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# Effect of Rotator Cuff Muscle Imbalance on Forceful Internal Impingement and Peel-Back of the Superior Labrum

## A Cadaveric Study

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**Background:** Throwing athletes with shoulder pain have been shown to have decreased rotator cuff muscle strength. Shoulder internal impingement and labral peel-back mechanism, as may occur during the late cocking phase of throwing motion, are thought to cause rotator cuff injury and type II superior labrum anterior and posterior lesions. Therefore, the objective of this study was to assess the effect of rotator cuff muscle force on internal impingement and the peel-back of the superior labrum by quantifying maximum external rotation, glenohumeral contact pressure, and position of the cuff insertion relative to the glenoid.

**Hypothesis:** A change in rotator cuff muscle force will lead to increased external rotation, glenohumeral contact pressure, and overlap of the cuff insertion relative to the glenoid.

**Study Design:** Controlled laboratory study.

**Methods:** Eight fresh-frozen cadaveric shoulders were tested at the simulated late cocking position. Glenohumeral contact pressure, location of the cuff insertion relative to the glenoid, and maximum humeral external rotation angle were measured. The forces of the supraspinatus, subscapularis, and infraspinatus muscles were determined based on published clinical electromyographic data. To assess the effect of cuff muscle imbalance, each muscle force was varied. Horizontal abduction positions of 20°, 30°, and 40° with respect to the scapular plane were tested.

**Results:** Decreased subscapularis strength resulted in a significant increase in maximum external rotation ($P < .001$) and increased glenohumeral contact pressure ($P < .01$). The cuff insertion overlapped the edge of the glenoid at 30° and 40° of horizontal abduction for all muscle loading conditions.

**Conclusion:** Decreased subscapularis muscle strength in the position simulating the late cocking phase of throwing motion results in increased maximum external rotation and also increased glenohumeral contact pressure.

**Clinical Relevance:** Athletes with decreased subscapularis muscle strength, such as fatigue with repetitive throwing, may be more susceptible to rotator cuff tears and type II superior labrum anterior and posterior lesions. Subscapularis muscle strengthening exercises may be beneficial for preventing these injuries.

**Keywords:** rotator cuff; muscle; imbalance; internal impingement; labrum; shoulder

Shoulder internal impingement, impingement of the undersurface of the rotator cuff on the posterior superior labrum and the glenoid during the late cocking phase of throwing motion, is thought to be a cause of posterior rotator cuff injury and type II superior labrum anterior and posterior (SLAP) lesions.[9,10,20] To a certain degree, internal impingement contact is physiologic because it occurs in both throwing and nonthrowing shoulders when the arm is in the abducted externally rotated position.[8] However, forceful and repetitive contact may lead to injury.[5]

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The peel-back mechanism is another pathomechanism of type II SLAP lesions.[3] Cadaveric studies have shown that excessive humeral external rotation causes increased strain on[19] and detachment of[12,15] the superior labrum, suggesting that increased humeral external rotation results in peel-back of the superior labrum. Although increased external rotation is often necessary to throw at a highly competitive level,[2] it can cause type II SLAP lesions.

In a previous electromyographic study, throwing athletes who had shoulder pain during the late cocking phase of throwing had decreased activity of the subscapularis muscle.[7] Disabled throwing shoulders have an altered force couple of the rotator cuff muscle, which may be caused by the change in scapular retraction and protraction[11] and fatigue after throwing.[16] Therefore, the objective of this study was to assess the effect of rotator cuff muscle force on internal impingement and the peel-back of the superior labrum by quantifying maximum external rotation, glenohumeral contact pressure, and position of the cuff insertion relative to the glenoid. We hypothesized that a change in rotator cuff muscle force will lead to increased external rotation, glenohumeral contact pressure, and overlap of the cuff insertion relative to the glenoid.

## MATERIALS AND METHODS

### Preparation of Specimens

Eight fresh-frozen cadaveric shoulders (2 female and 6 male) with an average age of 50.5 years (range, 46-55 years) were tested. The shoulders were screened macroscopically and arthroscopically for any signs of abnormality. Shoulders were dissected free of skin and subcutaneous tissue and rotator cuff insertions were preserved in all specimens. The scapula was placed in a scapular box and surrounded with plaster of Paris with the plane of the glenoid oriented parallel with the top of the scapular box. The humeral shaft was transected 2 cm distal to the deltoid tuberosity and fixed in polyvinyl chloride (PVC) pipe using plaster of Paris. To prevent humeral rotation within the PVC pipe, transfixing screws were inserted before the plaster of Paris was poured.

