# Original Article

# Influence of Radiographic Parameters on Reduction of the Critical Shoulder Angle With Arthroscopic Lateral Acromioplasty—A Mathematical Model

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**Objectives:** To develop a mathematical model for the preoperative planning of arthroscopic lateral acromioplasty (ALA) and to evaluate the role of radiographic parameters with regards to the critical shoulder angle (CSA). **Methods:** Anteroposterior (AP) radiographs of patients who underwent rotator cuff surgery were screened to identify true AP radiographs. Radiographs were assessed for (1) native CSA, (2) CSA after simulated resection of a spur if present, (3) amount of ALA necessary to achieve a CSA of 34°, (4) CSA after 5-mm ALA, (5) lateral acromion angle, (6) acromion index, and (7) sclerosis of the greater tuberosity. **Results:** A total of 1191 radiographs were screened. Of the 124 patients included, the native CSA was large (≥35°) in 56 patients (45%). In 30 patients (24%), a subacromial spur was detected and resection reduced the CSA by a median of 2°. Spur resection alone reduced the CSA to ≤34° in 19 patients (15.3%). Mean amount of ALA to achieve a CSA of 34° was 3.9 ± 1.8 mm, and this value strongly correlated with the CSA before ALA (R = 0.88, $P < .001$). The linear regression model to determine the amount of ALA to achieve a CSA of 34° was as follows: *Required ALA in mm* $= -39.120 + 1.165 * CSA_{native}$ The multiple $R^2$ for this model was 0.777. Mean reduction of CSA by 5-mm ALA was 3.8 ± 0.8° and 75% of large CSAs were reduced to a CSA of 30-34°. The acromion index had no significant independent influence on the model ($P = .427$), whereas lateral acromion angle was an independently significant predictor of required ALA to achieve a CSA of 34° ($P = .019$). Sclerosis of the greater tuberosity was significantly associated with a CSA of 35° or greater ($P = .003$). **Conclusions:** The amount of ALA needed to reduce a large CSA to 34° correlates with the CSA before ALA and can preoperatively be planned with the use of a simple equation. **Level of Evidence:** Level III; cross-sectional design; epidemiology study.

**B**ony scapular morphology has shown association with degenerative rotator cuff tears (RCTs), and various study groups have investigated different measuring techniques.[1-3] A large lateral extension of the acromion as measured by the acromion index (AI), an increased slope of the acromion in the frontal plane as measured by the lateral acromion angle (LAA), and an upwardly tilted glenoid were found to play an important role in full-thickness RCTs (Fig 1).[1,3,4]

The critical shoulder angle (CSA) combines the AI and glenoid inclination and is measured by a line connecting the inferior and superior bony margins of the glenoid and a line connecting the inferior bony margin of the glenoid with the most inferolateral part of the acromion (Fig 1).[2] The CSA is best measured on true anteroposterior (AP) radiographs[5]; however, magnetic resonance imaging and computed tomography also are reliable assessment tools.[6,7]

Whereas a normal CSA is considered to range from 30° to 34°, an angle of ≥35° has shown association with RCTs[7-11] and an angle below 30° has shown association with osteoarthritis.[2,7,10,11] Moor et al.[2] postulated that a CSA >35° may be associated with RCTs, as a long acromion would lead to an antagonistic direction of pull of the deltoid muscle compared with the supraspinatus muscle. In addition, Gerber et al.[12] found that a larger CSA would increase the ratio of joint shear-to-compression force, therefore necessitating an increased supraspinatus load. Furthermore, a large CSA may be associated with a greater retear rate following rotator cuff repair.[13,14] Thus, reduction of a large CSA to a "favorable" range of 30° to 34° may potentially prevent progression of rotator cuff tears or protect rotator cuff repair from re-tear.[15] Furthermore, subacromial spurs and sclerosis of the greater tuberosity are commonly encountered in shoulders with rotator cuff tears.[16-18] A subacromial osteophyte may enlarge the CSA and should therefore be included in measurement and therapy.

Recently, arthroscopic lateral acromioplasty (ALA) was found to effectively reduce the CSA without violating the acromial deltoid origin following resection of up to 10 mm.[19,20] More specifically, an ALA of 5 mm has been demonstrated to reduce the CSA to 35° or less in more than 90% of cases.[21] However, in patients with a very large CSA (≥38°), the recommended amount of 5 mm ALA may not reduce the CSA to a favorable range.[21,22] Conversely, in patients with a CSA on the lower end of this range, ALA of 5 mm could lead to overcorrection of the CSA. Thus, it would be beneficial to have a tool that helps in preoperative planning to individually calculate the amount of resection needed to achieve a CSA that is in the favorable range. The purposes of this study were to develop a mathematical model for preoperative planning of ALA and to evaluate the role of radiographic parameters with regards to the CSA.

