

# Impact of Arthroscopic Lateral Acromioplasty on the Mechanical and Structural Integrity of the Lateral Deltoid Origin: A Cadaveric Study

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**Purpose:** To determine whether a 5-mm and/or 10-mm arthroscopic lateral acromioplasty (ALA) would weaken the structural and mechanical integrity of the lateral deltoid. **Methods:** The acromion and lateral deltoid origin were harvested from 15 pairs ( $n = 30$ ) of fresh-frozen human cadaveric shoulder specimens. One side of each specimen pair (left or right) was randomly assigned to either a 5-mm ( $n = 7$ ) or 10-mm ( $n = 8$ ) ALA group, and the contralateral sides ( $n = 15$ ) were used as matched controls. Acromion thickness and width were measured pre- and postoperatively. After ALA, specimens were inspected for damage to the lateral deltoid origin. Each specimen was secured within a dynamic testing machine, and the deltoid muscle was pulled to failure. Statistical analysis was performed to determine whether ALA reduced the lateral deltoid's failure load. **Results:** There was no significant difference in failure load between the 5-mm ALA group ( $661 \pm 207$  N) and its matched control group ( $744 \pm 212$  N; mean difference = 83 N; 95% confidence interval [CI],  $-91$  to 258;  $P = .285$ ) nor between the 10-mm ALA group ( $544 \pm 210$  N) and its matched control group ( $598 \pm 157$  N; mean difference = 54 N; 95% CI,  $-141$  to 250;  $P = .532$ ). There was no correlation found between the amount of bone resected (measured by percent thickness and width of the acromion after ALA) and the failure load of the deltoid. Visual evaluation of the acromion after ALA revealed the lateral deltoid origin had no damage in any case. **Conclusions:** ALA did not weaken the structural or mechanical integrity of the lateral deltoid origin. Neither a 5-mm nor a 10-mm ALA significantly reduced the deltoid's failure load. The lateral deltoid origin was not macroscopically damaged in any case. **Clinical Relevance:** ALA can be performed without the potential risk of macroscopically damaging the lateral deltoid origin or reducing its failure load.

Symptomatic rotator cuff tears (RCTs) are common, with more than 270,000 repairs performed in the United States each year, 86% of which are performed on patients age 45 and older.<sup>1</sup> While the causes of

nontraumatic RCTs are multifaceted and poorly understood,<sup>2,3</sup> distinct variations in the scapular anatomy, such as superior glenoid inclination and a large acromial index, are associated with degenerative RCTs.<sup>4-10</sup> The critical shoulder angle (CSA) is a radiographic parameter that accounts for both the glenoid inclination and the lateral acromion extension.<sup>4</sup> A CSA  $>35^\circ$  has been identified as a risk factor for RCTs, and a CSA  $<30^\circ$  is associated with an increased prevalence of osteoarthritis, suggesting that patients with a CSA between these values are at the lowest risk for either condition.<sup>4,11-13</sup>

Few studies have looked at how scapular anatomy influences patient outcomes after treatment of RCTs. In one study, patients with a large acromial index who underwent arthroscopic repair of full-thickness RCTs had lower patient satisfaction scores when compared with those with a small acromial index.<sup>14</sup> Furthermore, in a long-term follow-up of patients who underwent latissimus dorsi tendon transfer for irreparable RCTs, patients with a significantly larger CSA reported inferior outcomes.<sup>15</sup>

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The fact that the scapular anatomy is not associated only with prevalence of RCTs but is also associated with inferior patient outcomes has led to the idea that an arthroscopic reduction of a large CSA ( $>35^\circ$ ) to a favorable range may be beneficial to reduce the risk of primary RCTs, rotator cuff retears, and unsatisfactory outcomes after treatment of RCTs for this patient population.

Anatomical cadaveric studies have demonstrated that the CSA can be significantly reduced by arthroscopic lateral acromioplasty (ALA).<sup>16,17</sup> However, there is a risk of potentially damaging the deltoid origin during acromioplasty, which may lead to postoperative deltoid avulsion.<sup>18,19</sup> Although it was reported that the deltoid origin was not macroscopically damaged by ALA,<sup>16,17</sup> it still remains unclear whether ALA affects the mechanical integrity of the deltoid. The purpose of this study was to determine whether a 5-mm and/or 10-mm ALA would weaken the structural and mechanical integrity of the lateral deltoid. It was hypothesized that ALA would not significantly affect the failure load of the lateral deltoid origin.

