The coracoacromial ligament (CAL) is widely attached to the area from the anterior edge to the anterolateral site of the acromial undersurface and extends across the lateral side of the acromion. Several anatomical studies have reported variations in CAL thickness at the acromial undersurface. The development of imaging modalities such as ultrasound and magnetic resonance imaging (MRI) has facilitated detailed assessment of the soft tissues around the acromial undersurface because the CAL is visible as a low-signal intensity area from the anterior edge to the anterolateral site of the acromial undersurface. MRI is more suitable than ultrasonography for observing the soft tissues beneath bone. Researchers have suggested that MRI may be useful for CAL assessment at the undersurface in cadaveric shoulders conducted by Ozaki et al, who found that the severity of pathological findings at the acromial undersurface was correlated with the severity of rotator cuff tears. These findings may assist toward understanding the progressive pathology in rotator cuff disease.

Background: Some researchers have stated that magnetic resonance imaging (MRI) is useful for assessing the coracoacromial ligament (CAL) at the acromial undersurface. However, few studies have investigated the reliability and clinical significance of MRI findings for the CAL at the acromial undersurface. The purpose of this study was to determine the association between CAL thickness at the acromial undersurface and rotator cuff tear size. Methods: The CAL thickness at the acromial undersurface was evaluated in 182 patients with rotator cuff tears (mean age: 64.9 ± 8.4 years) using a 3.0-Tesla MRI system. The association between CAL thickness at the acromial undersurface and rotator cuff tear size determined by the DeOrio and Cofield classification (partial; small: <1 cm; medium: 1-3 cm; and large or massive: >3 cm) was analyzed statistically. The intraobserver and interobserver reliabilities for MRI measurements of CAL thickness at the acromial undersurface were determined by calculation of intraclass correlation coefficients and their 95% confidence intervals. Results: The mean CAL thickness at the acromial undersurface was 2.7 ± 1.4 mm (range: 0-6.5 mm). Increasing rotator cuff tear size was significantly associated with decreasing CAL thickness at the acromial undersurface (P = .004). The intraobserver and interobserver intraclass correlation coefficients for CAL thickness at the acromial undersurface were almost perfect (0.98 and 0.91, respectively). Conclusion: The present study clarified that (1) MRI was a reliable tool for evaluation of CAL thickness at the acromial undersurface and (2) increasing rotator cuff tear size was significantly associated with decreasing CAL thickness at the acromial undersurface. These findings may assist toward understanding the progressive pathology in rotator cuff disease.

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alone cannot explain the pathogenesis for the development and progression of rotator cuff tears. However, thickness alteration of the CAL at the acromial undersurface, which is representative of extrinsic factors, may be involved in the pathogenesis of rotator cuff tear progression.

The purpose of this study was to determine the association between CAL thickness at the acromial undersurface and rotator cuff tear sizes. The hypothesis of the study was that increasing rotator cuff tear size was significantly associated with decreasing thickness of the CAL. Such information may help orthopedic surgeons to understand the pathology of subacromial impingement and to develop surgical treatment strategies for patients with subacromial impingement and rotator cuff tears.

**Methods**

Radiographic data were retrospectively reviewed for 213 patients who underwent arthroscopic shoulder surgery for a rotator cuff tear at our institution between April 2016 and March 2017. Patients who had previous shoulder surgery (n = 1), dislocation of the shoulder (n = 2), calcific tendinitis (n = 2), frozen shoulder (n = 1), recurrent hemorrhosis (n = 1), moderate or severe osteoarthritis of the shoulder (n = 2), and collagen disease (n = 1) were excluded. Nineteen shoulders were excluded because of poor-quality radiographs. Finally, 182 shoulders in 182 patients (90 men and 92 women; mean age: 64.89 ± 8.39 years) were included in the study. The surgical procedures were performed by 3 surgeons (S.M., M.T., and Y.T.). The shoulders were divided into 4 groups as per cuff tear size based on the classification of DeOrio and Cofield9: partial-thickness tear (P group); small tear (<1 cm; S group), 51 shoulders; medium tear (1-3 cm; M group), 43 shoulders; and large or massive tear (>3 cm; L group), 43 shoulders, with an arthroscopic probe (in 2-mm increments). Factors potentially related to subacromial impingement syndrome (age, sex, dominant side, and acromion morphology [critical shoulder angle, 12,22,23 acromial index, 26 lateral acromial tilt, 1 size of spurs 28]) were statistically compared among the 4 groups.