## Methods

This research was approved by a local institutional review board (Vail Health Hospital IRB, Protocol #2020-17). A total of 1191 preoperative shoulder AP radiographs of patients who underwent primary arthroscopic rotator cuff surgery at our institution (P.J.M.) between December 2007 to March 2016 were screened. Calibrated true AP radiographs[7,14] with fully visible glenohumeral and subacromial joint spaces, and the coracoid tip projected on superomedial quadrant of the humeral head were included (type A according to the Suter−Henninger classification system) (Fig 2).[5] Duplicated studies, patients with a history of previous shoulder surgery, and patients with previous fracture of the proximal humerus or scapula were excluded.

### Radiographic Assessment

The medical imaging program Merge PACS (IBM Corp., Armonk, NY) was used for radiographic measurements. One fellowship-trained orthopaedic surgeon (J.C.K.) evaluated the preoperative radiographs in the coronal plane. Measurements were only taken once, as intra- and interrater reliability for the CSA have been shown to be good to excellent.[2,8,11] Radiographs were assessed for (1) the native CSA (Fig 1),[2] (2) the CSA after theoretical resection of a spur if present (Fig 3), (3) the amount of ALA necessary to achieve a CSA of 34°, which is the upper limit of the favorable zone (Fig 4),[15] (4) the CSA after simulated 5mm ALA representing the clinically recommended amount (Fig 4),[21] (5) the LAA (Fig 1)[1], (6) the AI (Fig 1),[3] and (7) the existence of sclerosis of the greater tuberosity and/or subacromial spurs (Figs 2 and 3). According to Oh et al.,[23] heel-type, traction-type, and bird beak-types were included.

### Statistical Analysis

Simple and multiple linear regression were performed to predict the ALA amount required to achieve a postoperative CSA less than 35° as a function of the preoperative (native) CSA. The multipredictor model was built to adjust for LAA and AI while estimating the independent effect of preoperative CSA on the required ALA resection. The explanatory power of the regression models was assessed using the R-squared statistic. Both a confidence interval for the regression fit and a prediction interval for individual shoulders were presented graphically. Residual diagnostics were assessed to ensure model fit and that model assumptions were satisfied. Association between binary variables was assessed using the Fisher exact test, whereas association between continuous covariates was assessed using Pearson's correlation. $P$ values <.05 were interpreted as statistically significant. All statistical analysis and plots were produced using the statistical programming language R, version 4.0.0.[24]

## Results

High-quality calibrated true AP radiographs of 124 patients (124 shoulders; 86 men and 38 women) with a mean age of 57.7 years (range, 25-78 years) were included in the radiographic analysis. The mean CSA was 33.9° (range, 25°-43°) and was 35° or greater in 56 patients (45%). In 24% of patients (n = 30) a subacromial spur was detected (Fig 3). Sclerosis of the greater tuberosity was observed in 56 patients (45%) (Fig 2). Summaries of demographic and radiographic characteristics are presented in Table 1.

