Which shoulder motions cause subacromial impingement? Evaluating the vertical displacement and peak strain of the coracoacromial ligament by ultrasound speckle tracking imaging

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Background: Subacromial impingement is a common cause of shoulder pain and one cause of rotator cuff disease. We aimed to identify which shoulder motions cause subacromial impingement by measuring the vertical displacement and peak strain of the coracoacromial ligament using ultrasound speckle tracking imaging.

Methods: Sixteen shoulders without shoulder disability were enrolled. All subjects were men, and the average age was 28.6 years. The vertical displacement and peak strain of the coracoacromial ligament were analyzed by the motion tracing program during the following active assisted motions (active motion controlled by the examiner): (1) forward flexion in the scapular plane, (2) horizontal abduction in the axial plane, (3) external rotation with the arm at 0° abduction (ER\textdegree), (4) internal rotation with the arm at 0° abduction (IR\textdegree), (5) internal rotation with the arm at 90° abduction (IR90), and (6) internal rotation at the back (IRB).

Results: The mean vertical displacement of the coracoacromial ligament during forward flexion (2.2 mm), horizontal abduction (2.2 mm), and IR90 (2.4 mm) was significantly greater than that during the other motions (ER\textdegree, 0.7 mm; IR\textdegree, 0.5 mm; IRB, 1.0 mm; \(P < .003\)). The mean peak strain was significantly higher in forward flexion (6.88%), horizontal abduction (6.58%), and IR90 (4.88%) than with the other motions (ER\textdegree, 1.42%; IR\textdegree, 1.78%; IRB, 2.61%; \(P < .003\)).

Conclusions: Forward flexion, horizontal abduction, and IR90 showed higher vertical displacement and peak strain of the coracoacromial ligament, causing subacromial impingement. It is recommended that patients with impingement syndrome or a repaired rotator cuff avoid these shoulder motions.

Institutional Review Board approval for the study protocol was provided by Seoul St. Mary’s Hospital, The Catholic University of Korea: No. KC13OISI0679. Written informed consent was obtained from every subject.

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Subacromial impingement syndrome is a common cause of shoulder pain and disability. In 1972, Neer first reported subacromial impingement syndrome. He indicated that the coracoacromial ligament and the anterior third of the acromion are responsible for subacromial impingement of the rotator cuff. After this description, many investigators examined the clinical importance of impingement syndrome. Bigliani et al described the association of bone morphology of the acromion with rotator cuff disease, and Nyffeler et al emphasized that large lateral extension of the acromion is related to rotator cuff tear. It is well known that subacromial impingement is a major extrinsic factor in rotator cuff diseases, although intrinsic factors, such as degeneration, microtrauma, oxidative stress, and tendon apoptosis, might be initiating factors.

Several recent studies have suggested that subacromial bursal cells may be activated to secrete proinflammatory cytokines, such as substance P, stromal cell–derived factor 1, and vascular endothelial growth factor, by various stimuli, such as subacromial impingement, and that highly concentrated proinflammatory cytokines might result in subacromial bursitis in rotator cuff disease. Therefore, acromioplasty has traditionally been performed as a routine part of rotator cuff repair.

MacDonald et al designed multicenter randomized controlled trials to compare clinical outcomes of rotator cuff repair with and without acromioplasty. They concluded that there was no significant difference in functional scores between the 2 groups; however, they did find a strong trend toward a greater number of reoperations in the nonacromioplasty group. Furthermore, Bigliani et al demonstrated that insufficient subacromial decompression might be a cause of failed rotator cuff repair.

Many modalities are used to evaluate shoulder motions that reproduce subacromial impingement. Wu et al calculated the displacement of the coracoacromial ligament using dynamic ultrasonography in shoulders with rotator cuff tears during passive and active shoulder abduction and internal rotation. They observed greater displacement of the coracoacromial ligament in torn rotator cuffs than in intact ones during passive shoulder abduction and internal rotation. Yamamoto et al designed a cadaveric study to evaluate the contact pressure between the coracoacromial arch and rotator cuff tendons during several shoulder motions. Specific shoulder motions, such as flexion, horizontal abduction, and extension, resulted in higher contact pressure than other motions did. These previous studies show that specific shoulder motions are likely to cause subacromial impingement. However, few studies have explored the in vivo conditions of the coracoacromial ligament during these shoulder motions. Some studies were performed to evaluate the in vivo properties of the coracoacromial ligament, but only during limited shoulder motions.