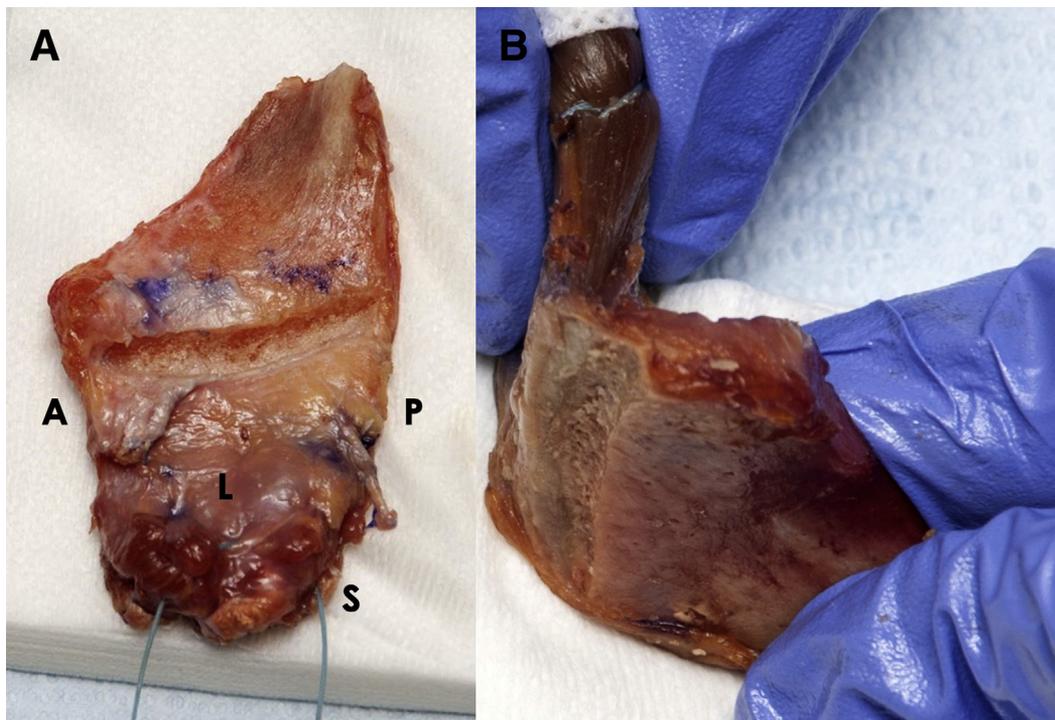
## Methods

### Cadaveric Specimen Preparation

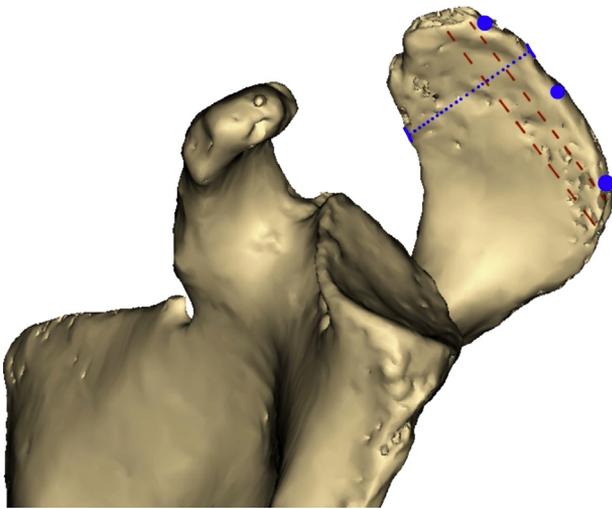
The acromion and lateral deltoid muscle were harvested from 15 pairs ( $n = 30$ ) of fresh-frozen human

cadaveric shoulder specimens (mean age, 57 years [range, 41 to 63 years]; 7 male, 8 female) that met the following inclusion criteria: intact and undamaged lateral deltoid origin, with at least 4-cm distal extension of intact deltoid muscle, and no macroscopic bony abnormalities of the acromion. Specimens were stored at  $-20^\circ\text{C}$  and thawed for 24 hours prior to dissection. Since the structural and mechanical integrity of the lateral deltoid origin in the proximity of the ALA was of interest, the anterior and posterior portions of the deltoid muscle were removed and only the lateral portion of the deltoid origin was included for biomechanical testing (Fig 1A). Starting 1 cm distal to the lateral deltoid origin, the deltoid muscle was whip-stitched using no. 2 polyethylene/polyester suture (FiberWire, Arthrex Inc., Naples, FL).