The simulated resection of the subacromial spur reduced the CSA by a median of 2° (range, 1-4°) among 30 patients (24.2%) where a subacromial spur was found (Fig 3). Spur resection alone was sufficient to
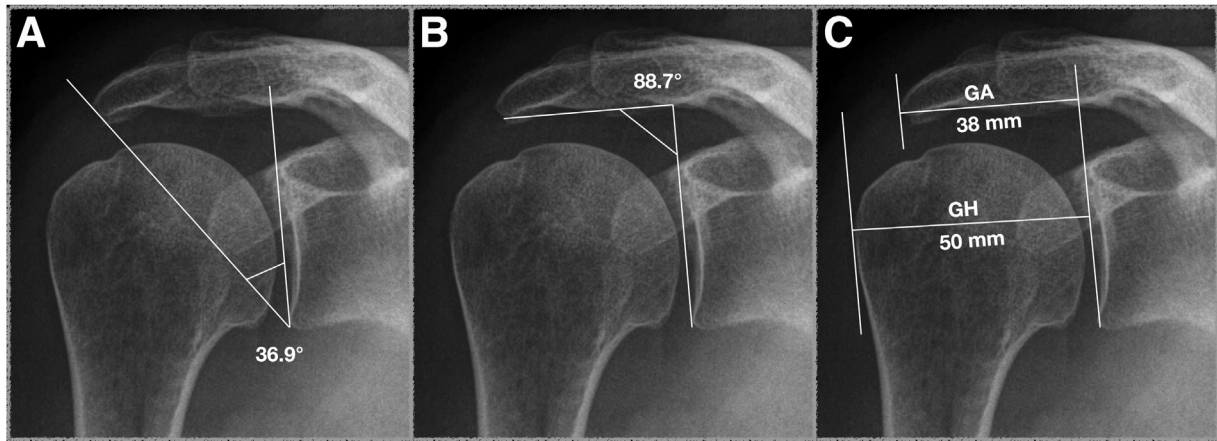
**Fig 1.** Illustration of measurement techniques for the CSA, LAA, and AI. (A) The CSA is measured by a line connecting the inferior and superior bony margins of the glenoid and a line connecting the inferior bony margin of the glenoid with the most inferolateral part of the acromion. In this case, the CSA is 36.9°. (B) The LAA is formed by the intersection of a line parallel to the undersurface of the acromion and a line connecting the inferior and superior bony margins of the glenoid. In this case the LAA is 88.7°. (C) The AI is measured by the distance between glenoid and lateral acromion (GA) divided by distance between glenoid and lateral humerus (GH). In this case the AI is 0.76 (AI = 38 mm/50 mm = 0.76). (AI, acromion index; CSA, critical shoulder angle; LAA, lateral acromion angle.)
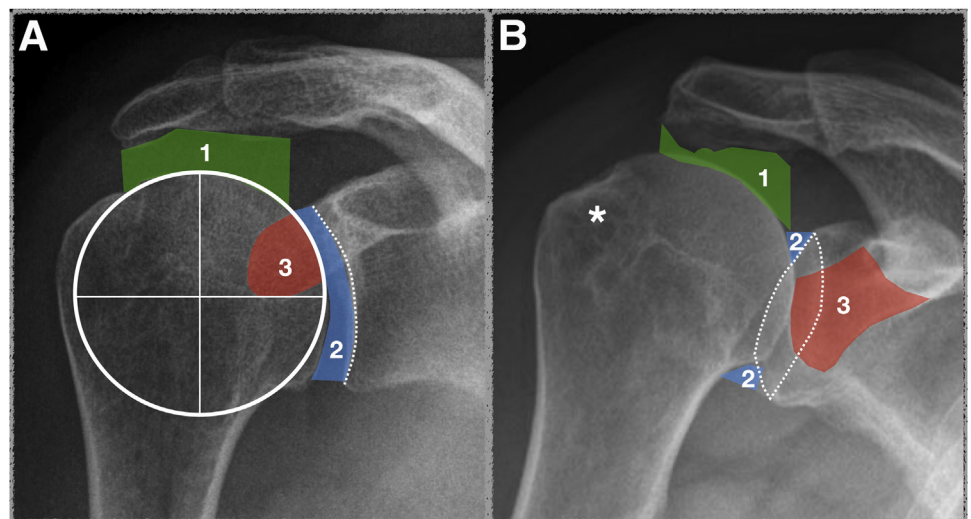
reduce the CSA to $\leq 34°$ in 19 patients (15.3%). The mean amount of ALA needed to achieve a CSA of 34° was 3.9 ± 1.8 mm, and this value strongly correlated with the CSA before ALA (R = 0.88, $P < .001$; Fig 5, Table 2). The linear regression model to determine required amount of ALA to achieve a CSA of 34° was

*Required ALA in mm = $- 39.120 + 1.165 * CSA_{native}$*

The multiple $R^2$ for this model was 0.777, indicating that nearly 78% of the variation in required lateral acromioplasty amount is explained by preoperative CSA. The mean reduction of the CSA by a simulated

5-mm ALA was 3.8 ± 0.8° and 75% of large CSAs were reduced to the favorable CSA range by 5mm ALA (Fig 4). When we adjusted for native CSA, the LAA (mean 80°; range 67-94°) was also an independently significant predictor of required ALA to achieve a CSA of 34° ($P = .019$) (Fig 1). However, this expanded model achieved only a marginally improved R-squared value of 0.805 compared with the single covariate regression model and thus did not add substantially to the clinical relevance of the model. Meanwhile, AI had no significant independent influence on the model ($P = .427$) (Fig 1).

