The influence of partial subscapularis tendon tears combined with supraspinatus tendon tears

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**Background:** With the advent of arthroscopy, more partial subscapularis tears are being recognized. The biomechanical effects of partial subscapularis tears are unknown, and there is no consensus as to their treatment. Therefore, the objective of this study was to evaluate and to quantify the changes in range of motion and glenohumeral kinematics for isolated subscapularis partial tears, combined subscapularis and supraspinatus tears, supraspinatus repair, and combined supraspinatus and subscapularis repair.

**Methods:** Six cadaveric shoulders were tested in the scapular plane with 0°, 30°, and 60° shoulder abduction under 6 conditions: intact; ¼ subscapularis tear; ½ subscapularis tear; ½ subscapularis and complete supraspinatus tear; supraspinatus repair; and supraspinatus and subscapularis repair. Maximum internal and external rotation and glenohumeral kinematics were measured under physiologic muscle loading condition. A repeated measures analysis of variance with a Tukey post hoc test was used for statistical analysis.

**Results:** Maximum external rotation was significantly increased after ¼ subscapularis tear at 30° abduction and in all abduction angles with ½ subscapularis tear (\(P < .05\)). The 2 repair conditions did not restore external rotation to the intact level. At maximum internal and external rotation, there was a significant superior shift in the humeral head apex position with ¼ subscapularis tear at 30° abduction and with ½ subscapularis tear at 60° abduction (\(P < .05\)). Repair of the supraspinatus tendon partially corrected abnormal kinematics; however, neither repair restored abnormal kinematics to intact.

**Conclusion:** Additional repair of the partial subscapularis tear with supraspinatus tear did not affect external rotation or glenohumeral kinematics. Further studies are needed to evaluate different subscapularis repair techniques.

**Level of evidence:** Basic Science Study, Biomechanics.

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**Keywords:** Subscapularis; kinematics; range of motion; arthroscopy

Whereas numerous studies have been devoted to supraspinatus-infraspinatus tendon tears, subscapularis tendon tears have been fairly underestimated and unrecognized.\(^4,24,26-28,31\) This may be partly due to the assumption that an isolated subscapularis tendon tear is a rare entity\(^5,19,24,28,31\) or that partial subscapularis tendon tears can be difficult to visualize arthroscopically, especially in...
tendons, therefore, we chose 4 lines of pull for subscapularis. Previous studies have shown the subscapularis to have 4 distinct insertion of each muscle with 2-0 FiberWire (Arthrex, Inc, Naples, FL, USA). Multiple lines of pull were used for each muscle. Suture loops were made with a modified Kessler stitch at the partial tears (both subscapularis and supraspinatus) were excluded. articular tendon. Any specimens with evidence of intra-articular pressure and for arthroscopic evaluation of the status of the upper minor, and subscapularis muscles were released from their origins, acohumeral ligament. The supraspinatus, infraspinatus, teres and each specimen was thawed overnight at room temperature in preparation for dissection and testing. The specimens were kept moist with physiologic saline solution to prevent dehydration. All soft tissues were removed except the rotator cuff muscles, gle- nohumeral joint capsule, coracoacromial ligament, and coracohumeral ligament. The supraspinatus, infraspinatus, teres minor, and subscapularis muscles were released from their origins, but their original insertions on the humerus were retained. The glenohumeral joint was vented by a 15-mm longitudinal incision through the rotator interval to remove the negative intra-articular pressure and for arthroscopic evaluation of the status of the upper portion of the subscapularis tendon and supraspinatus intra-articular tendon. Any specimens with evidence of intra-articular partial tears (both subscapularis and supraspinatus) were excluded. Suture loops were made with a modified Kessler stitch at the insertion of each muscle with 2-0 FiberWire (Arthrex, Inc, Naples, FL, USA). Multiple lines of pull were used for each muscle. Previous studies have shown the subscapularis to have 4 distinct tendons; therefore, we chose 4 lines of pull for subscapularis loading. Four lines of pull were also used for the infraspinatus/teres minor to balance the lines of pull with the subscapularis. The supraspinatus was sutured with 2 suture loops for 2 lines of pull, 1 anterior and 1 posterior. Three reference screws were inserted on the scapula (coracoid, anterior acromion, and posterior acromion) and the humerus (proximal bicipital groove, distal bicipital groove, and greater tuberosity) to provide consistent digitization markers to define local coordinate systems on each bone for kinematic measurement. The scapula was secured to an aluminum bracket that was attached to the custom shoulder testing apparatus in the anatomic resting position with 20° anterior tilt in the sagittal plane (Fig. 1). An aluminum rod was inserted into the medullary canal and secured to the distal humerus. The rod was then placed in a custom device attached to the testing system, which allows axial rotation of the humerus and shoulder abduction.