A digital caliper (Fowler Company, Inc., Newton, MA; manufacturer-reported accuracy of 0.02 mm) was used to take several measurements of the acromion and lateral deltoid origin. These measurements included the medial-lateral width of the acromion (measured from the most posterior point of the acromioclavicular joint to the lateral edge of the acromion) and the lateral acromion thickness (measured at the anterolateral and posterolateral edges of the acromion and the midpoint in between; Fig 2). After ALA, the acromion thickness and width were measured again using the exact same



**Fig 1.** (A) Specimen prepared for biomechanical testing with a no. 2 suture (S) whip stitch after a 5-mm arthroscopic lateral acromioplasty; anterior (A) and posterior (P) portions of the deltoid muscle were removed, and only the lateral (L) portion of the deltoid was included for biomechanical testing. (B) Postoperative image after ALA; the deltoid muscle is elevated superiorly to visually evaluate the lateral deltoid origin. The burr had only shaved down the bone and did not macroscopically damage the lateral deltoid origin.



**Fig 2.** Scapula computed tomography scan of an included specimen. Blue dots indicate the 3 measurement points for the lateral acromion thickness: anterolateral and posterolateral edges of the acromion and the midpoint in between. Blue dotted line shows the medial-lateral width measurements. Red dashed lines indicate the 5-mm arthroscopic lateral acromioplasty (ALA) and 10-mm ALA techniques.

points to evaluate the percentage of the acromion thickness and width remaining after ALA.

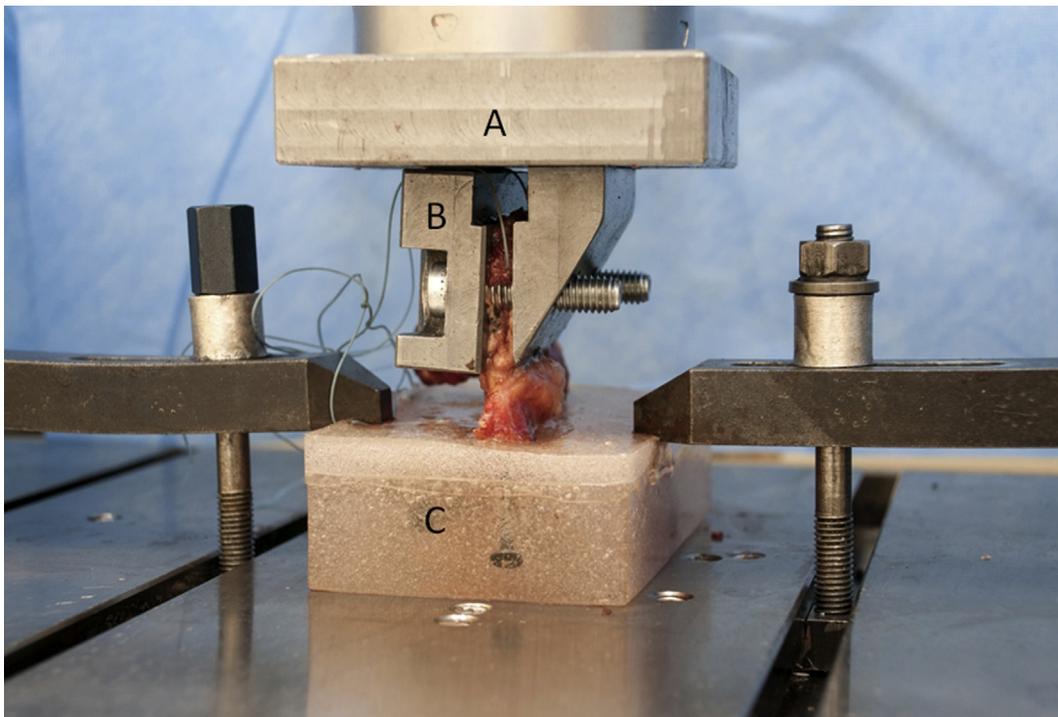
#### Surgical Technique and Biomechanical Testing