After the shoulder was securely affixed to the mounting devices, it was attached to the shoulder testing system (Figure 1). The scapular box was mounted on a 30° incline. The humerus was secured to a linear bearing system for horizontal adduction or flexion. To simulate the glenohumeral position during the late cocking phase of throwing motion, the long axis of the humerus was aligned parallel to the floor, thus achieving a total of 90° of shoulder abduction (30° of scapular inclination and 60° of glenohumeral abduction). We defined 90° of external glenohumeral rotation as the point at which the bicipital groove was aligned with the anterolateral acromion with 60° of glenohumeral abduction.[1,14] Horizontal abduction was created by translating the humeral mounting jig posteriorly with respect to the scapula. Horizontal abduction positions of 20°, 30°, and 40° with respect to the scapular plane were tested. All specimens were kept moist with 0.9% saline throughout the experiment. Muscle forces were applied by using cables sutured to the tendons of the supraspinatus, infraspinatus–teres minor, and subscapularis by using polyester sutures with a long-chain polyethylene core (No. 2 FiberWire, Arthrex, Naples, Florida) in a Krackow locked running stitch. Adjustable pulleys enabled simulated force vectors to approximate those of anatomic muscle loading.

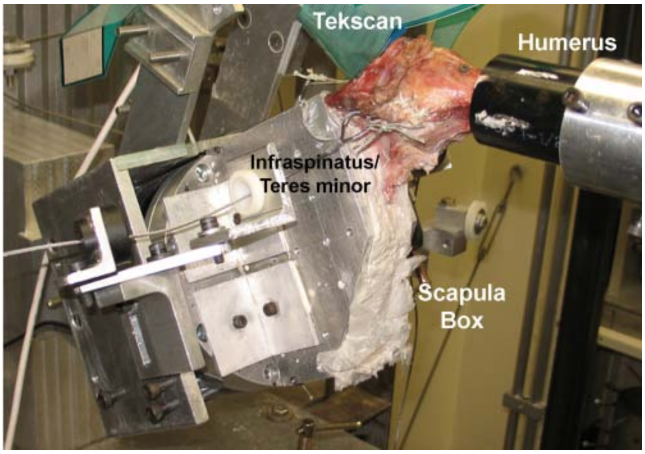

**Figure 1.** Shoulder testing system.

### Muscle Loading

Muscle forces were determined from previous published clinical studies by multiplying the maximum force generated within each muscle by the percentage of activity at the late cocking phase of throwing.[6,7] Specifically, the reported maximum strength of minor league baseball pitchers is 90 N for the supraspinatus muscle, 180 N for the internal rotator muscles, and 150 N for the external rotator muscles.[6] Muscle activity at the late cocking phase in symptomatic and asymptomatic shoulders was reported in a previous study that used dynamic electromyographic analysis.[7] Muscle activity expressed as a percentage of the maximal muscle strength for the supraspinatus, subscapularis, and infraspinatus was found to be 51%, 47%, and 52% in symptomatic versus 21%, 147%, and 66% for asymptomatic shoulders, respectively.[7] From these 2 studies, we calculated representative maximal shoulder muscle forces at the late cocking phase by multiplying the maximal muscle strength by the muscle activity.