The purpose of this study was to analyze the in vivo vertical displacement and intraligamentous strain of the coracoacromial ligament, which might reflect the presence of subacromial impingement during various shoulder motions. We hypothesized that subacromial impingement occurs in the normal shoulder and that specific shoulder motions are more closely related to subacromial impingement.

Materials and methods

This was an ultrasonographic observational study to analyze the in vivo vertical displacement and intraligamentous strain of the coracoacromial ligament during various shoulder motions. Eight healthy volunteers with no history of shoulder pain were enrolled for a total of 16 shoulders. All were men, and the average age was 28.6 years. All enrolled volunteers were Korean; the height ranged from 170 to 180 cm, and all were right handed. The exclusion criteria were as follows: patients younger than 18 years, a history of shoulder pain or trauma, and any pathologic findings during ultrasonographic examination. A single orthopedic surgeon (Y.-S.K. with 10 years of experience in ultrasonographic examination) examined all shoulders using 2-dimensional speckle tracking echocardiography (2D STE). During static ultrasonography, the examiner assessed structures including the biceps tendon, rotator cuff, and subacromial bursa with routine ultrasonographic examination maneuvers. Dynamic ultrasonography with the motion tracking program was used to evaluate the vertical displacement and peak strain of the coracoacromial ligament during the following motions: (1) forward flexion in the scapular plane, (2) horizontal abduction in the axial plane, (3) external rotation with the arm at 0° abduction (ER0), (4) internal rotation with the arm at 0° abduction (IR0), (5) internal rotation with the arm at 90° abduction (IR90), and (6) internal rotation at the back (IRB). All shoulder motions were evaluated during active assisted motion with an average velocity of 22.5°/s. During ultrasonographic examination, the examiner assisted the subjects in actively moving their arms at a constant velocity and precise direction that means active assisted shoulder motions. Forward flexion was performed with the arm in the neutral position and flexed in the scapular plane from 0° to 90° because ultrasonographic tracing of the coracoacromial ligament during forward flexion above 90° was technically difficult. Horizontal abduction was defined as backward movement of the arm from 0° to 45° with 90° of...
shoulder abduction.27 ER0 and IR0 were performed with the arm in the neutral position, the elbow flexed to 90°, and the shoulder internally or externally rotated through the entire range of motion. IR90 was checked with 90° shoulder abduction and internal rotation through the entire range of motion. IRB was checked with the hand placed at the back and subsequently elevated from the buttock to the thoracic vertebral level.

All ultrasonographic examinations were performed with an echocardiography system (Vivid S5; GE Vingmed Ultrasound AS, Horten, Norway) by 2D STE using a 12L-RS linear probe in harmonic mode (frequency, 6-13 MHz). A technician from the company provided technical support about ultrasonographic settings. Table I shows a complete overview of the recording and algorithm settings. During ultrasonographic examination, each subject was seated upright with the arm in the neutral position and the elbow flexed to 90°. The coracoacromial ligament was identified with the ultrasonographic transducer placed perpendicular to the skin between the coracoid process and the acromial tip. The coracoacromial ligament was traced throughout each shoulder motion. All motions were recorded with animated films at a rate of 72 frames/s and imported into MATLAB (MathWorks, Natick, MA, USA) for further analysis. The vertical displacement of the coracoacromial ligament with various degrees of superior bulging away from the surface of the rotator cuff could be seen, and degree of vertical displacement was measured from the vertex of the coracoacromial ligament convexity to a line connecting the acromion and coracoid process (Fig. 1).24 The longitudinal peak strain of the coracoacromial ligament was calculated by the horizontal fractional change. A region of interest was placed in a longitudinal direction along the coracoacromial ligament. The region of interest consisted of 3 speckles, and the greatest measurement between the 3 speckles was recorded (Fig. 2). 2D STE allows noninvasive tracking of tissues such as the myocardium or tendons in real time. Recently, many studies evaluated the efficacy of 2D STE, and they verified the diagnostic accuracy of 2D STE compared with more conventional techniques, such as magnetic resonance imaging.1,9,19 This ultrasonographic technique to analyze strain was used in other studies to evaluate strain on the supraspinatus tendon or myocardium.2,12 We acquired 3 image loops and then analyzed each image 3 times.

