



# Radiographs Are Comparable With 3-Dimensional Computed Tomography-Based Models as a Modality for the Preoperative Planning of the Arthroscopic Lateral Acromioplasty: A Retrospective Comparative Study

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**Purpose:** To compare plain radiographs with 3-dimensional (3D) computed tomography (CT) data for preoperative planning of arthroscopic lateral acromioplasty (ALA) for patients in whom ALA was performed along with arthroscopic rotator cuff repair (ARCR). **Methods:** Patients older than 25 years old who underwent ALA along with ARCR in our institution between October 2019 and February 2021 were included in this study. Preoperative ALA simulations were performed on plain radiographs and 3D models based on CT data. The critical shoulder angle (CSA) was compared between simulations based on radiographs and those based on 3D models. The ALA procedure was performed using the 3D model simulation, along with ARCR. The CSA after surgery was investigated using radiographs. **Results:** We evaluated 11 shoulders in 10 patients. There was no significant difference between the mean preoperative CSA on radiographs and 3D models ( $38.0^\circ \pm 2.6^\circ$  vs  $38.6^\circ \pm 1.8^\circ$ , respectively;  $P = .55$ ). The mean CSA after 4-mm ALA simulation using radiographs was not significantly different to that using 3D models ( $34.1^\circ \pm 2.6^\circ$  vs  $34.3^\circ \pm 2.5^\circ$ , respectively;  $P = .84$ ). Four cases (36.4%) required 8-mm ALA to reduce the CSA to  $<35^\circ$  on radiographic analysis, and 2 (18.2%) required 8-mm ALA on 3D model analysis. The mean CSA on postoperative radiographs was significantly smaller than that on preoperative radiographs ( $32.1^\circ \pm 2.7^\circ$  vs  $38.0^\circ \pm 2.6^\circ$ , respectively;  $P < .01$ ). **Conclusions:** There was no significant difference between the mean CSA after a 4-mm ALA simulation using radiographs and that using 3D models based on preoperative CT data, which suggests that radiographs are comparable with 3D CT data models as a reliable modality for the preoperative simulation of ALA. **Level of Evidence:** III, retrospective comparative study.

Arthroscopic rotator cuff repair (ARCR) is a widely used procedure for treating rotator cuff tear (RCT).<sup>1</sup> However, a relatively high rate of retear after

ARCR is reported (13%-27%),<sup>2-4</sup> and retear after ARCR therefore remains an unsolved issue with ARCR.

The critical shoulder angle (CSA) is a radiologic parameter that combines the extent of the lateral extension of the acromion and the inclination of the glenoid, and was first advocated by Moor et al.<sup>5</sup> Previous studies reported that a large CSA is associated with development of RCT<sup>5-9</sup> and a high retear rate after ARCR.<sup>10-12</sup> A previous biomechanical study revealed that a large CSA destabilized the glenohumeral joint and charged the supraspinatus tendon with additional load during arm abduction.<sup>13</sup>

Arthroscopic lateral acromioplasty (ALA) has been proposed as a procedure for reducing the CSA and the load on the supraspinatus tendon after ARCR, which may improve the integrity of the post-ARCR supraspinatus tendon. However, the full procedure for performing ALA in the clinical setting, including

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preoperative planning, has not yet been established.<sup>14,15</sup>

Plain radiographs could be suitable for the preoperative planning of ALA because the CSA is a parameter that was originally measured on the anteroposterior view of the shoulder joint radiograph,<sup>5</sup> and a preoperative plain radiograph is usually obtained as a matter of routine. However, it is difficult to obtain radiograph images that allow the precise measurement of CSA.<sup>16</sup> In contrast, computed tomography (CT) may be superior to radiographs for obtaining detailed morphologic information of the bone. On the basis of this possible superiority, previous studies used CT data to analyze the detailed anatomy of the scapula and to measure the CSA.<sup>17-20</sup> Moreover, CT data allow for a 3-dimensional (3D) software model to be created, which allows 3D simulation and analysis. Therefore, we performed ALA along with ARCR in patients with a relatively large CSA using preoperative planning based on a 3D model.

An important clinical question is whether there is a discrepancy between preoperative planning performed using radiographs and that performed using a 3D model. The purpose of this study was to compare plain radiographs with 3D CT data for preoperative planning of ALA for patients in whom ALA was performed along with ARCR. We hypothesized that the results of preoperative planning using radiographs and 3D simulations would be comparable.