Because the calculated muscle forces exceeded those we could generate in our laboratory setting, we used 30% of the calculated muscle forces as our baseline values (asymptomatic shoulder model: 5 N for the supraspinatus, 80 N for the subscapularis, and 30 N for the infraspinatus). The asymptomatic shoulder model was defined as the initial condition. To assess the effect of rotator cuff muscle imbalance, each muscle force was then either increased or decreased. When 1 rotator cuff muscle loading was changed, the other 2 remained at the asymptomatic force value (Table 1). Based on the muscle activity of symptomatic shoulders, the increased supraspinatus, decreased

TABLE 1
Muscle Loading Conditions
to Evaluate Rotator Cuff Muscle Imbalance

| | Supraspinatus | Subscapularis | Infraspinatus |
|---|---|---|---|
| Initial loading condition (asymptomatic) | 5 N | 80 N | 30 N |
| Supraspinatus decreased | 2 N | 80 N | 30 N |
| Supraspinatus increased | 15 N | 80 N | 30 N |
| Subscapularis decreased | 5 N | 30 N | 30 N |
| Subscapularis increased | 5 N | 100 N | 30 N |
| Infraspinatus decreased | 5 N | 80 N | 20 N |
| Infraspinatus increased | 5 N | 80 N | 40 N |

subscapularis, and decreased infraspinatus forces were determined. The increased subscapularis force and increased infraspinatus force were determined based on the assumption that maximum muscle strength increased by 20%. The decreased supraspinatus force of 2 N was determined so as to identify clearly the effect of change in muscle force, because a 20% decrease of the initial force was only 1 N.

## Maximum External Rotation

Maximum external rotation was measured with a 360° goniometer attached to the testing system. The goniometer degree measurements were inscribed in 1° increments on a stationary circular plate, making the precision of the measurement 0.5°. The specimens were preconditioned with ten 5-second cycles of 1.1 N·m of torque in external rotation. The maximum external rotation was then measured with 2.2 N·m of torque.[1,14,15]

## Glenohumeral Contact Pressure and Area

Glenohumeral joint contact pressures and areas were obtained using a Tekscan pressure sensor (Model 4000, saturation pressure 10.3 MPa, Tekscan, South Boston, Massachusetts). Before each specimen was tested, the glenohumeral joint was loaded with the initial force to condition the sensor. The sensor was then calibrated with the resultant glenohumeral joint force measured with a multiaxis load cell (Assurance Technologies, Garner, North Carolina) at 60° of abduction and 90° of external rotation. The sensor was inserted carefully into the glenohumeral joint through the rotator interval and placed between the humeral head and glenoid. The glenohumeral contact pressure and area were measured at the maximum external rotation position with 2.2 N·m of external torque[1,14,15] and for each of the different muscle forces applied.

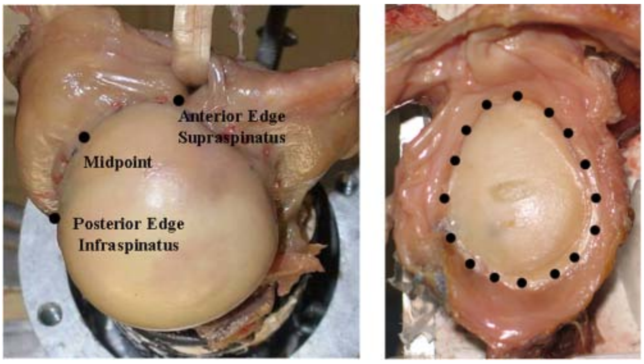

**Figure 2.** MicroScribe anatomic markers digitized after testing (3 rotator cuff insertion points and 16 glenoid circumference points).

## Location of the Rotator Cuff Insertion

A 3-dimensional digitizing system (MicroScribe 3DLX [accuracy, 0.3 mm], Immersion Corporation, San Jose, California) was used to define the location (relative to the glenoid) of the rotator cuff insertion on the greater tuberosity. A total of 6 MicroScribe markers were placed on each specimen. Scapula markers were placed on the tip of the coracoid process, at the anterolateral acromion, and on the posterior acromion. Humeral markers were positioned in the proximal bicipital groove, in the distal bicipital groove, and on the humeral metaphysis posteriorly. After each specimen was tested, MicroScribe coordinates were obtained for 3 rotator cuff insertion points on the greater tuberosity (supraspinatus anterior edge, infraspinatus posterior edge, and the point midway between the supraspinatus anterior edge and the infraspinatus posterior edge) and 16 glenoid circumference points (Figure 2). From these data points, the locations of the 3 rotator cuff insertion points relative to the glenoid were calculated at maximum external rotation. The amount of overlap between the rotator cuff insertion on the greater tuberosity and the glenoid represented the impinged area of the rotator cuff tendon.