**Fig 2.** Inclusion and exclusion criteria for AP radiographs. (A) Included true AP radiograph. (1) Fully visible subacromial and (2) glenohumeral joint spaces, and the (3) coracoid tip projected on superomedial quadrant of the humeral head. Dotted area represents the anterior and posterior glenoid rims which are overlapping. (B) Excluded radiograph. (1) Subacromial and (2) glenohumeral joint spaces not fully visible, and the (3) coracoid tip not projected on superomedial quadrant of the humeral head. Dotted area represents the anterior and posterior glenoid rims which are not overlapping suggesting that this radiograph is not true AP. Asterisk indicates sclerosis of greater tuberosity. (AP, anteroposterior.)
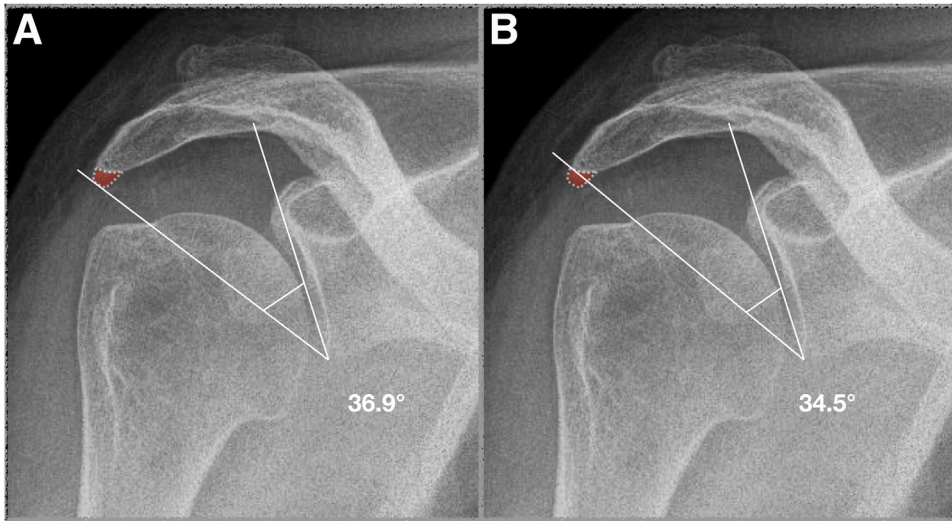
**Fig 3.** Effect of spur resection on CSA. (A) The native CSA with a traction-type spur (dotted area) is 36.9°. (B) Simulated resection of the spur (dotted area) results in a CSA of 34.5°. (CSA, critical shoulder angle.)

Sclerosis of the greater tuberosity was significantly associated with a CSA of 35° or larger (odds ratio 3.22, 95% confidence interval 1.41-7.55, $P = .003$) (Fig 2).

## Discussion

The most important finding of this study was that the amount of ALA needed to reduce a large CSA to 34° ($3.9 \pm 1.8$ mm) strongly correlates with the CSA before ALA and can preoperatively be planned on a true AP radiograph by using a simple equation with minimal uncertainty. This finding could potentially aid surgeons in preoperative planning of ALA. In addition, the presence of a subacromial spur increased the CSA and sclerosis of the greater tuberosity was significantly associated with a CSA of ≥35°.

Bony morphology of the scapula has long been suspected to play an important role in the pathogenesis of

RCTs.[16,25] Numerous measuring techniques have been introduced, with the goal to show association with rotator cuff pathology.[1-4] The CSA described by Moor et al.[2] has received a great deal of scientific attention since it was introduced in 2013. By combining the lateral extension of the acromion[3] and glenoid inclination,[4] both of which individually have been shown to be associated with RCTs, the CSA is potentially superior to previous measurements.[7,11]