One side of each paired shoulder specimen (left or right) was randomly assigned to either a 5-mm ( $n = 7$ )

or 10-mm ( $n = 8$ ) ALA group. The contralateral side of each paired shoulder specimen, which was not assigned to an ALA group, remained intact as a matched control. The medial end of the acromion was clamped to a shoulder surgical tower. Using a 5-mm burr, a single orthopaedic surgeon (J.C.K.) resected one burr width of the most lateral edge of the inferior surface of the acromion for the 5-mm group and 2 burr-widths for the 10-mm group (Fig 2). After ALA, the lateral deltoid origin was analyzed macroscopically to assess its integrity. Then the medial 2 cm of the acromion were meticulously dissected down to the bone and potted in polymethylmethacrylate (Fricke Dental International Inc., Streamwood, IL). Each potted specimen was securely fixed to the base of a dynamic testing machine (Instron ElectroPuls, E10000, Instron Systems, Norwood, MA). The whip-stitched deltoid muscle was wrapped with 24-gauge helical wire to increase the mechanical clamping effectiveness<sup>20-23</sup> and then rigidly clamped to the actuator (Fig 3). The setup was oriented such that the deltoid was pulled directly laterally, simulating the arm in 90° of abduction since it has previously been shown that the lateral deltoid exerts the greatest force at 90° of glenohumeral abduction.<sup>24</sup>

#### Imaging and CSA Measurements

Clinical-grade computed tomography (CT) scans were performed on all 30 specimens to obtain CSA measurements prior to specimen preparation and biomechanical testing. Scans were performed at a 0.5-mm



**Fig 3.** Setup within the dynamic testing machine: (A) load controlled actuator, (B) mechanical clamp used to fasten the augmented deltoid muscle, (C) potted acromion secured to the base of the testing machine.

**Table 1.** Acromion Width and Thickness, Deltoid Thickness, and Failure Load Values for the 5-mm and 10-mm Arthroscopic Lateral Acromioplasty Groups and Their Respective Control Groups

| Group   | Acromion Width |            |              | Acromion Thickness |           |              | Failure Load, N |
|---------|----------------|------------|--------------|--------------------|-----------|--------------|-----------------|
|         | Pre, mm        | Post, mm   | Remaining, % | Pre, mm            | Post, mm  | Remaining, % |                 |
| 5 mm    | 26.7 ± 2.9     | 21.7 ± 2.9 | 81 ± 2       | 9.0 ± 1.5          | 4.9 ± 1.2 | 55 ± 11      | 661 ± 207       |
| Control | 27.6 ± 2.5     | —          | 100          | 8.6 ± 1.3          | —         | 100          | 744 ± 212       |
| 10 mm   | 27.7 ± 3.8     | 17.7 ± 3.8 | 63 ± 5       | 8.9 ± 0.8          | 4.7 ± 1.4 | 53 ± 13      | 544 ± 210       |
| Control | 26.6 ± 3.5     | —          | 100          | 8.9 ± 1.2          | —         | 100          | 598 ± 157       |

NOTE. Values are shown as mean ± standard deviation.

slice thickness, 120 kVp voltage, 150 mA current, and 750 msec exposure time, using a helical scan (Aquilion Premium; Toshiba America Medical Systems, Inc., Tustin, CA). Mimics (Materialise, Leuven, Belgium) computational modeling software was then used to create a 3-dimensional (3D) bone model from the CT data. CSA measurements have been shown to be highly correlated between true anterior-posterior radiographs and CT and have previously been performed on 3D CT models<sup>25,26</sup>; therefore, the 3D-rendered scapulae were oriented to mimic a true anterior-posterior radiograph and the CSA was measured for each of the 30 specimens according to the technique described by Moor et al.<sup>4</sup> (ImageJ, National Institutes of Health, Bethesda, MD).

### Statistical Analysis

Continuous measurement data were not observed to be skewed or overdispersed, so parametric testing methods were used. The paired *t*-test was used for comparing resection amounts within matched pairs. Welch's 2-sample *t*-test was used to compare independent samples, and Pearson correlation was used to assess the association between continuous measurements. Fisher's exact test was used to test for associations between binary variables, and odds ratios (OR) were reported. Ninety-five percent confidence intervals (CIs) were reported throughout the manuscript to indicate the precision of the estimates and statistical power of the study. All statistical analyses and graphics were produced using the statistical programming language R version 3.2.3 (R Development Core Team, Vienna, Austria). The level of significance was set at  $P < .05$ .