## Data Analysis

All measurements were performed twice, and averages were calculated. Statistical analysis was performed using a repeated-measures analysis of variance followed by Tukey post hoc test using Statistica 6.0 (StatSoft Inc, Tulsa, Oklahoma) with a significance level of .05. Data are shown as mean ± 1 standard deviation of the mean.

# RESULTS

## Maximum External Rotation

A decrease in subscapularis muscle strength caused a significant ($P < .001$) increase in maximum external rotation angle with the same external torque (Table 2). The increase in external rotation due to a decrease in subscapularis

TABLE 2
Maximum External Rotation in Degrees for Each Muscle Condition and Position of Horizontal Abduction (HA)[a]

| | Initial | Supraspinatus Decreased (2 N) | Supraspinatus Increased (15 N) | Subscapularis Decreased (30 N) | Subscapularis Increased (100 N) | Infraspinatus Decreased (20 N) | Infraspinatus Increased (40 N) |
|---|---|---|---|---|---|---|---|
| 20° HA | 114.1 ± 16.7 | 115.3 ± 17.1 | 114.2 ± 16.8 | 123.0 ± 18.9[b] | 113.5 ± 17.5 | 117.1 ± 18.7 | 116.3 ± 17.5 |
| 30° HA | 110.6 ± 19.1 | 110.6 ± 19.4 | 109.9 ± 18.9 | 115.2 ± 21.4[b] | 110.1 ± 18.8 | 110.4 ± 19.8 | 111.0 ± 19.1 |
| 40° HA | 99.8 ± 20.8 | 100.5 ± 20.8 | 100.4 ± 20.7 | 104.4 ± 21.7[b] | 100.8 ± 20.5 | 101.3 ± 20.8 | 101.8 ± 20.4 |

[a] Data are given as mean ± standard deviation.
[b] $P < .001$ for the difference compared to the initial loading condition.

TABLE 3
Glenohumeral Contact Pressure (MPa) for Each Muscle Loading Condition and Position of Horizontal Abduction (HA)[a]

| | Initial | Supraspinatus Decreased (2 N) | Supraspinatus Increased (15 N) | Subscapularis Decreased (30 N) | Subscapularis Increased (100 N) | Infraspinatus Decreased (20 N) | Infraspinatus Increased (40 N) |
|---|---|---|---|---|---|---|---|
| 20° HA | 0.83 ± 0.21 | 0.86 ± 0.16 | 0.88 ± 0.15 | 1.23 ± 0.35[b] | 0.83 ± 0.12 | 0.82 ± 0.13 | 0.83 ± 0.11 |
| 30° HA | 0.98 ± 0.18 | 0.96 ± 0.15 | 0.98 ± 0.16 | 1.17 ± 0.25[b] | 0.94 ± 0.14 | 0.92 ± 0.14 | 0.99 ± 0.16 |
| 40° HA | 1.32 ± 0.31 | 1.29 ± 0.30 | 1.31 ± 0.28 | 1.37 ± 0.30[b] | 1.22 ± 0.23 | 1.21 ± 0.26 | 1.22 ± 0.22 |

[a] Data are given as mean ± standard deviation.
[b] $P < .001$ for the difference compared with the initial loading condition.

TABLE 4
Glenohumeral Contact Area ($mm^2$) for Each Muscle Loading Condition and Position of Horizontal Abduction (HA)[a]

| | Initial | Supraspinatus Decreased (2 N) | Supraspinatus Increased (15 N) | Subscapularis Decreased (30 N) | Subscapularis Increased (100 N) | Infraspinatus Decreased (20 N) | Infraspinatus Increased (40 N) |
|---|---|---|---|---|---|---|---|
| 20° HA | 169.9 ± 80.2 | 156.9 ± 43.5 | 156.4 ± 50.6 | 92.3 ± 41.6[b] | 175.9 ± 49.3 | 151.5 ± 48.4 | 171.8 ± 40.6 |
| 30° HA | 185.0 ± 74.2 | 192.2 ± 69.7 | 191.8 ± 73.7 | 134.6 ± 57.1[b] | 209.3 ± 71.4 | 195.4 ± 70.1 | 200.2 ± 77.0 |
| 40° HA | 163.0 ± 47.0 | 172.9 ± 49.1 | 175.0 ± 46.9 | 139.9 ± 37.7[b] | 194.3 ± 50.1 | 185.4 ± 48.2 | 193.3 ± 49.7 |

[a] Data are given as mean ± standard deviation.
[b] $P < .001$ for the difference between consecutive muscle force conditions.

muscle strength was 8.9° ± 3.0° in 20° of horizontal abduction, 4.6° ± 2.5° in 30° of horizontal abduction, and 4.6° ± 2.7° in 40° of horizontal abduction with respect to the scapular plane. Other muscle loading conditions did not change the external rotation angle.