**Measurement of CAL thickness**

The MRI examinations were performed using a T2 spin echo sequence (echo time = 119; reception time = 4510) with 3-mm sections at 0.6-mm intervals, matrix size of 448 × 358, and field of view of 150 mm. As previously reported, 8,13,15,32,35 the CAL was defined as the low-signal region on the acromial undersurface. The CAL thickness measurement was performed at the lateral margin of the acromion at the insertion of the CAL. 9 A vertical line was drawn at the thickest point of the CAL insertion (Fig. 1). 13

**Statistical analysis**

Statistical analyses were performed using SPSS software (version 17.0; IBM, Armonk, NY, USA). First, 1-way analysis of variance, the Kruskal–Wallis test, and the chi-square test were used to assess differences in factors potentially related to subacromial impingement among the 4 groups. Second, the association between CAL thickness at the acromial undersurface and rotator cuff tear size was assessed by assigning ranks of 0–3 to a partial-thickness tear (0), small tear (1), medium tear (2), and large or massive tear (3). The Jonckheere–Terpstra trend test was used to test the association between CAL thickness at the acromial undersurface and rotator cuff tear size. P < .05 was considered to indicate a statistically significant difference.

To determine the intraobserver and interobserver reliabilities for subacromial CAL thickness measurements on MRI, intraclass correlation coefficients (ICCs) and their 95% confidence intervals were calculated. For intraobserver reliability, measurements of CAL thickness at the acromial undersurface were carried out twice with an interval of 1 month by 1 examiner (S.M.). For interobserver reliability, measurements of CAL thickness were carried out by 2 examiners (S.M. and Y.T.) with more than 10 years of experience. The agreement of the findings was assessed in accordance with the Landis and Koch criteria 30 as slight (ICC: 0.00–0.20), fair (ICC: 0.21–0.40), moderate (ICC: 0.41–0.60), substantial (ICC: 0.61–0.80), and almost perfect (ICC: 0.81–1.00).

**Results**

The comparisons revealed no significant differences in any of the factors potentially related to subacromial impingement among the 4 groups (Table I).

The mean CAL thickness at the acromial undersurface was 2.74 ± 1.40 mm (range: 0–6.5 mm). Regarding the sizes of the rotator cuff tears, the mean CAL thickness at the acromial undersurface was 2.89 ± 1.27 mm in group P, 3.02 ± 1.19 mm in group S, 3.13 ± 1.06 mm in group M, and 1.87 ± 1.71 mm in group L. A trend test indicated that increasing rotator cuff tear size was significantly associated with decreasing thickness of the subacromial CAL (P < .004).

The ICCs for the intraobserver and interobserver reliabilities for MRI measurements of CAL thickness at the acromial undersurface were almost perfect (0.98 and 0.91, respectively).

**Discussion**

The present study involving MRI evaluation of shoulders in patients with rotator cuff tears revealed that (1) the mean CAL thickness at the acromial undersurface was 2.74 ± 1.40 mm and (2) increasing rotator cuff tear size was significantly associated with decreasing thickness of the CAL at the acromial undersurface (P = .004).