A large CSA is considered to be 35° or greater and has shown association with rotator cuff tears,[7-11] whereas a small CSA lower than 30° has shown association with osteoarthritis.[2,7,11] When performing rotator cuff repair, an ALA may be considered to reduce the CSA to protect the repair from retear. Gerber et al.[14] have demonstrated that ALA is a safe adjunct to rotator cuff repair and that the CSA should be reduced to 33° or less to avoid retears in patients with large CSAs. This is in
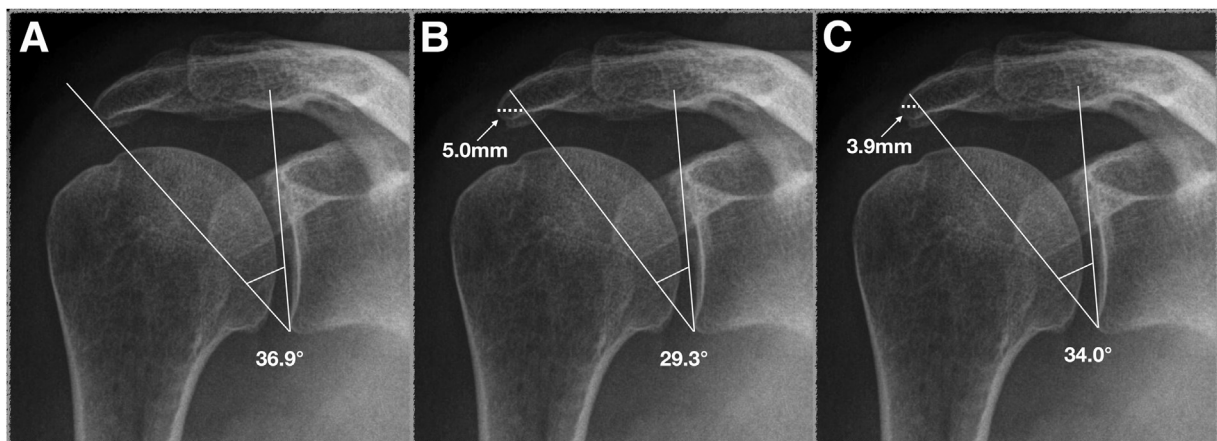


**Fig 4.** Simulated lateral acromioplasty. (A) Native CSA. (B) The CSA is reduced to 29.3° after 5 mm (dotted line) of simulated lateral acromioplasty. (C) Simulated lateral acromioplasty of 3.9 mm (dotted line) was necessary to reduce the CSA from 36.9° to 34.0°. (CSA, critical shoulder angle.)

**Table 1.** Patient Characteristics

| Variable | |
| --- | --- |
| N | 124 |
| Male, n (%) | 86 (69.4) |
| Age, y, mean (range) | 57.7 (25-78) |
| CSA, ° mean (range) | 33.9 (25-43) |
| CSA ≥35°, n (%) | 56 (45) |
| Native CSA among patients with CSA ≥35°, median (range) | 37 (35-43) |
| Greater tuberosity sclerosis, n (%) | 56 (45) |
| Subacromial spur, n (%) | 30 (24) |

CSA, critical shoulder angle.

line with a recent systematic review that has demonstrated that there may be an association of a greater CSA with retears.[13] However, indications for ALA do not only involve rotator cuff repair: Katthagen and Millett[15] suggested that ALA should be considered for patients with a CSA >38° if the rotator cuff is at risk (severe tendinopathy or partial-thickness tears >50%) when operatively treating subacromial impingement syndrome.

Although performing ALA to reduce the CSA to a favorable range is often supported, there remains a paucity on how much of the lateral acromion to resect. One of the main concerns is that the deltoid insertion might be injured, thus leading to weakness and/or rupture. Gerber et al.[14] resected 3 to 8mm of the lateral acromion in 49 shoulders to achieve a favorable CSA according to the preoperative measurement. No significant damage to the deltoid insertion was found in their investigation. Katthagen et al.[19] showed, that a lateral acromion resection of 5mm significantly reduces the CSA and did not damage the deltoid origin. These findings were supported by Marchetti et al.[20] who demonstrated that ALA of up to 10 mm neither reduced the deltoid's failure load nor did any macroscopic changes occur. Our findings that a mean ALA of 3.9 ± 1.8 mm is needed to achieve a favorable CSA of 34° can therefore be considered safe in the light of previous research. According to our equation, only a CSA of ≥43° would lead to a potentially critical ALA over 10 mm. In this case, we believe, that it should be carefully evaluated whether an ALA of more than 10 mm is necessary and outweighs the risks of injury to the deltoid insertion. However, a CSA of this magnitude is rather uncommon.