### Results

The mean CSA for all specimens prior to ALA was  $31.8^\circ \pm 3.8^\circ$  (range,  $24.7^\circ$  to  $37.0^\circ$ ). There was no significant difference (mean difference = 115; 95% CI, -23 to 254;  $P = .099$ ) in the mean failure load between specimens with a CSA  $>35^\circ$  ( $556 \pm 148$  N) and those with a CSA  $<35^\circ$  ( $671 \pm 216$  N). Furthermore, there was no correlation between failure load and CSA ( $R = -0.32$ ,  $P = .082$ ).

Neither a 5-mm nor a 10-mm ALA resulted in a significant reduction in the failure load of the lateral deltoid origin when compared with its contralateral, matched control. There was no clinically relevant or statistically significant difference in acromion width and thickness at baseline between the resected and control groups ( $P = .729$ ,  $P = .409$ , respectively). A 5-mm ALA resulted in an acromion with  $81\% \pm 2\%$  of the width and  $55\% \pm 11\%$  of the thickness compared with its intact state before surgery. A 10-mm ALA resulted in an acromion with  $63.3\% \pm 5.2\%$  of the width and  $52.7\% \pm 13.3\%$  of the thickness compared with its intact state before surgery (Table 1). During visual evaluation of the acromion after ALA, the lateral deltoid origin was found to be intact without macroscopic damage in any case (Fig 1B).

### Failure Load

There was no significant difference (mean difference = 83; 95% CI, -91 to 258;  $P = .285$ ) in measured failure load between the 5-mm ALA group ( $661 \pm 207$  N) and its matched control group ( $744 \pm 212$  N). There was also no significant difference (mean difference = 54; 95% CI, -141 to 250;  $P = .532$ ) in measured failure load between the 10-mm ALA group ( $544 \pm 210$  N) and its matched control group ( $598 \pm 157$  N). Furthermore, there was no correlation between the amount of bone resected (as measured by percent thickness and width of the acromion remaining after resection) and the failure load of the deltoid for either the width (correlation = 0.36; 95% CI, -0.18 to 0.74;  $P = .185$ ) or thickness (correlation = 0.06; 95% CI, -0.47 to 0.55;  $P = .833$ ) for all resected specimens.

### Mode of Failure

There were 2 observed modes of failure in this study: (1) bone fracture/avulsion and (2) muscle tear. Thirteen specimens failed by bone fracture/avulsion, whereas 17 failed by muscle tear. Mean failure load for all specimens was  $667 \pm 226$  N for bone fracture failures and  $606 \pm 183$  N for muscle tear failures. There was no significant difference between failure loads of either mode of failure for all specimens (mean difference = 66; 95% CI, -98.5 to 218.9;  $P = .440$ ), ALA specimens that had a failure load of  $565 \pm 212$  N for bone fracture and  $620 \pm 218$  N (mean

difference = 55; 95% CI, -305 to 193;  $P = .631$ ), and control specimens that had a failure load of  $754 \pm 212$  N for bone fracture and  $590 \pm 147$  N (mean difference = 164; 95% CI, -48 to 375;  $P = .116$ ). Lastly, there was no difference in failure mode (bone fracture or muscle tear) between the resected and control groups (OR = 1.3; 95% CI, 0.25-7.01;  $P = 1$ ).

## Discussion

The most important finding of this study was that neither a 5-mm ALA nor a 10-mm ALA significantly decreased the failure load of the lateral deltoid origin. Furthermore, there was no correlation between failure load and the percentage of acromion resected or between failure load and failure method.

