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Posterior shoulder tightness can be a risk factor of scapular malposition: a cadaveric biomechanical study

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Background: Scapular malposition and posterior shoulder tightness are key pathologic processes in the shoulder of throwing athletes. The objective of this study was to investigate the effects of posterior capsule tightness, posterior rotator cuff muscle tightness, or both on scapular position.

Methods: Ten shoulders from 5 fresh frozen cadaveric male torsos were tested in maximum internal, neutral, and maximum external shoulder rotations at 0°, 45°, and 90° of shoulder abduction. Scapular rotation—namely, upward and downward rotation, internal and external rotation, and anterior and posterior tilt—and the scapula-spine distance were measured by using a MicroScribe digitizer (Revware, Raleigh, NC, USA). Each shoulder underwent 4 experimental stages: intact; isolated posterior rotator cuff muscle (infraspinatus and teres minor) tightness; both posterior rotator cuff muscle and capsule tightness; and isolated posterior capsule tightness.

Results: Posterior muscle tightness significantly decreased upward rotation ($P < .05$) only in maximum shoulder internal rotation at 45° or 90° of shoulder abduction, whereas posterior capsule tightness did not affect upward rotation ($P = .09$ to .96). Posterior capsule tightness significantly increased scapular internal rotation ($P < .01$), but posterior muscle tightness did not change scapular internal rotation ($P = .62$ to .89). Posterior capsule tightness significantly increased both the superior and inferior scapula-spine distance (ie, caused scapular protraction) in maximum shoulder external rotation at 90° of abduction ($P <$ .01).

Conclusion: Posterior shoulder tightness resulted in scapular malposition. However, the muscular and capsular components of that tightness affected the scapular position differently. For the treatment of scapula malposition, stretching of the posterior shoulder capsule and muscles is recommended.

The Research & Development Committee of VA Long Beach Health Care System approved this study.

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Keywords: Capsule; infraspinatus; posterior tightness; scapula; shoulder; teres minor; throwing

Throwing athletes commonly have posterior tightness in the throwing shoulder.[1,4,14] This posterior shoulder tightness results from posterior capsular contracture[4,16,18] or tightness of the infraspinatus and teres minor muscles due to repetitive throwing motion.[9] Severe posterior shoulder tightness is thought to cause subacromial impingement,[3,7,19] pathologic internal impingement,[12,16] and superior labral anterior and posterior lesions.[4,6] When athletes have severe posterior tightness, physical therapy, including stretching of the posterior capsule, infraspinatus muscle, and teres minor muscle, or posterior capsular release is required.

Because of its position between the trunk and humerus, the scapula can transmit tremendous force, which is generated in the lower legs and trunk, to the arm. Once the scapular position or orientation is changed, the force transmitted can decrease because of alteration of the kinematic chain between the upper and lower extremities.[8,17] Alteration of the scapular position or orientation can also change the center of shoulder rotation[8] and decrease shoulder muscle function,[5,8] thereby increasing the risk of shoulder injury.[5,8,20]

Scapular malposition in throwing athletes can cause shoulder injuries. One pathologic malposition is increased internal rotation of the scapula. Burkhart et al[5] investigated scapular dyskinesis in a study of 64 patients with posterosuperior labral tear. In 61 (95%) of the 64 patients, there was prominence of the medial scapular border resulting from increased scapular internal rotation, scapular protraction, or both. A cadaveric biomechanical study showed that increased internal scapular rotation significantly increased the pressure between the greater tuberosity and the glenoid in association with internal impingement, thereby increasing the risk of tearing the impinged rotator cuff tendons and superior labrum.[13] Another pathologic scapular malposition is decreased upward rotation. Decreased upward scapular rotation can cause subacromial[8,10,11,15] or internal[13] impingement. These scapular malpositions result from soft tissue imbalance after throwing. Birkelo et al[2] reported that pathologic scapular malpositions, such as increased internal scapular rotation and decreased upward scapular rotation, occurred after 5 innings of throwing.