## Methods

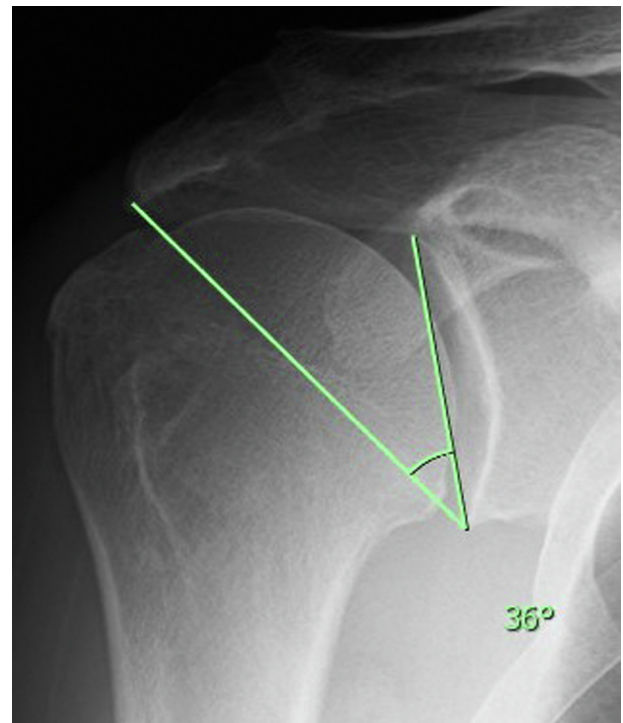
Our institutional review board approved this study (no. B201200081).

### Patient Inclusion

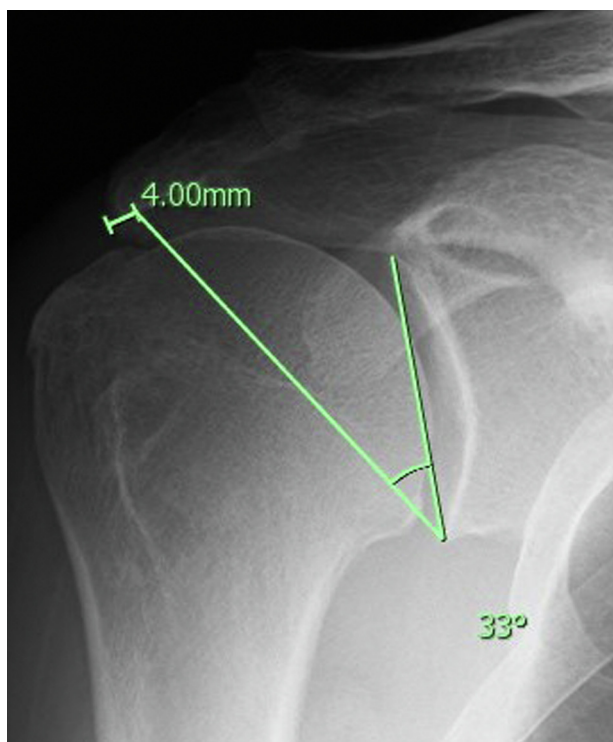
The shoulders of patients of more than 25 years old (because the epiphyseal line of the acromion closes around 25 years) who underwent ALA along with ARCR at our institution between October 2019 and February 2021 were identified. Patients were diagnosed with RCT using 1.5- or 3.0-T MRI and the indication for ARCR was unmanageable pain or functional disability despite conservative treatment for more than 3 months. Preoperative CT examination was performed using Aquilion ONE / GENESIS Edition (Canon Medical Systems Corporation, Tochigi, Japan) for all patients indicated for ARCR. ALA was performed on shoulders with a CSA of  $>35^\circ$  on the 3D model based on preoperative CT data. All patients who underwent performed ALA along with ARCR provided written informed consent before surgery. Shoulders with RCT that did not include supraspinatus tendon tear, shoulders that were not operated on according to the results of the 3D simulation, and shoulders with glenoid fracture including bony Bankart lesion were excluded from this study.

### ALA Planning on Radiographs

On preoperative anteroposterior view of shoulder joint radiograph, the CSA was measured as the angle made by the line connecting the most superior and most inferior edge of the glenoid with the line connecting the most inferior edge of the glenoid and the most lateral edge of the acromion (Fig 1). If the CSA was  $>35^\circ$ , the point 4 mm medial from the most lateral edge of the acromion along its inferior plane was detected. Referencing this point as the most lateral point of the resected acromion, the CSA was measured as the CSA after 4-mm ALA on radiographs (4-mm CSA-R; Fig 2). If the 4-mm CSA-R was  $>35^\circ$ , the medial point 8 mm from the most lateral edge of the acromion was detected, and the CSA after 8 mm ALA (8-mm CSA-R) was measured on radiographs. In all cases, 4 or 8 mm of bone resection was enough to reduce the CSA to  $<35^\circ$ . As described in several previous studies,<sup>14,15,21-23</sup> the diameter of the bone resection burr tip can be a good indicator during the ALA procedure, and the unit of bone resection was defined as 4 mm in this study.



**Fig 1.** Measurement of the critical shoulder angle (CSA) on a plain radiograph of the right shoulder. The CSA was measured as the angle made by the line connecting the most superior and most inferior edge of the glenoid and the line connecting the most inferior edge of the glenoid and most lateral edge of the acromion.



**Fig 2.** The 4-mm ALA simulation on a plain radiograph of the right shoulder. The point 4 mm medial from the most lateral edge of the acromion along the inferior plane of the acromion was detected. Referencing this point as the most lateral point of the resected acromion, the critical shoulder angle (CSA) was measured as the CSA after 4-mm ALA on radiograph (4-mm CSA-R).