## Glenohumeral Contact Pressure and Area

With decreased subscapularis muscle strength, the posterosuperior glenohumeral contact pressure increased significantly ($P < .01$) by 0.39 ± 0.26 MPa in 20° of horizontal abduction, 0.17 ± 0.15 MPa in 30° of horizontal abduction, and 0.05 ± 0.09 MPa in 40° of horizontal abduction, with respect to the scapular plane (Table 3). Decreased subscapularis muscle strength also led to a significant ($P < .001$) decrease in glenohumeral contact area: 77.6 ± 52.0 $mm^2$ in 20° of horizontal abduction, 51.1 ± 33.2 $mm^2$ in 30° of horizontal abduction, and 23.1 ± 15.3 $mm^2$ in 40° of horizontal abduction (Table 4). Other muscle force conditions did not affect the glenohumeral contact pressure or area.

## Location of the Rotator Cuff Insertion

The position of the rotator cuff insertion on the greater tuberosity shifted posteriorly relative to the glenoid with decreased subscapularis muscle strength ($P < .05$) (Figure 3). At 20° of horizontal abduction, the cuff insertion was posterior to the posterior edge of the glenoid due to a decrease in subscapularis muscle force, representing no internal impingement. However, at 30° and 40° of horizontal abduction, the cuff insertion remained overlapped with the posterosuperior glenoid. Therefore, the rotator cuff tendon was impinged between the greater tuberosity and glenoid with all muscle strength conditions at 30° and 40° of horizontal abduction.

## DISCUSSION

Shoulder internal impingement is thought to cause posterosuperior labral tears,[5,9,10] partial articular surface tearing of the posterior half of the supraspinatus tendon and superior half of the infraspinatus tendon,[5,9,10] and

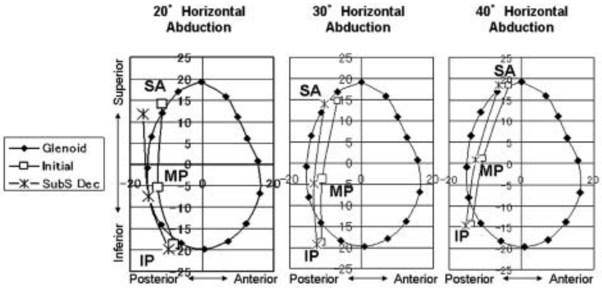

**Figure 3.** Location of the rotator cuff insertion (posterior edge of infraspinatus [IP], anterior edge of supraspinatus [SA], point midway between SA and IP [MP]) relative to the glenoid circumference in millimeters at maximum external rotation for the initial load condition and the subscapularis decreased (SubS Dec) loading condition.

humeral head cysts at the insertions of the supraspinatus and infraspinatus.[18] This entity was described by Walch et al[20] in 1992 and was applied to the throwing shoulder by Jobe.[9,10] Although some contact between the greater tuberosity and posterosuperior glenoid is normal during full abduction and external rotation,[8] increased repetition and intensity of contact are thought to lead to labral and rotator cuff damage. Here, we measured the glenohumeral contact pressure to investigate whether internal impingement was excessive under conditions of increased abduction and external rotation. Glenohumeral contact pressure was significantly increased with a decreased subscapularis muscle force. This result suggested that an impinged rotator cuff tendon and cartilage between the greater tuberosity and glenoid may wear or become torn subsequent to decreased subscapularis muscle strength, such as during fatigue.