Methods

Specimen preparation

Six cadaveric shoulders were used (mean age, 59 years; range, 44-78 years). There were 1 female and 5 male specimens, thereof 1 left and 5 right shoulders. Specimens with a rotator cuff tear, glenohumeral joint contracture, glenohumeral arthrosis, history of previous fractures, or previous shoulder surgery were excluded. The specimens were stored at –20°C until the day before testing, and each specimen was thawed overnight at room temperature in preparation for dissection and testing. The specimens were kept moist with physiologic saline solution to prevent dehydration. All soft tissues were removed except the rotator cuff muscles, gle- nohumeral joint capsule, coracoacromial ligament, and coracohumeral ligament. The supraspinatus, infraspinatus, teres minor, and subscapularis muscles were released from their origins, but their original insertions on the humerus were retained. The glenohumeral joint was vented by a 15-mm longitudinal incision through the rotator interval to remove the negative intra-articular pressure and for arthroscopic evaluation of the status of the upper portion of the subscapularis tendon and supraspinatus intra-articular tendon. Any specimens with evidence of intra-articular partial tears (both subscapularis and supraspinatus) were excluded. Suture loops were made with a modified Kessler stitch at the insertion of each muscle with 2-0 FiberWire (Arthrex, Inc, Naples, FL, USA). Multiple lines of pull were used for each muscle. Previous studies have shown the subscapularis to have 4 distinct tendons; therefore, we chose 4 lines of pull for subscapularis loading. Four lines of pull were also used for the infraspinatus/teres minor to balance the lines of pull with the subscapularis. The supraspinatus was sutured with 2 suture loops for 2 lines of pull, 1 anterior and 1 posterior. Three reference screws were inserted on the scapula (coracoid, anterior acromion, and posterior acromion) and the humerus (proximal bicipital groove, distal bicipital groove, and greater tuberosity) to provide consistent digitization markers to define local coordinate systems on each bone for kinematic measurement. The scapula was secured to an aluminum bracket that was attached to the custom shoulder testing apparatus in the anatomic resting position with 20° anterior tilt in the sagittal plane (Fig. 1). An aluminum rod was inserted into the medullary canal and secured to the distal humerus. The rod was then placed in a custom device attached to the testing system, which allows axial rotation of the humerus and shoulder abduction.

Muscle loading conditions and testing positions

The amount of muscle loading was determined on the basis of physiologic muscle cross-sectional area ratios: supraspinatus, 20 N (10 N for each line of pull); subscapularis, 30 N; infraspinatus/teres minor, 30 N (7.5 N for each line of pull). On the basis of data from 2 pilot studies that included rotator cuff, deltoid, pectoralis major, and latissimus dorsi loading, we chose to load only the rotator cuff to accentuate the effect of its conditions. Loading the deltoid, pectoralis major, and latissimus dorsi resulted in trends similar to rotator cuff loading alone, with lower magnitudes of changes due to the stabilizing effect of these muscles. Testing was performed in the scapular plane (30° anterior to the coronal plane) at 0°, 30°, and 60° shoulder abduction, considering a 2:1 ratio of glenohumeral to scapulothoracic abduction.