Recent literature has revealed the association of a large CSA with the prevalence of RCTs.<sup>4,11-13,27</sup> Furthermore, a large acromial index and a large CSA have been associated with inferior patient outcomes after rotator cuff repair and latissimus dorsi transfer for irreparable RCTs.<sup>14,15</sup> Regarding these findings, it has been suggested that reduction of a large CSA ( $>35^\circ$ ) to the more favorable range of  $30^\circ$  to  $35^\circ$  may potentially reduce the risk of RCTs, retears after rotator cuff repair, and inferior patient outcomes.<sup>16</sup> Therefore, 2 studies have recently assessed whether ALA is an effective and safe procedure to reduce the CSA. Katthagen et al. reported that a 5-mm ALA significantly reduced the CSA by a mean of  $2.8^\circ$  (95% CI,  $2.1^\circ$ - $3.5^\circ$ ) in an anatomic biomechanical cadaver model.<sup>16,28</sup> In a similar study, Altintas et al.<sup>17</sup> performed a 1-cm arthroscopic lateral acromion resection and found that the CSA was significantly reduced from  $31.6^\circ \pm 7.7^\circ$  to  $25.1^\circ \pm 8.3^\circ$ . Although both studies reported that the deltoid origin was not macroscopically damaged, there is an inherent risk of damaging or weakening the deltoid origin and muscle during acromioplasty and rotator cuff repair.<sup>18,19,29</sup>

The risk of deltoid detachment or rupture has been a well-documented complication after acromioplasty and primary or revision rotator cuff repair.<sup>18,19,29-34</sup> However, little is known regarding the mechanical properties (in terms of failure load) of the lateral deltoid origin and muscle, especially whether or not it is significantly affected by ALA. It has also been suggested that the ALA could increase the risk of fractures due to its thinning of the lateral acromion.<sup>16</sup> Acromion fractures associated with surgical procedures have been described mainly after reverse total shoulder arthroplasty.<sup>35,36</sup> In these cases, the fracture typically occurs more medially on the acromion than the region in which ALA is performed.

This study provides data regarding the implications of ALA on the mechanical and structural integrity of the lateral deltoid origin. Neither a 5-mm ALA nor a 10-mm ALA reduced the lateral deltoid's failure load when compared with its contralateral, matched control.

Although 2 concerning modes of failure were observed (deltoid muscle tear and acromion fracture/avulsion), both modes occurred at similar failure loads, and furthermore, they also occurred at failure loads similar to those of the intact, nonoperative control groups. Therefore, the findings of this study suggest that ALA does not increase the likelihood of lateral deltoid muscle rupture or acromion fracture and would not be expected to occur in the clinical setting.

The clinical implications of whether or not an ALA would reduce the risk of RCTs, retears, or inferior patient outcomes after treatment of RCTs in patients with a CSA  $>35^\circ$  are still unknown. To date, we are aware of only one study that has assessed the potential negative influence of a large CSA on postoperative outcomes after treatment of RCTs: Gerber et al.<sup>15</sup> reported inferior functional results for patients with a large CSA after latissimus dorsi transfer as treatment for irreparable RCTs. Furthermore, it remains unclear whether reduction of the CSA to the potentially more favorable range of  $30^\circ$  to  $35^\circ$  has an effect on the natural history of RCTs or the risk of rotator cuff retears after rotator cuff repair. Further research regarding the effect of ALA on clinical outcomes is warranted to better understand its efficacy.

While the aforementioned biomechanical ALA studies used similar study designs, they investigated different surgical techniques.<sup>16,17</sup> Katthagen et al.<sup>16</sup> described a 5-mm ALA in which the inferior surface, from anterior to posterior, of the lateral acromion was resected using a 5-mm burr. This technique has the advantage of preserving the superior surface of the acromion with the attached lateral deltoid origin macroscopically (Fig 1B). On the other hand, it leaves a thinned acromion and, therefore, a potential risk of fracture at that location. The 1-cm arthroscopic lateral acromion resection (ALAR) described by Altintas et al.<sup>17</sup> effectively removed the entire lateral 1 cm of the acromion as opposed to the inferior surface in the previously described technique<sup>16</sup> and the technique used in the current investigation. While ALAR leaves less bone for the deltoid origin attachment, it does not present the same risk of acromion fracture at the ALA site since the lateral 1 cm of the acromion is not thinned but completely resected. However, increased forces may be acting on the remainder of the acromion.

Both techniques<sup>16,17</sup> significantly reduced the CSA with different potential advantages and disadvantages and, in theory, increased the subacromial space, thus decreasing the likelihood of supraspinatus tendon impingement. However, further biomechanical and clinical research is warranted to fully evaluate whether ALA may result in superior clinical outcomes.

