomes after surgery (eg, rotator cuff repair or shoulder replacement). Furthermore, future studies are required to better define accurate ranges of pathological/non-pathological CSA values and the measurement error to which a patient’s CSA is susceptible to. Lastly, future studies should determine the mechanism through which shoulder pathologies such as tendinitis calcarea, impingement and so on develop as a result of variations in CSAs.

**CONCLUSION**

The CSA is an effective radiographic parameter that is associated with rotator cuff tears and osteoarthritis. Lower CSAs (<30°) are associated with osteoarthritis, whereas higher CSAs (>35°) are associated with primary rotator cuff tears and re-tear after arthroscopic repair. Currently, there is limited predictive value of the CSA in patient-reported outcomes after rotator cuff repair. The CSA is measured with high intrarater and inter-rater reliability for both radiographs and CT scans. Measuring the radiographs using radiographs with the arm in the neutral rotation is currently recommended. Future studies are required to further investigate how best use the CSA to guide patient management and its predictive value.

**Contributors**

GNK, AS and NSH: carried out the search, screening process, assessment of study quality, completed the data abstraction. GNK: drafted the manuscript with assistance from AS, NSH, SE and EC. ORA and NSH: conceived the study, and provided key expert input and editing throughout the process. NS: provided feedback on methodological and statistical aspects. All authors read and approved the final manuscript.

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