Biomechanical testing

Rotational range of motion was measured with a goniometer located at the distal humeral aluminum rod. Before testing, neutral humeral rotation was defined as the midpoint between maximum internal and external rotation in 30° abduction in the scapular plane with 3.3 Nm of torque using an electronic torque wrench (Jetco, Irwindale, CA, USA); 3.3 Nm of torque was an adequate torque to reach a consistent capsular endpoint but low enough not
to cause any capsular damage. The specimen was then returned to 0° abduction. Before testing at each abduction angle, all muscles were loaded and the specimen was preconditioned from the maximum internal to maximum external rotation for 5 cycles with 3.3 Nm of torque in each direction. Once the maximum internal and external range of motion was determined, the glenohumeral kinematics were recorded throughout the range of motion by digitizing the local coordinate systems (3 small screws inserted previously) of both the glenoid and humerus using a MicroScribe 3DLX (Revware Inc, Raleigh, NC, USA) from maximum internal to maximum external rotation in 5 positions: maximum internal rotation, 30° internal rotation, neutral, 30° external rotation, and maximum external rotation. After testing at 0° shoulder abduction, testing was repeated at 30° and 60° shoulder abduction in the scapular plane.

Testing conditions

After testing of the intact cuff condition, sequential testing was performed for each condition following the same testing procedures repeated at each shoulder abduction angle. Six conditions were tested: intact; ¼ subscapularis tear; ½ subscapularis tear; ½ subscapularis and complete supraspinatus tear; supraspinatus repair; supraspinatus and subscapularis repair. The subscapularis tears were based on the footprint anatomy of the subscapularis.2,9,10,15,34 Because the subscapularis has approximately ⅓ tendinous insertion on the lesser tuberosity and ⅔ muscular insertion directly to the humerus, the ¼ subscapularis tear condition was made by releasing the superior ⅓ subscapularis insertion on the lesser tuberosity. This was measured with a digital caliper (Mitutoyo Corp, Kanagawa, Japan) from top to bottom of the lesser tuberosity. Tear of ½ of the subscapularis insertion was then made by releasing the subscapularis from the superior ⅔ of the lesser tuberosity insertion (Fig. 2). After testing of both, partial subscapularis and supraspinatus tendon complete tear was performed to simulate the common finding of this combination during arthroscopic surgery.

After testing of all tear pattern conditions, 2 repair conditions were tested. First, repair of only the supraspinatus was performed by a transosseous-equivalent method. Two 5.5-mm Bio-Corkscrew FT Suture Anchors loaded with No. 2 FiberWire (Arthrex, Inc) were inserted for the medial row, and the 4 sutures were passed through the supraspinatus tendon. After knotting the sutures at the medial row, 1 suture from each anchor was inserted into a 4.75-mm BioComposite SwiveLock (Arthrex, Inc) and then fixed laterally. For the second (complete) repair, the subscapularis was repaired by a single-row repair with a double-loaded 5.5-mm Bio-Corkscrew FT Suture Anchor (Arthrex, Inc) inserted on the superior-lateral footprint. Two simple sutures, 1 superior and 1 inferior to the anchor location, were then used to reattach the subscapularis to the footprint (Fig. 3).

After all testing procedures, the specimens were carefully disarticulated and the humeral head and glenoid geometry were digitized using the MicroScribe 3DLX to calculate the position of the humeral head apex with respect to the geometric center of the glenoid.25 The differences in the location of the humeral head apex from the intact condition were calculated in the anterior-posterior, superior-inferior, and medial-lateral directions.

Statistics

All measurements were performed twice and the averages were used for data analysis. A repeated measures analysis of variance with a Tukey post hoc test (Statistica, StatSoft, Inc, Tulsa, OK, USA) was used to determine significant differences between each condition. The level of significance was set at $P < .05$.

Results

Maximum external rotation was significantly increased after ¼ subscapularis tear in 30° of abduction ($P = .03$) and after ½ subscapularis tear in both 0° and 60° of abduction ($P < .05$) (Table 1). The addition of a supraspinatus tear significantly increased external rotation compared with ½ subscapularis tear in both 0° and 30° abduction. The 2 repair conditions did not restore maximum external rotation to the level of intact. There were no significant differences in maximum internal rotation for any condition.