## Limitations

This study has several limitations. First, not all specimens used in this study had a CSA  $>35^\circ$ , despite the

fact that, in the clinical setting, this procedure would be indicated only in patients with a CSA  $>35^\circ$ . Ideally, the specimens used in this study would have paralleled this clinical scenario. However, the number of specimens that would need to be screened radiographically to identify 30 cadaveric shoulders with a CSA  $>35^\circ$  would have exceeded a reasonable and feasible amount. As a time zero, biomechanical cadaveric model, this study does not reflect the in vivo postoperative environment and the accompanied biological healing process. Therefore, it cannot be determined if, and how, ALA may affect the function of the deltoid muscle or the forces acting on it in vivo. Moreover, it remains unclear whether additional arthroscopic lateral portals would have a negative effect on the mechanical integrity of the lateral deltoid origin. The failure load of the deltoid was only tested in a simulated position of  $90^\circ$  of glenohumeral abduction and may be different in other positions of abduction. Also, no study to date has described a biomechanical testing setup to assess the failure strength of the deltoid, making it impossible to design this study similarly to previous work and compare the findings of this study with existing data. Cyclic loading at lower loads may have been useful to represent nontraumatic loading of the lateral deltoid, however, the authors felt that load-to-failure testing would be the most relevant for evaluation of the structural integrity since the clinically observed failure methods occur in a traumatic setting. Postoperative radiographs to compare how the 5-mm ALA and 10-mm ALA reduced the CSA would have been informative, however, the biomechanical model did not allow for postoperative measurement of CSA. Lastly, we can only understand the effects of the ALA technique, described by Katthagen et al.,<sup>16</sup> which was used in this study, on deltoid failure load and not the full resection technique described by Altintas et al.<sup>17</sup> Nevertheless, this study provides a baseline biomechanical model for assessing the implications of ALA on the mechanical integrity of the lateral deltoid.

### Conclusions

ALA did not weaken the structural or mechanical integrity of the lateral deltoid origin. Neither a 5-mm nor a 10-mm ALA significantly reduced the deltoid's failure load. The lateral deltoid origin was not macroscopically damaged in any case.

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### References

- Jain NB, Higgins LD, Losina E, Collins J, Blazar PE, Katz JN. Epidemiology of musculoskeletal upper extremity ambulatory surgery in the United States. *BMC Musculoskel Disord* 2014;15:4.
- Matthews TJ, Hand GC, Rees JL, Athanasou NA, Carr AJ. Pathology of the torn rotator cuff tendon. Reduction in potential for repair as tear size increases. *J Bone Joint Surg Br* 2006;88:489-495.
- Hashimoto T, Nobuhara K, Hamada T. Pathologic evidence of degeneration as a primary cause of rotator cuff tear. *Clin Orthopaed Rel Res* 2003;111-120.
- 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.
- Bigliani LU, Morrison DS, April EW. The morphology of the acromion and its relationship to rotator cuff tears. *Orthopaed Trans* 1986;10:228.
- Hughes RE, Bryant CR, Hall JM, et al. Glenoid inclination is associated with full-thickness rotator cuff tears. *Clin Orthopaed Rel Res* 2003;86-91.
- Wong AS, Gallo L, Kuhn JE, Carpenter JE, Hughes RE. The effect of glenoid inclination on superior humeral head migration. *J Shoulder Elbow Surg* 2003;12:360-364.
- 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.
- Banas MP, Miller RJ, Totterman S. Relationship between the lateral acromion angle and rotator cuff disease. *J Shoulder Elbow Surg* 1995;4:454-461.
- Tetreault P, Krueger A, Zurakowski D, Gerber C. Glenoid version and rotator cuff tears. *J Orthopaed Res* 2004;22:202-207.
- Spiegel 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.
- Moor BK, Rothlisberger M, Muller DA, et al. Age, trauma and the critical shoulder angle accurately predict supraspinatus tendon tears. *Orthopaed Traumatol Surg Res* 2014;100:489-494.
- 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.
- Ames JB, Horan MP, Van der Meijden OA, Leake MJ, Millett PJ. Association between acromial index and outcomes following arthroscopic repair of full-thickness rotator cuff tears. *J Bone Joint Surg Am* 2012;94:1862-1869.
- Gerber C, Rahm SA, Catanzaro S, Farshad M, Moor BK. Latissimus dorsi tendon transfer for treatment of irreparable posterolateral rotator cuff tears: long-term results at a minimum follow-up of ten years. *J Bone Joint Surg Am* 2013;95:1920-1926.