Our second finding was, that subacromial spurs increased the CSA by a median of 2° and the resection of theses spurs alone was sufficient to reduce the CSA to the favorable range of 30 to 35° in some cases. Subacromial spurs have been previously shown to be associated with RCTs.[17,18] Ogawa et al.[17] observed 69% of large spurs in cases with bursal-sided tears, complete tears of the supraspinatus and massive rotator cuff

tears. Similarly, Oh et al.[23] found a relationship between subacromial osteophytes and full-thickness rotator cuff tears, such that subacromial spurs were found in 78% of patients with full-thickness tears, as opposed to only 58% in the control group. A potential reason for the quantitative differences compared to our study is that Oh et al.[23] also used images in the sagittal plane (e.g., sagittal magnetic resonance imaging/supraspinatus outlet view) therefore identifying spurs that we were not able to detect in coronal plane (AP) radiographs. One of the early studies to investigate subacromial spurs in relationship to the CSA proposed that RCTs were affected more by osteophytes than by the CSA when evaluated together as risk factor.[18] In cases with a high CSA of more than 38°, patients without an osteophyte had RCTs in 76.9% and patients with an osteophyte had RCTs in 92.3% of cases.[18] However, this study did not explicitly state if the CSA was measured with or without including the subacromial spur. In the present study a subacromial spur, if present, was included in the CSA measurement and its resection may be sufficient to correct the CSA to favorable values. However, if the spur is not included in the CSA measurement and ALA is planned according to the CSA, this could potentially lead to under-resection intraoperatively.

Interestingly, we found that sclerosis of the greater tuberosity was identified as indicator for a large CSA. In
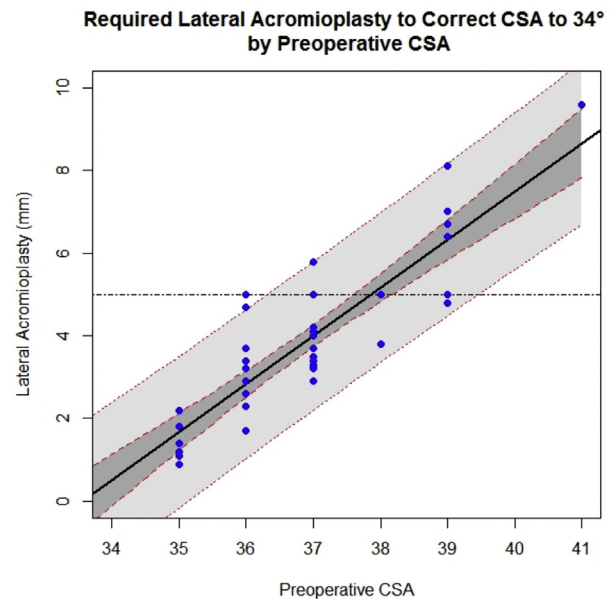


**Fig 5.** Relationship between the CSA and amount of arthroscopic lateral acromioplasty required to achieve a CSA of 34°. The solid black line represents linear regression fit while the dark gray region denotes the 95% confidence interval for the regression line and the light gray region denotes the 95% prediction interval for individual patients. (CSA, critical shoulder angle.)

**Table 2.** Required Resection of the Lateral Acromion According to the Native CSA to Achieve a CSA of 34°

| Native CSA, ° | Required Resection, mm |
| --- | --- |
| 36 | 2.82 |
| 37 | 3.985 |
| 38 | 5.15 |
| 39 | 6.315 |
| 40 | 7.48 |

CSA, critical shoulder angle.

shoulders with a large CSA, sclerosis may be the result of mechanical conflict between acromion and greater tuberosity. If this radiographic parameter is encountered, one should think of a large CSA that may require treatment in the setting of RCT.

### Limitations

We recognize that our study has some weaknesses. First, a limitation of the CSA itself is that it does not consider the morphology of the humeral head and the greater tuberosity. The CSA is also dependent on true AP radiographs, and even slight changes in scapula alignment can lead to a variability in CSA.[5] For this reason, computed tomography scans may have been more accurate. However, we tried to minimize this potential conflict by only using true AP shoulder radiographs with fully visible glenohumeral and subacromial joint spaces, and the coracoid tip projected on superomedial quadrant of the humeral head. Second, the measurements of the CSA were only taken once by an orthopaedic surgeon, and we did not evaluate for intra- and interrater reliability. However, we believe that this was not necessary, as it has been demonstrated numerous times that the CSA shows good to excellent intra- and interrater reliability.[2,8,11] Third, there may be a selection bias as we have only used true AP radiographs (124 of 1191 patients) for CSA measurement according to the criteria described above. Therefore, we might have not included some patients with a large CSA who did not have adequate radiographs. Fourth, the ALA was performed virtually only. This is why we cannot state with certainty that the recommended virtual resection would equally translate to the desired postoperative CSA in the clinical setting or to improvements in postoperative patient outcomes.

### Conclusions

The amount of ALA needed to reduce a large CSA to 34° correlates with the CSA before ALA and can preoperatively be planned with the use of a simple equation.

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