At maximum internal and external rotation, there was a significant superior shift in the humeral head apex position.
with ¼ subscapularis tear at 30°/C14 abduction and with ½ subscapularis tear at 60°/C14 abduction (P < .05). The largest changes in glenohumeral kinematics, however, were seen at the maximum external rotation position. Overall, rotator cuff tear shifted the humeral head apex posteriorly, superiorly, and laterally. There was a significant posterior shift of the humeral head compared with intact with ½ subscapularis tear at 60°/C14 abduction and with combined ½ subscapularis tear and supraspinatus tear at 60°/C14 abduction (Fig. 4). There was a significant superior shift with ¼ subscapularis tear at 30°/C14 of abduction and after ½ subscapularis tear at all abduction angles (Fig. 5). There was a significant lateral shift after ½ subscapularis tear at 0°/C14 abduction and with combined ½ subscapularis tear and supraspinatus tear at 30°/C14 abduction (Fig. 6). Supraspinatus repair shifted the humeral head medially at 0° and 30° abduction and anteriorly at 30° abduction compared with the rotator cuff torn state; however, glenohumeral kinematics were not returned to normal for either repair condition.

### Discussion

Partial subscapularis tendon tears increased the maximum external rotation and affected glenohumeral kinematics. However, as expected, the addition of a supraspinatus tendon tear further increased the maximum external rotation and displacement of the humeral head in the end range of motion. Supraspinatus tendon repair partially corrected abnormal kinematics but not to the level of the intact tendon. Additional repair of the partial subscapularis tear did not affect external rotation or glenohumeral kinematics.

The prevalence of subscapularis tendon tears seen in cadavers varies between 29% and 37%. Identifying subscapularis tendon tears in either open or arthroscopic surgery is difficult. This is especially true for partial subscapularis tendon tears (whether complete thickness or not), which are even more difficult to detect on magnetic resonance images and clinical examinations. However, recently in clinical studies specifically looking for subscapularis tears, including our series, subscapularis tendon tears have been reported in more than 50% of cases. Subscapularis tendon tears have an impact on treatment, surgical approach, and postsurgical prognosis. Lo and Burkhart have described the subscapularis tendon as the “forgotten tendon,” relatively ignored in the literature despite its importance. However, because of its large size, partial tears might have less impact on overall shoulder joint kinematics and function; nonetheless, with the

### Table I

<table>
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<th>Intact</th>
<th>¼ SB tear</th>
<th>½ SB tear</th>
<th>½ SB + SS tear</th>
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<td>59.8 (6.1)</td>
<td>63.8 (5.2)</td>
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<td>79.7 (2.7)</td>
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<td>81.5 (5.1)</td>
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<tr>
<td>60° Abduction</td>
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<td>73.8 (7.1)</td>
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<td>79.5 (7.5)</td>
<td>77.5 (7.9)</td>
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SB, subscapularis; SS, supraspinatus.
* P < .05 vs intact.
† P < .05 vs ½ subscapularis tear.

![Figure 4](image-url) Anterior-posterior humeral head apex shift compared with the intact condition at maximum external rotation and each abduction angle. *P < .05 vs intact; †P < .05 vs ½ subscapularis (SB) and supraspinatus (SS) tear.

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**Table I** Maximum external rotation (degrees) (mean (standard error)) for each condition and abduction angle.
increase in the prevalence of arthroscopic rotator cuff surgery, more partial subscapularis tendon tears are being recognized.

There are currently few papers that have classified subscapularis tears. Lafosse et al. described a relatively simple and practical classification of subscapularis partial tears by dividing the subscapularis into thirds, perhaps based on the tears evaluated in their cohort of 17 patients with isolated subscapularis tears. In the current study, we developed a criterion for tears by dividing the subscapularis into 4 parts in the superior-inferior direction, based on the anatomy of the subscapularis footprint and a clinical study that reported a mean of 3.88 tendons (range, 3-5) within the subscapularis in 89 consecutive shoulder magnetic resonance images from patients younger than 30 years without any shoulder disease.