### ALA Planning Using a 3D Model Based on CT Data

ALA planning was performed using a 3D model created and analyzed using Mimics and 3-matic software (Materialize, Leuven, Belgium). First, a 3D model based on preoperative CT data was created. In this model, the most superior and inferior points on the glenoid were detected, and the most lateral point of the acromion was detected on the A1 or C1 type view according to the Suter-Henninger classification.<sup>20</sup> The preoperative CSA was measured on the 3D model using the angle measuring function in the software (preCSA-3D; Fig 3). Next, an ALA simulation was performed on the 3D model. A previous anatomical study revealed that the acromion has 3 facets on its lateral side, that is, the anterior, middle, and posterior facets.<sup>24</sup> Therefore, a simulated resection was performed for each of the 3 facets. On the 3D model, the planes perpendicular to each facet were created on the lateral edge of the acromion and were then moved 4 mm medially. The lateral lesions on these planes were deleted, and if there was an anterior bone spur, it also was deleted. This model after the serial deletions was considered as the post-4 mm ALA planning model. On this model, the CSA was measured in the same way as on the

preCSA-3D model and was defined as the CSA after modeling the 4-mm ALA on the 3D model (4-mm CSA-3D). The serial method for performing 4-mm ALA simulation on the 3D model is shown in Figure 4. If the 4-mm CSA-3D was  $>35^\circ$ , an 8-mm ALA planning model was made in the same way, and the CSA after 8 mm ALA was measured on the 3D model (8-mm CSA-3D). In all cases, 4 mm or 8 mm of bone resection was enough to reduce the CSA to  $>35^\circ$  on the 3D model. All CSA measurements using radiographs and 3D models were performed twice after an interval of at least 6 weeks by 2 investigators with more than 10 years of experience as orthopaedic surgeons. Intra-observer and interobserver reliability were analyzed using intraclass correlation coefficients.

### Surgical Technique

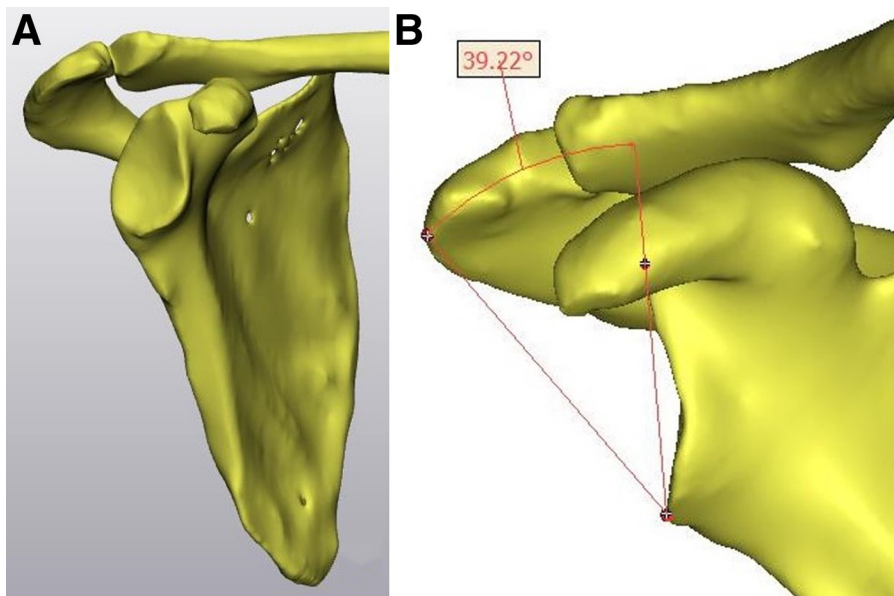
All operations were performed by a single senior surgeon (T.O.) with the patient in a beach-chair position under general anesthesia. The sagittal and coronal lengths of the RCT were measured by a probe with a scale, and the larger of the 2 lengths was adopted as the tear size for that case ( $<1$  cm, small; 1-3 cm, medium; 3-5 cm, large;  $>5$  cm, massive tear). The rotator cuff repair was performed using the transosseous-equivalent suture bridge technique with suture anchors. Partial tears of 50% or more of the thickness were converted to a complete tear and repaired. ALA was performed according to the preoperative planning on the 3D model using a burr with a tip diameter of 4 mm. The diameter of the burr tip was referred for quantifying the width of the bone resection during the procedure (Fig 5). Moreover, if there was a bone spur in the anterior edge of the acromion, an arthroscopic standard anterior bone resection was performed.

### Postoperative Evaluation

The postoperative CSA (postCSA-R) was measured on a radiograph obtained within 1 month after the operation, in the same way as the CSA measurement on the presurgical radiograph described previously.