### Statistical analysis

All statistical analyses were performed with the SPSS software package (version 21.0; SPSS, Chicago, IL, USA). We used the Kruskal-Wallis test and Mann-Whitney test to compare the differences in vertical displacement and peak strain of the coracoacromial ligament during each shoulder motion. P < .05 was considered statistically significant on the Kruskal-Wallis test, and P < .003 (.05/15) was considered statistically significant on the Mann-Whitney test. Interobserver and intraobserver reliabilities for each shoulder motion measurement were determined for 2 independent blinded observers using Pearson correlation analysis.

### Results

There were no findings of shoulder disease in any subject on static ultrasonography. On dynamic ultrasonography, the vertical displacement and peak strain of the coracoacromial ligament differed among shoulder motions. Table II shows a complete overview of the measurement values.

The mean vertical displacements of the coracoacromial ligament during shoulder flexion (2.2 ± 1.1 mm), horizontal abduction (2.2 ± 0.7 mm), and IR90 (2.4 ± 0.8 mm) were significantly greater than those of the other shoulder motions (ER0, −0.7 ± 0.9 mm; IR0, 0.5 ± 0.7 mm; IRB,
1.0 ± 0.7 mm; *P < .003*. There was no statistical difference in vertical displacement between forward flexion, horizontal abduction, and IR90. The mean peak strains were significantly higher during forward flexion (6.88% ± 3.02%), horizontal abduction (6.58% ± 2.60%), and IR90 (4.88% ± 2.45%) than during the other shoulder motions (ER0, 1.42% ± 0.80%; IR0, 1.78% ± 0.89%; IRB, 2.61% ± 1.66%; *P < .003*). There was no statistical difference in the mean peak strain between forward flexion, horizontal abduction, and IR90 (Fig. 3 and Table III). There was no significant difference between both sides of the shoulder in the same person.

The correlation coefficient for interobserver variability in vertical displacement measurement was 0.86, and that for intraobserver reliability was 0.90 (*P < .003*). The correlation coefficient of the interobserver reliability in peak strain measurement was 0.77, and that for intraobserver reliability was 0.82 (*P < .05*).

### Discussion

In this study, the vertical displacement and peak strain of the coracoacromial ligament during forward flexion, horizontal abduction, and IR90 were significantly higher than those during other shoulder motions. These motions are different from those performed during classic shoulder impingement tests, such as the Neer test and Hawkins–Kennedy test, but these motions are closely related to our activities of daily living, such as follow-through during throwing a ball, descending from a lift, or reaching to the back seat in a car. Previous studies also demonstrated that some specific shoulder motions resulted in subacromial impingement phenomenon. However, the studies were limited to only a few shoulder motions or those performed during shoulder impingement testing. In this study, we focused on impingement-provoking shoulder motions in activities of daily living.

We also demonstrated that normal shoulders without any pathologic change could result in physiologic contact beneath the coracoacromial ligament. The peak strain of the coracoacromial ligament could be measured during almost all motions in all subjects. Furthermore, the coracoacromial ligament was vertically displaced during some shoulder motions in all subjects. These findings indicate that there is physiologic contact between the coracoacromial ligament and the rotator cuff in normal shoulders. Although this physiologic contact would not cause symptoms in normal shoulders, repetitive contact during shoulder motions of daily living, especially during forward flexion, horizontal abduction, and IR90, could result in accumulated stress on the coracoacromial ligament or the rotator cuff, which might be a risk factor for subacromial impingement. Furthermore, in patients with subacromial bursitis or a repaired rotator cuff, these motions might cause symptom aggravation and retear of a repaired rotator cuff. Our findings are consistent with those of a previous study that demonstrated the same contact phenomenon between the coracoacromial arch and the rotator cuff in cadavers without any shoulder disease. The investigators evaluated 8 shoulder motions in fresh frozen cadaveric shoulders without any shoulder disease, and they observed this contact phenomenon of the coracoacromial arch during all motions.