16. 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.
17. Altintas B, Kaab M, Greiner S. Arthroscopic lateral acromion resection (ALAR) optimizes rotator cuff tear relevant scapula parameters. *Arch Orthopa Trauma Surg* 2016;136:799-804.
18. Neer CS 2nd. Anterior acromioplasty for the chronic impingement syndrome in the shoulder: a preliminary report. *J Bone Joint Surg Am* 1972;54:41-50.
19. Frank JM, Chahal J, Frank RM, Cole BJ, Verma NN, Romeo AA. The role of acromioplasty for rotator cuff problems. *Orthoped Clin N Am* 2014;45:219-224.
20. Clanton TO, Haytmanek CT, Williams BT, et al. A biomechanical comparison of an open repair and 3 minimally invasive percutaneous Achilles tendon repair techniques during a simulated, progressive rehabilitation protocol. *Am J Sports Med* 2015;43:1957-1964.
21. LaPrade CM, Smith SD, Rasmussen MT, et al. Consequences of tibial tunnel reaming on the meniscal roots during cruciate ligament reconstruction in a cadaveric model. Part 1. The anterior cruciate ligament. *Am J Sports Med* 2015;43:200-206.
22. LaPrade CM, Smith SD, Rasmussen MT, et al. Consequences of tibial tunnel reaming on the meniscal roots during cruciate ligament reconstruction in a cadaveric model. Part 2. The posterior cruciate ligament. *Am J Sports Med* 2015;43:207-212.
23. Bhatia S, Civitarese DM, Turnbull TL, et al. A novel repair method for radial tears of the medial meniscus: biomechanical comparison of transtibial 2-tunnel and double horizontal mattress suture techniques under cyclic loading. *Am J Sports Med* 2016;44:639-645.
24. Karlsson D, Peterson B. Towards a model for force predictions in the human shoulder. *J Biomech* 1992;25:189-199.
25. Bouaicha S, Ehrmann C, Slankamenac K, Regan WD, Moor BK. Comparison of the critical shoulder angle in radiographs and computed tomography. *Skel Radiol* 2014;43:1053-1056.
26. 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.
27. Balke M, Liem D, Greshake O, Hoehner J, Bouillon B, Banerjee M. Differences in acromial morphology of shoulders in patients with degenerative and traumatic supraspinatus tendon tears. *Knee Surg Sports Traumatol Arthrosc* 2016;24:2200-2205.
28. Milano G. Editorial commentary: is lateral acromioplasty effective and safe? *Arthroscopy* 2016;32:576-577.
29. Whatley AN, Fowler RL, Warner JJ, Higgins LD. Post-operative rupture of the anterolateral deltoid muscle following reverse total shoulder arthroplasty in patients who have undergone open rotator cuff repair. *J Shoulder Elbow Surg* 2011;20:114-122.
30. Kumar VP, Satku K, Liu J, Shen Y. The anatomy of the anterior origin of the deltoid. *J Bone Joint Surg Br* 1997;79:680-683.
31. Gumina S, Di Giorgio G, Perugia D, Postacchini F. Deltoid detachment consequent to open surgical repair of massive rotator cuff tears. *Int Orthopaed* 2008;32:81-84.
32. Neviasser RJ, Neviasser TJ. Reoperation for failed rotator cuff repair: analysis of fifty cases. *J Shoulder Elbow Surg* 1992;1:283-286.
33. Groh GI, Simoni M, Rolla P, Rockwood CA. Loss of the deltoid after shoulder operations: an operative disaster. *J Shoulder Elbow Surg* 1994;3:243-253.
34. Bigliani LU, Cordasco FA, McIlveen SJ, Musso ES. Operative treatment of failed repairs of the rotator cuff. *J Bone Joint Surg Am* 1992;74:1505-1515.
35. Dennis DA, Ferlic DC, Clayton ML. Acromial stress fractures associated with cuff-tear arthropathy. A report of three cases. *J Bone Joint Surg Am* 1986;68:937-940.
36. Dubrow S, Streit JJ, Muh S, Shishani Y, Gobeze R. Acromial stress fractures: correlation with acromioclavicular osteoarthritis and acromiohumeral distance. *Orthopedics* 2014;37:e1074-e1079.