### Statistical Analysis

A priori power analysis was performed with a confidence level of 95% and statistical power of 80% using the data reported by Moor et al.<sup>5</sup> With a mean difference of  $4.9^\circ$  between the groups and a standard deviation of 3.3, a minimum of 6 patients per group was needed to detect significant differences in CSA measurements using radiographs and 3D models. The mean CSA measured on the preoperative radiograph (preCSA-R) was compared with the mean preCSA-3D using a paired *t*-test. Similarly, paired *t*-tests were used for comparisons between 4-mm CSA-R and 4-mm CSA-3D, and between preCSA-R and postCSA-R. The number of cases that needed 4 mm ALA to reduce the



**Fig 3.** (A) The 3-dimensional (3D) model based on preoperative computed tomography data of the right shoulder. (B) Measurement of the critical shoulder angle (CSA) on the 3D model. The most superior and inferior points were detected on the glenoid, and the most lateral point of the acromion was detected on the A1 or C1 type view according to the Suter-Henninger classification. The CSA was measured using the angle measuring function in the software as the preoperative CSA on the 3D model (preCSA-3D).

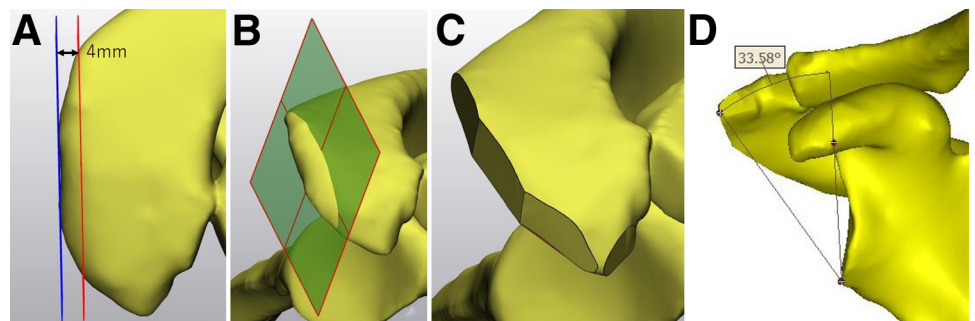
CSA to  $<35^\circ$ , and the number of cases that needed 8 mm ALA to reduce the CSA to  $<35^\circ$ , were investigated on both radiographs and 3D models, and were then compared using the Fisher exact test. A  $P < .05$  was considered statistically significant.

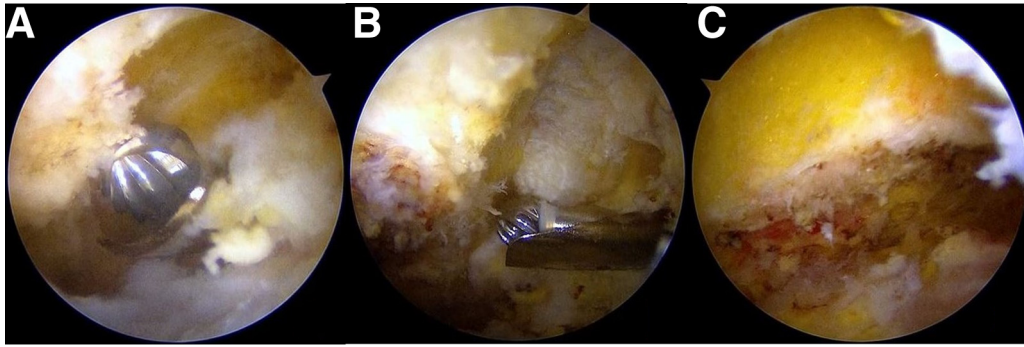
### Results

Between October 2019 and February 2021, ARCR was performed on 41 shoulders of 40 patients at our institution. All patients were older than 25 years. Sixteen of these 41 shoulders had a CSA of  $>35^\circ$  on the preoperative 3D model. Fifteen shoulders underwent ALA, with one being excepted because of an isolated subscapularis tendon tear. Of these 15 shoulders, 3

cases were excluded because the ALA was not performed according to the results of the 3D simulation, and one shoulder was excluded because of a bony Bankart lesion on the glenoid. Finally, 11 shoulders in 10 patients (7 female, 3 male) with a mean age of 62.7 years (range, 48-77 years) were investigated in this study (Fig 6). The characteristics of the included cases are summarized in Table 1. The mean preoperative CSA on radiographs (preCSA-R) was  $38.0^\circ \pm 2.6^\circ$ , and the mean preCSA-3D was  $38.6^\circ \pm 1.8^\circ$ . There was no significant difference between the mean preCSA-R and preCSA-3D ( $P = .55$ ). The mean 4-mm CSA-R and 4-mm CSA-3D were  $34.1^\circ \pm 2.6^\circ$  and  $34.3^\circ \pm 2.5^\circ$ , respectively, and showed no significant difference

**Fig 4.** A series of images of arthroscopic lateral acromioplasty (ALA) simulation on the 3D model of the right shoulder. (A-B) Perpendicular plane to middle facet was created on the lateral edge of the acromion and was then moved 4 mm medially. (C) Perpendicular planes to each facet were created and were then moved 4 mm medially. The lateral lesions from these planes were deleted, and if there was an anterior bone spur, it was also deleted. The model after the serial deletions was considered as the model after 4 mm ALA planning. (D) The critical shoulder angle (CSA) was measured and defined as the CSA after 4-mm ALA on the 3D model (4-mm CSA-3D).