2D STE is a noninvasive technique that allows tracking of tissues, such as the myocardium or tendons, in real time. Many previous studies demonstrated that 2D STE showed diagnostic accuracy comparable to that of more conventional techniques, such as magnetic resonance imaging. Although earlier studies focused on tracking the cardiac organs or blood flow, speckle tracking studies have become widely used to estimate the displacement and strain of tendons or muscles. Stegman et al demonstrated the efficacy and accuracy of 2D STE in estimating the displacement of the flexor digitorum superficialis (FDS) tendon. They assessed the displacement of the FDS tendon using 2D STE at wrist level while a video microscope simultaneously imaged the exposed FDS tendon as a reference for validation during open carpal tunnel surgeries. They concluded that the error rate of 2D STE was generally within 5%, and this technique may have applications in clinical tendon assessment. Korstanje et al also emphasized that 2D STE can quantify tendon displacement with high accuracy.


<table>
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<th>Case</th>
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<tr>
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<td>3</td>
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<td>1.09 1.41 7.81 5.16</td>
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<td>Mean ± SE</td>
<td>6.88 ± 3.02</td>
<td>6.58 ± 2.60</td>
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ER, external rotation; IR, internal rotation; R, right shoulder; L, left shoulder; SE, standard error.
They evaluated the in vivo displacement of the FDS tendon using 2D STE, and the average tracking error was only 1.0% to 1.6% compared with cadaveric data. Kim et al assessed not only the displacement but also the strain of the supraspinatus tendon using 2D STE. They evaluated the in vivo strain of the intact supraspinatus tendon during isotonic and isometric shoulder motion. They demonstrated that interobserver and intraobserver reliabilities for isotonic strain measurement ($r = 0.78$ and $0.81$) was relatively lower than that for isometric strain measurement ($r = 0.88$ and $0.90$). In our study, we evaluated the strain of the coracoclavicular ligament during active assisted shoulder motions, and the interobserver and intraobserver reliabilities of the strain measurement ($r = 0.78$ and $0.82$) were similar to those of the previous study examining isotonic strain. Although further studies are necessary to confirm the clinical applicability of 2D STE for

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**Figure 3** The difference in vertical displacement and peak strain for each shoulder motion. (A) Forward flexion, horizontal abduction, and internal rotation at 90° abduction showed significantly higher vertical displacement than that of the other shoulder motions. (B) Forward flexion, horizontal abduction, and internal rotation at 90° abduction showed significantly higher peak strain than that of the other shoulder motions. IR, internal rotation; ER, external rotation.
the musculoskeletal system, we believe that this technique allows accurate and objective quantification of tendon displacement during active movement.

There are some limitations to this study. First, we performed dynamic ultrasonography during active assisted shoulder motions, so a bias might occur in the ultrasonographic scanning. To reduce the variance, the examiner assisted the subjects in actively moving their arms at a constant velocity that means active assisted shoulder motions, not active shoulder motions. Second, the peak strain and vertical displacement of the coracoacromial ligament were evaluated only in the longitudinal plane. Out-of-plane stress on the coracoacromial ligament could have contributed to subacromial impingement. Furthermore, we did not evaluate the stress on the undersurface of the acromion. Motion of the coracoacromial ligament does not fully represent subacromial impingement. Third, the authors did not evaluate magnetic resonance images or radiographs, so we could not investigate the glenohumeral lesion, bone abnormality, acromion shape, and scapulothoracic motion. We admit these factors also influence the degrees of subacromial impingement. To minimize these factors, the subjects with shoulder pain or disability were excluded. Last, the subjects were selected from a specific population of young, healthy men without shoulder disease, and the sample size was relatively small. Therefore, our results may not be representative of subacromial impingement in elderly patients or those with shoulder disability. Also, nonparametric study due to small sample size might have many limitations for this type of investigation. Further studies are required to better understand the effect of these shoulder motions in pathologic shoulders, such as those with a rotator cuff tear or symptomatic impingement syndrome.

### Conclusion

Coracoacromial ligament displacement away from the rotator cuff was observed in almost all shoulder motions in normal shoulders. The degrees of displacement and peak strain were increased during specific shoulder motions, such as forward flexion, horizontal abduction, and IR90. These shoulder motions might result in subacromial impingement syndrome, particularly when these motions are repetitive. Therefore, we recommend that patients with impingement syndrome or a repaired rotator cuff tendon avoid these shoulder motions.

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