Plain X-ray and computed tomography examinations have been used to evaluate the CAL attachments at the acromial undersurface in shoulders with rotator cuff disease. These imaging modalities allow visualization of bony changes such as osteophytes, but cannot show changes in soft tissues such as ligaments. Anatomical studies that examined the CAL thickness at the acromial undersurface revealed individual variation in its thickness (range: 0.7 – 6.5 mm). 6,10 Developments in MRI technology have made it possible to measure the CAL thickness in the shoulder of the living body. 8,13,15,32,35 The present MRI observational study revealed a thickness range of 0.65 mm, consistent with the previous anatomical reports. 3 This consistency indicates that the CAL thickness at the acromial undersurface can be adequately evaluated by MRI. However, there is still no consensus on the optimal method for MRI observation of the CAL at the acromial undersurface. To the best of our knowledge, the only study to investigate the reproducibility and accuracy of MRI measurements of the CAL at the acromial undersurface was conducted by Incesoy et al. 12 Although there were some differences in the magnetic field strength and imaging conditions, the measurements in both studies were highly reproducible. Therefore, the CAL thickness at the acromial undersurface can be successfully measured on oblique coronal images obtained with 1.5- to 3.0-Tesla MRI systems.

The clinical significance of the CAL thickness at the acromial undersurface remains unclear, but several MRI observational studies suggested that a thickened CAL may be related to subacromial impingement and rotator cuff tears. 6,13,32,35,36 Smith et al 35 and Steinbach et al 36 presented MRI images of a thickened CAL in patients with signs of impingement. Farley et al 13 described that the prevalence of CAL thickness ≥2 mm was 38% in a supraspinatus...
tendon tear group, compared with 10% in an asymptomatic group. Gagey et al\textsuperscript{11} reported that an “aggressive” thickened CAL was found in 45% of patients with impingement, compared with 12% of patients in the control group. Incesoy et al\textsuperscript{13} found that the CAL at the acromial undersurface in patients with rotator cuff tears was significantly thicker than that in control patients. Taken together, these studies all suggest that the thickness of the CAL, a structure at the acromial undersurface of the shoulder, is related to rotator cuff disease.\textsuperscript{8,11,13,35,36}

The clinical significance of the CAL thickness “alteration” at the acromial undersurface also remains unclear. The present MRI observational study is the first to show a relationship between rotator cuff tear size and CAL thickness at the acromial undersurface. This finding may reflect the process of gradual wear and tear due to repeated pathological contact between the rotator cuff and the CAL at the acromial undersurface. Routine contacts between the acromial undersurface (where the CAL is attached) and the rotator cuff were revealed in several studies.\textsuperscript{7,12,17,19,25,29,33,41,42} The repeated contact is considered to turn into a pathological contact termed subacromial impingement associated with shoulder motion pain in response to certain triggers. As per previous anatomical and histological studies, subacromial impingement leads to structural and histological changes (rupture) of the rotator cuff with irreversible degenerative changes, including “thickened fibrocartilaginous change of the acromial undersurface”, and finally eburnation of the acromial undersurface.\textsuperscript{24,27,37,38} The development of arthroscopy has allowed intraoperative assessment of changes at the acromial undersurface in patients with rotator cuff disease. Recently, Levy et al\textsuperscript{18} presented an arthroscopic grading system for damage to the acromial undersurface, including the CAL (Copeland–Levy classification). Miyake et al\textsuperscript{21} assessed the extent and degree of damage to the acromial undersurface in shoulders with rotator cuff tears, using the Copeland–Levy classification.\textsuperscript{18} The results showed that increasing cuff tear size was significantly associated with worsening damage to the acromial undersurface.\textsuperscript{21} The findings in the present MRI observational study support the previous anatomical and arthroscopic observational findings\textsuperscript{15,21,30} and contribute toward an understanding of the progressive pathogenesis of rotator cuff tears. However, it is not clear whether the CAL thickness “alteration” is a result of the rotator cuff tear or a cause of the rotator cuff tear. This uncertainty is similar to the case of the formation of subacromial osteophytes. To clarify this point, the CAL thickness alterations in individual patients require repeated observation by MRI for a long period.