**Fig 5.** Intraoperative images of the right shoulder. (A) Posterior portal view. The arthroscopic image of the arthroscopic lateral acromioplasty (ALA) procedure using a bone resection burr of 4-mm diameter. (B) After the ALA procedure, the deltoid tendon can be seen at the bone resection site. (C) Lateral portal view of the bone resection site.

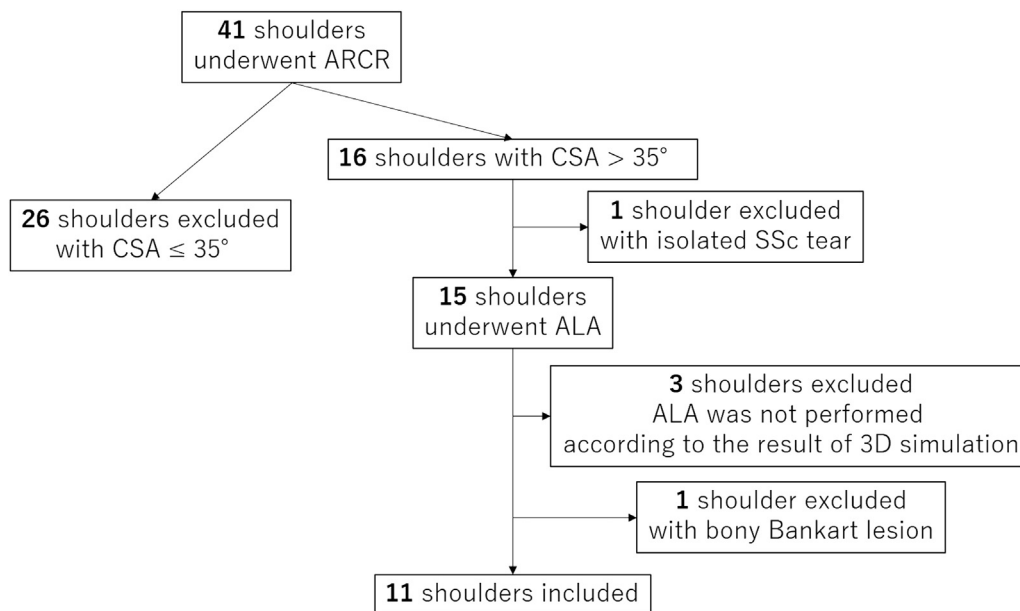
( $P = .84$ ). Four of the 11 cases (36.4%) needed 8-mm ALA to reduce the CSA to  $<35^\circ$  according to radiographic analysis, and 2 of 11 (18.2%) needed 8-mm ALA according to 3D model analysis (Table 2). The mean postCSA-R was  $32.1^\circ \pm 2.7^\circ$ , which was significantly smaller than the mean preCSA-R ( $32.1^\circ \pm 2.7^\circ$  vs  $38.0^\circ \pm 2.6^\circ$ ;  $P < .01$ ). The CSA measurements taken using the radiographs and 3D models are summarized in Table 3. The intraclass correlation coefficients for intra-observer and inter-observer reliability of all CSA measurements were  $>0.7$ . The reproducibility of all measurements was considered high.

### Discussion

The most important finding of the current study is that there was no significant difference in mean CSA between radiograph-based after 4 mm ALA simulation

and 3D preoperative CT model-based 4-mm ALA simulation. This result implies that plain radiographs are comparable with 3D models as a modality for the preoperative planning of ALA. This is an important matter because a plain radiograph is inexpensive to acquire and routinely obtained as part of the preoperative examination before ARCR by most shoulder surgeons.

Several studies reported the effect of a lateral extension of the acromion on the rotator cuff. Gerber et al.<sup>13</sup> performed a biomechanical study and found that a larger CSA made the glenohumeral joint unstable during abduction of  $6-61^\circ$ , and increased the load by 13% to 33% on the supraspinatus tendon to stabilize the arm in space. Nyffeler et al.<sup>25</sup> investigated lateral extension in patient groups with a full-thickness RCT, osteoarthritis of the shoulder, and an intact rotator cuff.



**Fig 6.** Flowchart of patient inclusion and exclusion. (3D, 3-dimensional; ALA, arthroscopic lateral acromioplasty; ARCR, arthroscopic rotator cuff repair; CSA, critical shoulder angle; SSc, subscapularis.)