We also evaluated the location of the rotator cuff insertion on the greater tuberosity relative to the glenoid. At maximum external rotation, the rotator cuff insertion shifted posteriorly with decreased subscapularis muscle force due to an increase in the external rotation angle, because the rotator cuff insertion moves posteriorly relative to the glenoid with humeral external rotation. Although this result indicated that the impinged area of the rotator cuff tendon decreased with a decreased subscapularis muscle force, the rotator cuff insertion was located anterior to the posterior edge of the glenoid in 30°, which was the simulated coronal plane, and 40° of horizontal glenohumeral abduction from the scapular plane. Therefore, at more than 30° of horizontal abduction from the scapular plane, internal impingement may occur with any muscle loading condition.

Burkhart and Morgan[3] postulated the "peel-back mechanism," the theory that superior labral lesions can be produced and exacerbated by the torsional force that peels back the biceps and posterosuperior labrum as the shoulder goes into extreme abduction and external rotation during the late cocking phase of throwing motion. Previous cadaveric studies have shown that excessive humeral external rotation causes detachment of the superior labrum[12,15] and that the strain of the superior labrum increases with increased external rotation,[19] suggesting that an increase in humeral external rotation results in peel-back of the superior labrum. In this study, we measured humeral external rotation under various rotator cuff muscle force conditions. Surprisingly, only decreased subscapularis muscle force significantly increased humeral external rotation under equal amounts of external rotation torque. This result suggests that decreased subscapularis muscle force may lead to peel-back of the superior labrum due to increased external rotation.

Professional baseball players show marked postseasonal loss in internal rotation strength.[21] Furthermore, when investigating the selective fatigue of shoulder muscles after throwing, Mullaney et al[16] found that internal rotation strength in baseball players showed marked fatigue after a game, indicating that the internal rotators experience high performance demand during pitching. Our results showed that decreased subscapularis muscle strength resulted in increased posterosuperior glenohumeral contact pressure and increased humeral external rotation. Together, these results suggest that throwing with decreased subscapularis muscle strength may cause forceful internal impingement and peel-back of the posterosuperior labrum. Therefore, athletes with decreased subscapularis muscle strength, such as fatigue after throwing, may be more susceptible to rotator cuff tears and type II SLAP lesions. Exercises that strengthen the subscapularis muscle may help decrease the incidence of injury for throwers.

Alteration in scapular position and movement, such as retraction and protraction, can change the force couples of the rotator cuff muscles.[11,17] Burkhart et al[4] described the presence of a "SICK" scapula (scapular malposition, inferior medial border prominence, coracoid pain and malposition, and dyskinesis of scapular movement) in throwing athletes with labral abnormality, rotator cuff tear, and/or subacromial impingement. These studies, as well as the current study, suggest that decreased subscapularis muscle strength due to scapular malposition or dyskinesis of scapular movement may cause forceful internal impingement and/or peel-back of the superior labrum; however, it is unclear what scapula position decreases subscapularis muscle force.

There are several limitations to this study. First, only isolated rotator cuff muscles were loaded. Other internal rotators, such as the latissimus dorsi and pectoralis major, may have an effect on glenohumeral contact pressure and maximum humeral external rotation angle. The effect of latissimus dorsi and pectoralis major muscles will be assessed in future studies. Second, the age of the cadaveric specimens used in this study was older than that of throwers. Lee et al[13] reported that the structural properties and material characteristics of the shoulder soft tissue for a younger group of fresh-frozen cadaveric specimens were significantly superior to the older group. However, Lee et al[13] also showed that the stiffness in the functional range of the shoulder soft tissue was similar between the younger and older groups, suggesting that for nondestructive biomechanical studies, the older specimens are appropriate. Third, the muscle force of the supraspinatus was decreased more than 20% to identify clearly the effect of change in muscle force. Although the supraspinatus muscle force was decreased by 60%, there were no significant differences in all data compared with the initial condition. Therefore, changes in the supraspinatus muscle force do not affect shoulder internal impingement and peel-back of the superior labrum. Fourth, the baseline forces were applied via the rotator cuff tendons as 30% of the calculated force, because the calculated muscle forces exceeded those we could generate in our laboratory setting. Although each value in this study may be less than actual forces generated by throwers, we believe that the results of comparison among all muscle conditions are reliable because the ratio of each muscle force was kept similar to that of actual throwers.

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