Figure 1 (a) The oblique coronal section of an MRI image showing measurement of the CAL thickness at the acromial undersurface. The CAL thickness was measured at the lateral margin of the acromion at the insertion of the CAL. A vertical line was drawn at the thickest point of the CAL insertion. (b) The oblique coronal section of an MRI image showing a thick subacromial CAL with a deep bursal-side partial-thickness rotator cuff tear (CAL thickness: 3.9 mm). (c) The oblique coronal section of an MRI image showing a thin subacromial CAL with a large rotator cuff tear and a thin subacromial CAL (CAL thickness: 0 mm). MRI, magnetic resonance imaging; CAL, coracoacromial ligament.
Table I
Relationships of patient characteristics and acromial radiographic characteristics in the rotator cuff tear groups.

| Groups | P | S | M | L | P value |
|--------|---|---|---|---|--------|
| Age (yr) | 63.8 ± 9.1 | 63.4 ± 8.8 | 65.5 ± 8.0 | 67.1 ± 6.9 | .13* |
| Sex (male/female) | 22/23 | 25/26 | 20/23 | 23/20 | .93 |
| Dominant side | 25 | 26 | 25 | 24 | .92 |
| Critical shoulder angle (°) | 34.5 | 34.4 | 34.8 | 35.5 | .43 |
| Acromion index | 0.67 | 0.65 | 0.64 | 0.67 | .06 |
| Lateral acromial tilt (°) | 81.4 | 82 | 81.6 | 79.5 | .31 |
| Acromial spur (nm) | 1.8 ± 3.0 | 3.1 ± 4.6 | 3.4 ± 5.0 | 4.5 ± 5.8 | .1* |

P group, a partial-thickness tear; S group, a small tear (<1 cm); M group, a medium tear (1-3 cm); L group, a large or massive tear (>3 cm).
*One-way analysis of variance.
**Kruskal–Wallis test.
***Chi-square test.

The present findings raise questions about the predictors proposed by Incesoy et al., among which increased CAL thickness was an independent risk factor for rotator cuff tear development. These questions arise because the sizes of the rotator cuff tears included in the previous study remain unclear. The present results showed that patients with smaller rotator cuff tears had greater CAL thicknesses, but as the tear size increased, the CAL became significantly thinner. Therefore, high CAL thickness may not necessarily be a predictor of rotator cuff tear development in cases with larger rotator cuff tears.

Measurement of CAL thickness at the acromial undersurface may contribute to surgical treatment strategies in patients with rotator cuff tears. Prolonged conservative therapy may be detrimental to patients with an aggressive thickened subacromial CAL with subacromial impingement signs or rotator cuff tears. In these patients, arthroscopic subacromial decompression may be considered as a treatment option. To clarify this point, prospective randomized trials focusing on CAL thickness in patients with rotator cuff tears and subacromial impingement syndrome are warranted.

The present study had several limitations. First, it was unclear whether or not the low-intensity structures at the acromial undersurface were histological ligamentous components. Second, there were no comparisons with CAL thicknesses in a healthy control group. Third, the rotator cuff tendon tear size data were not recorded accurately, although the patients were divided into 4 groups as per cuff tear size based on the classification of DeOrio and Cofield. Fourth, it was not clear whether rotator cuff tears were traumatic or nontraumatic.

Conclusion

The present study clarified that (1) MRI was a reliable tool to evaluate CAL thickness at the acromial undersurface and (2) increasing rotator cuff tear size was significantly associated with decreasing thickness of the CAL at the acromial undersurface.