**Table 1.** Patient Characteristics

	Data
Total cases	11 shoulders of 10 patients
Mean age, y (range)	62.7 (48-77)
Sex	
Male, n	3
Female, n	7
Laterality	
Right, n	5
Left, n	6
Tear size, n	partial, 3; small, 0; medium, 4; large, 4; massive, 0

They found an association between the lateral extension of the acromion and a full-thickness RCT and assumed that a large lateral extension of the acromion makes the force vector of the middle deltoid more vertical during shoulder joint abduction, predisposing the supraspinatus tendon to degeneration. Furthermore, several previous studies have reported a relationship between a large CSA and high rate of retear after ARCR.<sup>10-12</sup> On the basis of these previous studies, ALA, a procedure used to reduce the CSA, may reduce the retear rate after ARCR because it reduces the load on the supraspinatus tendon.

There are a few reports evaluating the clinical practice of ALA along with ARCR.<sup>14,15</sup> Olmos et al.<sup>15</sup> performed ALA of 6 mm width along with ARCR in patients with a CSA  $\geq 35^\circ$ . They found that the CSA was not corrected to  $<35^\circ$  in most patients with a preoperative CSA of  $>40^\circ$ , and concluded that further studies are necessary to verify the ideal bone resection amount for individual patients when performing ALA. Gerber et al.<sup>14</sup> performed ALA with an average width of 6 mm (range, 3-8 mm) along with ARCR in patients with a CSA of  $34^\circ$  or greater. Although they obtained a mean postoperative CSA of  $33.9^\circ$ , the CSA correction was insufficient in some cases, and they proposed a preoperative planning method using MRI for more precise ALA. On the basis of these previous reports, we tried a new preoperative planning method for ALA using 3D models based on CT data. Furthermore, Sakoma et al.<sup>24</sup> demonstrated that the segments of deltoid muscle playing a main role in shoulder abduction originate from the anterior and middle facet of the lateral acromion. Theoretically, bone resection on the anterior and middle facet is needed for

**Table 2.** The Numbers of Cases Needing 4- and 8-mm ALA to Reduce the CSA to  $<35^\circ$  on Radiographs and 3D Models

	4 mm	8 mm
Radiograph, n	7	4
3D model, n	9	2

NOTE. Fisher exact test,  $P = .64$ .

3D, 3-dimensional; ALA, arthroscopic lateral acromioplasty; CSA, critical shoulder angle.

**Table 3.** Summary of the CSA Measurements on Radiographs and 3D Models

	Degree
PreCSA-R	$38.0 \pm 2.6$ (36-42)
PreCSA-3D	$38.6 \pm 1.8$ (35.5-42.8)
4-mmCSA-R	$34.1 \pm 2.6$ (32-38)
4-mmCSA-3D	$34.3 \pm 2.5$ (31.3-40.7)
8-mmCSA-R (4 cases)	$33.3 \pm 0.8$ (32-34)
8-mmCSA-3D (2 cases)	$32.5 \pm 2.0$ (30.5-34.6)
PostCSA-R	$32.1 \pm 2.7$ (28-37)

NOTE. Data are presented as mean  $\pm$  standard deviation (range). 3D, 3-dimensional; CSA, critical shoulder angle; PreCSA-R, the mean preoperative CSA on the radiographs; PreCSA-3D, the mean preoperative CSA on 3D models based on preoperative CT data; 4-mmCSA-R, the mean CSA after 4 mm arthroscopic lateral acromioplasty (ALA) simulation using radiographs; 4-mmCSA-3D, the mean CSA after 4 mm ALA simulation using 3D models; 8-mmCSA-R, the mean CSA after 8 mm ALA simulation using radiographs; 8-mmCSA-3D, the mean CSA after 8 mm ALA simulation using 3D models; PostCSA-R, the mean postoperative CSA on radiographs.

clinical effectiveness when performing ALA, and we therefore invented a novel method for the preoperative planning of ALA, with resection of each facet of the lateral acromion. In the current study, the mean 4-mm CSA-R and 4-mm CSA-3D were not significantly different, and the number of cases requiring 8 mm ALA to reduce the CSA to  $<35^\circ$  according to radiographs was not significantly different to that according to the 3D models. On the basis of these results, ALA performed according to the simulation using radiographs could make the force vector of the deltoid more horizontal, which could reduce the load on the supraspinatus tendon after ARCR.

CT data provide us detailed morphologic information. Previous studies have used CT data for the investigation of scapula anatomy, glenoid inclination, and the CSA.<sup>17-20</sup> Bouaicha et al.<sup>18</sup> compared CSAs measured on radiographs with those measured on CT in patients with different clinical shoulder pathologies and could not find a significant difference between radiographs and CT. In the current study, we measured the CSA of the 3D model on the plane defined by the most superior point of the glenoid, the most inferior point of the glenoid, and the most lateral point of the acromion, in the same manner as that of Bouaicha et al.<sup>18</sup> Our result was consistent with their result, in that preCSA-R and preCSA-3D were not significantly different. Moreover, the results of the 4-mm ALA simulations on radiographs and 3D models were not significantly different in the current study.