There are few studies investigating the biomechanical role of partial subscapularis tear or anterosuperior tear. Kedgley et al. investigated unconstrained glenohumeral abduction with an electromagnetic tracking system, creating anterosuperior tears as the last condition. These authors concluded that the plane of elevation moved posteriorly and became more abnormal as the tear size increased. Su et al. investigated the effect of anterosuperior tear on glenohumeral translation by performing serial cutting of the supraspinatus followed by 50% of the subscapularis and finally 100% of the subscapularis on superior and anterosuperior translation. They found that anterosuperior translation was greater than superior translation in every combination of anterosuperior rotator cuff defect. In addition, at higher loading conditions (40-50 N), supraspinatus tears combined with tears of the superior half of the subscapularis led to increased translation in both directions. These previous studies evaluated only subscapularis tears combined with supraspinatus tears and did not evaluate isolated subscapularis tears.

**Figure 5** Superior-inferior humeral head apex shift compared with the intact condition at maximum external rotation and each abduction angle. *P < .05 vs intact. SB, subscapularis. SS, supraspinatus.

**Figure 6** Medial-lateral humeral head apex shift compared with the intact condition at maximum external rotation and each abduction angle. *P < .05 vs intact; #P < .05 vs ½ subscapularis (SB) and supraspinatus (SS) tear.
Partial subscapularis tear and repair

Pearsall et al22 evaluated 35 patients with recalcitrant frozen shoulder, who were treated with arthroscopic release of the anterior capsule and the intra-articular component of the subscapularis tendon, which represents about 25% of the entire subscapularis tendon in the superior-inferior dimension. They reported minimal effect on shoulder function, especially in terms of instability after these releases. However, Marquardt et al10 showed in a cadaveric biomechanical study that release of the intra-articular portion of the subscapularis increased glenohumeral translation, especially in the midrange of glenohumeral motion. This study showed translational effect with isolated partial subscapularis tears, whereas the current study did not find any rotational kinematic differences with isolated upper subscapularis tear. In our study, we did not evaluate the effect of subscapularis tears on glenohumeral translation using translational loads; however, we did see an increase in external rotation with partial subscapularis tears, which might indicate an increase in glenohumeral laxity.

Even though arthroscopic subscapularis repair can be technically challenging, it is advocated by several authors. Ticker and Burkhart56 reported that repair of the subscapularis tear may help repair the supraspinatus, whereas Ladermann et al23 have shown that anterior propagation of a subscapularis tear is correlated with pseudoparalysis that may be avoided with repair. Even though we hypothesized that repair of either tendon would restore glenohumeral kinematics and range of motion, we did not detect any differences in comparison to the sole repair of the supraspinatus tendon. This may be due to the subscapularis tendon repair technique or anchor placement. Use of a double-row or transosseous-equivalent repair may have produced better biomechanical results; however, these repairs are difficult to perform arthroscopically, and when they are done in addition to supraspinatus repair, the amount of hardware used becomes an issue. Also, margin convergence between the subscapularis and supraspinatus was not performed, which may have provided greater resistance to external rotation. Further studies should be performed to evaluate different repair techniques of the subscapularis.

There are several limitations to the current study; like all cadaver studies, our study has the limitation of being a time zero study, and pain, which may have an effect on gleno-humeral kinematics or rotational range of motion, cannot be considered. The rotator cuff tears were surgically created, and muscle retraction and fatty infiltration after rotator cuff tear were not evaluated. The tear creation model was limited to complete-thickness partial upper portion tears; in the clinical setting, there is a more diverse scenario, including partial-thickness subscapularis tears. Although different muscle loading may affect gleno-humeral kinematics, constant muscle loading conditions were used on the basis of previous studies and the muscle cross-sectional area ratios; additional studies are needed to evaluate the effect of changes in muscle loading. Finally, limited positions at lower abduction angles were tested on the basis of the influence of cuff muscles at these positions; further studies should be performed evaluating more positions. Despite these limitations, the current study is a comprehensive biomechanical analysis of partial subscapularis tendon tears with added supraspinatus tear. It will give some guidelines to future studies on this difficult topic of partial subscapularis tears.

Conclusions

Partial subscapularis tears increased external rotation and altered glenohumeral kinematics. Supraspinatus tendon repair partially corrected abnormal kinematics but not to the level of the intact tendon. Additional repair of the partial subscapularis tear did not affect external rotation or glenohumeral kinematics. Further studies are needed to evaluate different repair techniques of the subscapularis.

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