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References

1. Banas MP, Miller RJ, Totterman S. Relationship between the lateral acromion angle and rotator cuff disease. J Shoulder Elbow Surg 1995;4:454-61.
2. Chiapat L, Palmer WE. Shoulder magnetic resonance imaging. Clin Sports Med 2006;25:371-86. https://doi.org/10.1016/j.csm.2006.03.002.
3. Codman EA. The shoulder. Boston: Thomas Todd Company; 1934.
4. Cook TS, Stein JM, Simonson S, Kim W. Normal and variant anatomy of the shoulder on MRI. Magn Reson Imaging Clin N Am 2011;19:581-94. https://doi.org/10.1016/j.mric.2011.05.005.
5. De Maeseneer M, Van Roy P, Shahabpour M. Normal MR imaging anatomy of the rotator cuff tendons. Glenoid fossa, labrum, and ligaments of the shoulder. Radiol Clin North Am 2006;44:479-87. https://doi.org/10.1016/j.rcl.2006.04.002.
6. DeOrio JK, Cofield RH. Results of a second attempt at surgical repair of a failed initial rotator-cuff repair. J Bone Joint Surg Am 1984;66:563-7.
7. Flattow EL, Soslowski LJ, Tischer TJ, Pawlik RJ, Hepler M, Ark J, Mow VC, Biglani LJ. Excision of the rotator cuff under the acromion. Patterns of subacromial contact. Am J Sports Med 1994;22:779-88.
8. Farley TE, Neumann CH, Steinbach LS, Petersen SA. The coracoacromial arch: MR evaluation and correlation with rotator cuff pathology. Skeletal Radiol 1994;23:641-5.
9. Fealy S, April EW, Khazzam M, Armengol-Barallat J, Biglani LJ. The coracoacromial ligament: morphology and study of acromial enthesopathy. J Shoulder Elbow Surg 2005;14:542-8. https://doi.org/10.1016/j.jse.2005.02.006.
10. Gallino M, Battiston B, Annaratone G, Terragnoli F. Coracoacromial ligament: a comparative arthroscopic and anatomic study. Arthroscopy 1995;11:564-7.
11. Gagey N, Ravaud E, Lassau JP. Anatomy of the acromial arch: correlation of imaging and MR findings. Rev Chir Orthop 2003;89:617-22. https://doi.org/10.1016/S0034-7250(03)00592-3.
12. Hymon P, Lantto V, Jalovaara P. Local pressures in the subacromial space. Int Orthop 2003;27:373-7. https://doi.org/10.1007/s00264-003-0488-z.
13. Incesoy MA, Kuldak A, Yildiz KI, Misir A. Higher coracoacromial ligament thickness, critical shoulder angle and acromion index are associated with rotator cuff tears in patients who undergo arthroscopic rotator cuff repair. Arthroscopy 2021;11. https://doi.org/10.1016/j.arthro.2021.05.057.
14. Kanatli U, Ayanoglu T, Akrajt E, Atoaglu MB, Ozer M, Çetinkaya M. Grade of coracoacromial ligament degeneration as a predictive factor for impingement syndrome and type of partial rotator cuff tear. J Shoulder Elbow Surg 2016;25: 1824-8. https://doi.org/10.1016/j.jse.2016.02.026.
15. Kaplan PA, Bryans KC, Davick JP, Otte M, Stinson WW, Dussault RG. MR imaging of the normal shoulder: variants and pitfalls. Radiology 1992;184:519-24.
16. Landis JR, Koch GG. The measurement of observer agreement for categorical data. Biometrics 1977;33:159-74.
17. Lee SB, Ito E, O’Driscoll SW, An KN. Contact geometry at the undersurface of the acromion with and without a rotator cuff tear. Arthroscopy 2001;17:365-72.
18. Levy O, Sforza G, Dodenhoff R, Copeland S. Arthroscopic evaluation of the impingement lesion: pathoanatomy and classification. J Bone Joint Surg Br 2000;82B:233.
19. Lochnuiller EM, Maier U, Anetzberger H, Habermeyer P, Müller-Gerbl M. Determination of subacromial space width and inferior acromial mineralization by 3D CT. Preliminary data from patients with unilateral supraspinatus outlet syndrome. Surg Radiol Anat 1997;19:329-37.
20. Milz S, Jakob J, Büttner A, Tischer T, Putz R, Benjamin M. The structure of the coracoacromial ligament: fibrocartilaginous differentiation does not necessarily mean pathology. Scand J Med Sci Sports 2008;18:16-22. https://doi.org/10.1111/j.1600-0838.2007.00644.x.
21. Miyake S, Tamai M, Takeuchi Y, Izaki T, Shibata T, Tachibana K, Irie Y, Yamamoto T. Where and what damage occurs at the acromial undersurface in patients with rotator cuff tear? J Shoulder Elbow Surg 2020;29:2065-71. https://doi.org/10.1016/j.jse.2020.02.002.
22. 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;95:935-41. https://doi.org/10.1302/0301-620X.95B7.31028.