Some authors reported the results of ALA simulation using 3D models based on CT data.<sup>26,27</sup> Karns et al.<sup>27</sup> simulated 2.5- and 5-mm ALA and found that 5-mm ALA could reduce CSA to  $<35^\circ$  in cases with CSA of up to  $38^\circ$ . Although the current study included cases with CSA of  $>40^\circ$ , ALA simulation of up to 8 mm

reduced the CSA to  $<35^\circ$  in all included cases. In most cases, ALA of up to 8 mm width may be enough to reduce CSA to an adequate range when it is performed with ARCR.

There was no statistically significant difference among the numbers of cases needing 4 mm and 8 mm ALA to reduce the CSA to  $<35^\circ$  on radiographs and 3D models. However, there was a difference in 2 cases between the results of radiographs and those of 3D models, which is a significant difference in clinical practice. The resection unit of 4 mm, which was defined as the diameter of burr tip, is arbitrary, so a new procedure or device that enables bone resection of units smaller than 4 mm, e.g., 1 mm, should be developed for more precise bone resection.

The ALA procedure was validated in respect to safety considerations in cadaver and in vivo studies.<sup>14,15,21-23</sup> Marchetti et al.<sup>23</sup> and Altintas et al.<sup>21</sup> performed 10 mm ALA in cadavers, and Gerber et al.<sup>14</sup> performed up to 8 mm ALA in vivo. All cases showed no injury to the lateral deltoid origin. In our study, postoperative MRI was available for 6 cases, and we could not find any injury to the lateral deltoid origin.

In the current study, arthroscopic bone resection according to the simulation using 3D models was performed, and the postoperative CSA in all but one case was  $<35^\circ$ . One case with preCSA-3D of  $38.8^\circ$  showed a simulated 4-mmCSA-3D of  $33.8^\circ$ , but a postCSA-R of  $37^\circ$ . Although we referred to the diameter of the burr tip during the ALA procedure, as in previous ALA studies,<sup>15,21-23</sup> the precise bone resection on the lateral acromion that was simulated, especially the posterior portion, was deemed technically demanding. To achieve the utmost performance of ALA, some ingenuity should be exercised, and a detailed comparison between the simulated ALA model and the model after the ALA procedure may be helpful. In addition, further investigations into the functional and structural outcomes of ALA accompanied by ARCR are needed to fully evaluate the efficacy of the preoperative planning performed in the current study.

### Limitations

This study is not without limitations. It is a retrospective study involving a series of performed by a single surgeon. Thus, there could be selection and observer biases. Furthermore, the sample size was relatively small, although the number of patients was statistically sufficient. Finally, the radiograph protocol of the shoulder joint was not standardized for precise measurement of CSA. The measurement of CSA on radiographs is influenced by the viewing perspective,<sup>20</sup> and the appropriate radiograph image for the precise measurement of CSA is difficult to obtain.<sup>16</sup> In fact, all but 2 of the preoperative radiographs were inappropriate for precise measurement of the CSA according to

the Sutter-Henninger classification, with 1 case classified into A-1 type, one case into C-1 type, seven cases into D-1 type and 2 cases into D-3 type. However, despite the lack of appropriate radiographs, the results of preoperative planning on radiographs were comparable with that on 3D models.

### Conclusions

There was no significant difference between the mean CSA after 4-mm ALA simulation using radiographs and that using 3D models based on preoperative CT data, which suggests that radiographs are comparable with 3D CT data models as a reliable modality for the preoperative simulation of ALA.

### References

1. Zhang AL, Montgomery SR, Ngo SS, Hame SL, Wang JC, Gamradt SC. Analysis of rotator cuff repair trends in a large private insurance population. *Arthroscopy* 2013;29:623-629.
2. Diebold G, Lam P, Walton J, Murrell GAC. Relationship between age and rotator cuff retear: A study of 1,600 consecutive rotator cuff repairs. *J Bone Joint Surg Am* 2017;99:1198-1205.
3. Le BT, Wu XL, Lam PH, Murrell GA. Factors predicting rotator cuff retears: An analysis of 1000 consecutive rotator cuff repairs. *Am J Sports Med* 2014;42:1134-1142.
4. McElvany MD, McGoldrick E, Gee AO, Neradilek MB, Matsen FA 3rd. Rotator cuff repair: published evidence on factors associated with repair integrity and clinical outcome. *Am J Sports Med* 2015;43:491-500.
5. Moor BK, Bouaicha S, Rothenfluh DA, Sukthankar A, Gerber C. Is there an association between the individual anatomy of the scapula and the development of rotator cuff tears or osteoarthritis of the glenohumeral joint? A radiological study of the critical shoulder angle. *Bone Joint J* 2013;95-B:935-941.
6. Moor BK, Wieser K, Slankamenac K, Gerber C, Bouaicha S. Relationship of individual scapular anatomy and degenerative rotator cuff tears. *J Shoulder Elbow Surg* 2014;23:536-541.
7. Kim JH, Min YK, Gwak HC, Kim CW, Lee CR, Lee SJ. Rotator cuff tear incidence association with critical shoulder angle and subacromial osteophytes. *J Shoulder Elbow Surg* 2019;28:470-475.
8. Spiegl UJ, Horan MP, Smith SW, Ho CP, Millett PJ. The critical shoulder angle is associated with rotator cuff tears and shoulder osteoarthritis and is better assessed with radiographs over MRI. *Knee Surg Sports Traumatol Arthrosc* 2016;24:2244-2251.
9. Tang Y, Hou J, Li Q, et al. The effectiveness of using the critical shoulder angle and acromion index for predicting rotator cuff tears: Accurate diagnosis based on standard and nonstandard anteroposterior radiographs. *Arthroscopy* 2019;35:2553-2561.
10. Garcia GH, Liu JN, Degen RM, et al. Higher critical shoulder angle increases the risk of retear after rotator cuff repair. *J Shoulder Elbow Surg* 2017;26:241-245.

11. Li H, Chen Y, Chen J, Hua Y, Chen S. Large critical shoulder angle has higher risk of tendon retear after arthroscopic rotator cuff repair. *Am J Sports Med* 2018;46:1892-1900.
12. Scheiderer B, Imhoff FB, Johnson JD, et al. Higher critical shoulder angle and acromion index are associated with increased retear risk after isolated supraspinatus tendon repair at short-term follow up. *Arthroscopy* 2018;34:2748-2754.
13. Gerber C, Snedeker JG, Baumgartner D, Viehofer AF. Supraspinatus tendon load during abduction is dependent on the size of the critical shoulder angle: A biomechanical analysis. *J Orthop Res* 2014;32:952-957.
14. Gerber C, Catanzaro S, Betz M, Ernstbrunner L. Arthroscopic correction of the critical shoulder angle through lateral acromioplasty: A safe adjunct to rotator cuff repair. *Arthroscopy* 2018;34:771-780.
15. Olmos MI, Boutsiadis A, Swan J, et al. Lateral acromioplasty cannot sufficiently reduce the critical shoulder angle if preoperatively measured over 40 degrees. *Knee Surg Sports Traumatol Arthrosc* 2021;29:240-249.
16. Chalmers PN, Salazar D, Steger-May K, Chamberlain AM, Yamaguchi K, Keener JD. Does the critical shoulder angle correlate with rotator cuff tear progression? *Clin Orthop Relat Res* 2017;475:1608-1617.
17. Beeler S, Hasler A, Getzmann J, Weigelt L, Meyer DC, Gerber C. Acromial roof in patients with concentric osteoarthritis and massive rotator cuff tears: Multiplanar analysis of 115 computed tomography scans. *J Shoulder Elbow Surg* 2018;27:1866-1876.
18. Bouaicha S, Ehrmann C, Slankamenac K, Regan WD, Moor BK. Comparison of the critical shoulder angle in radiographs and computed tomography. *Skeletal Radiol* 2014;43:1053-1056.
19. Daggett M, Werner B, Collin P, Gauci MO, Chaoui J, Walch G. Correlation between glenoid inclination and critical shoulder angle: A radiographic and computed tomography study. *J Shoulder Elbow Surg* 2015;24:1948-1953.
20. Suter T, Gerber Popp A, Zhang Y, Zhang C, Tashjian RZ, Henninger HB. The influence of radiographic viewing perspective and demographics on the critical shoulder angle. *J Shoulder Elbow Surg* 2015;24:e149-e158.
21. Altintas B, Kaab M, Greiner S. Arthroscopic lateral acromion resection (ALAR) optimizes rotator cuff tear relevant scapula parameters. *Arch Orthop Trauma Surg* 2016;136:799-804.
22. Katthagen JC, Marchetti DC, Tahal DS, Turnbull TL, Millett PJ. The effects of arthroscopic lateral acromioplasty on the critical shoulder angle and the anterolateral deltoid origin: An anatomic cadaveric study. *Arthroscopy* 2016;32:569-575.
23. Marchetti DC, Katthagen JC, Mikula JD, et al. Impact of arthroscopic lateral acromioplasty on the mechanical and structural integrity of the lateral deltoid origin: A cadaveric study. *Arthroscopy* 2017;33:511-517.
24. Sakoma Y, Sano H, Shinozaki N, et al. Anatomical and functional segments of the deltoid muscle. *J Anat* 2011;218:185-190.
25. Nyffeler RW, Werner CM, Sukthankar A, Schmid MR, Gerber C. Association of a large lateral extension of the acromion with rotator cuff tears. *J Bone Joint Surg Am* 2006;88:800-805.
26. Kaiser D, Bachmann E, Gerber C, Meyer DC. Influence of the site of acromioplasty on reduction of the critical shoulder angle (CSA)—an anatomical study. *BMC Musculoskelet Disord* 2018;19:371.
27. Karns MR, Jacxsens M, Uffmann WJ, Todd DC, Henninger HB, Burks RT. The critical acromial point: The anatomic location of the lateral acromion in the critical shoulder angle. *J Shoulder Elbow Surg* 2018;27:151-159.