23. 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;23:536-41. https://doi.org/10.1016/j.jse.2013.11.008.

24. Neer CS 2nd. Impingement lesions. Clin Orthop Relat Res 1983;173:70-7.

25. Nordt WE 3rd, Garretson RB 3rd, Plotkin E. The measurement of subacromial contact pressure in patients with impingement syndrome. Arthroscopy 1999;15:121-5.

26. 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;88:800-5. https://doi.org/10.2106/JBJS.D.03042.

27. Ogata S, Uhthoff HK. Acromial enthesopathy and rotator cuff tear. A radiologic and histologic postmortem investigation of the coracoacromial arch. Clin Orthop Relat Res 1990;254:39-48.

28. Ogawa K, Yoshida A, Inokuchi W, Naniwa T. Acromial spur: relationship to aging and morphologic changes in the rotator cuff. J Shoulder Elbow Surg 2005;14:591-8. https://doi.org/10.1016/j.jse.2005.03.007.

29. Oizumi N, Suenaga N, Minami A, Iwasaki N, Miyazawa T. Stress distribution patterns at the coracoacromial arch in rotator cuff tear measured by computed tomography osteoabsorptiometry. J Orthop Res 2003;21:393-8. https://doi.org/10.1016/S0736-0266(02)00231-0.

30. Ozaki J, Fujimoto S, Nakagawa Y, Masuhara K, Tamai S. Tears of the rotator cuff of the shoulder associated with pathological changes in the acromion. A study in cadaver. J Bone Joint Surg Am 1988;70:1224-30.

31. Park J, Chai JW, Kim DH, Cha SW. Dynamic ultrasonography of the shoulder. Ultrasound 2018;37:190-9. https://doi.org/10.14366/usg.17055.

32. Rudez J, Zanetti M. Normal anatomy, variants and pitfalls on shoulder MRI. Eur Radiol 2008;18:25-33. https://doi.org/10.1007/s00330-007-0668-9.

33. Sigholm G, Styf J, Körner L, Herberts P. Pressure recording in the subacromial bursa. J Orthop Res 1988;6:123-8.

34. Seeger LL, Gold RH, Bassett LW, Ellman H. Shoulder impingement syndrome: MR findings in 53 shoulders. AJR Am J Roentgenol 1988;150:343-7.

35. Smith EP, Vassiliou CE, Pack JR, von Borstel D. Shoulder impingement and associated MRI findings. J Am Osteopath Coll Radiol 2018;7:5-14.

36. Steinbach LS, Gunther SB. Magnetic resonance imaging of the rotator cuff. Semin Roentgenol 2000;35:200-16.

37. Suenaga N, Minami A, Fukuda K, Kaneda K. The correlation between bursectopic and histologic findings of the acromion undersurface in patients with subacromial impingement syndrome. Arthroscopy 2002;18:16-20. https://doi.org/10.1053/jars.2002.25963.

38. Takase K, Yamamoto K. Histological and ultrastructural changes in the undersurface of the acromion with subacromial impingement. Acta Orthop 2005;76:386-91.

39. Tottenman SM, Miller RJ, Meyers SP. Basic anatomy of the shoulder by magnetic resonance imaging. Top Magn Reson Imaging 1994;6:86-93.

40. Wu CH, Chang KV, Su PH, Kuo WH, Chen WS, Wang TG. Dynamic ultrasonography to evaluate coracoacromial ligament displacement during motion in shoulders with supraspinatus tendon tears. J Orthop Res 2012;30:1430-4. https://doi.org/10.1002/jor.22084.

41. Wueckner N, Roetman B, Roessig S. Coracoacromial pressure recordings in a cadaveric model. J Shoulder Elbow Surg 1995;4:462-7.

42. Yamamoto N, Muraki T, Sperling JW, Steinmann SP, Itoi E, Cofield RH, An KN. Contact between the coracoacromial arch and the rotator cuff tendons in nonpathologic situations: a cadaveric study. J Shoulder Elbow Surg 2010;19:681-7. https://doi.org/10.1016/j.jse.2009.12.006.