The posterior capsule and 2 posterior rotator cuff muscles (infraspinatus and teres minor) run from the greater tuberosity to the posterior scapula. This anatomy suggests that tightness of posterior capsule, muscles, or both affects the positional relationship between the humerus and scapula. To our knowledge, no previous study has investigated the biomechanical effect of posterior shoulder tightness on scapular position. Our objective here was to assess the effects of posterior capsule tightness, posterior rotator cuff muscle tightness, or both on scapular position. We hypothesized that tightness of the posterior capsule, rotator cuff muscles, or both would increase internal scapular rotation and decrease upward scapular rotation as seen in the pathologic throwing shoulder.

Materials and methods

Preparation of specimens

Ten shoulders from 5 fresh frozen cadaveric male torsos (University of California willed body program) of average age 75.0 years (range, 68-84 years) were thawed for 48 hours at room temperature before dissection and experimentation. The shoulders were screened by visual inspection for signs of abnormality and pathologic change, such as rotator cuff tears, capsular injury, or bone deformity after injury or surgery. Each specimen was dissected free of skin and subcutaneous tissue. All of the muscles, capsule, and ligaments were preserved in all specimens. The trunk was fixed to a custom testing system with 2 titanium screws. The forearm was transected 10 cm distal to the elbow joint, and an intramedullary rod was inserted into the humerus with the elbow fixed to 90° flexion. The rod was fixed to the humerus with a transverse screw to prevent rotation within the humerus. Three small titanium screws that served as digitizing markers were inserted on the scapula (inferior angle, medial edge of scapular spine, and anterior acromion), and 3 small titanium screws were inserted on the humerus (medial and lateral epicondyles and 3 cm proximal to the lateral epicondyle) to track the positions of the scapula and humerus. Two additional small titanium screws were inserted at the spinous processes of the first and seventh thoracic vertebrae to measure the distance from the spine to the medial scapular border (scapula-spine distance [SSD]). Three No. 2 FiberWires (Arthrex, Naples, FL, USA) sutured to the anterior, middle, and posterior deltoid muscles with Krackow stitch applied 15 N of deltoid muscle force to simulate physiologic movement without inferior shoulder subluxation.

Testing positions

Each measurement was performed in maximum shoulder internal rotation, 0° of shoulder internal rotation (neutral rotation), and maximum shoulder external rotation at 0°, 45°, and 90° of shoulder abduction (Fig. 1) to evaluate scapula malposition during throwing motion. All specimens were kept moist with 0.9% saline throughout the experiments.

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Figure 1 Testing positions. (**A**) At 0° of shoulder abduction. (**B**) At 45° of shoulder abduction. (**C**) At 90° of shoulder abduction.

Measurement of scapular rotation

Scapular rotation (Fig. 2), including upward rotation/downward rotation (rotation around a rotary axis Z; the torso's anterior-posterior axis), internal rotation/external rotation (rotation around a rotary axis Y; the torso's superior-inferior axis), and anterior tilt/posterior tilt (rotation around a rotary axis X; the torso's medial-lateral axis), was calculated from location data on the 3 scapular points, which were digitized by using a 3-dimensional digitizer (MicroScribe 3DLX; Revware, Raleigh, NC, USA; accuracy, 0.3 mm) at each position. Upward rotation/downward rotation was calculated by using a frontal plane scapular projection vector, the direction of which was based on a line joining the screw points on the medial scapular spine and the inferior angle of the scapula relative to the axis Y. Internal rotation/external rotation was calculated by using the scapula's transverse plane projection vector, the direction of which was based on a line joining the screw points on the medial scapular spine and the anterior acromion relative to the axis X. Anterior tilt/posterior tilt was calculated by using the scapula's sagittal plane projection vector, the direction of which was based on a line joining the screw points on the medial scapular spine and the inferior angle of the scapula relative to the axis Y.

Measurement of SSD

Measurement of the SSD involved 2 specific measurements (Fig. 3): the distance from the medial edge of the scapular spine to the spinous process of the first thoracic vertebra (superior SSD); and the distance from the inferior angle of the scapula to the spinous process of the seventh thoracic vertebra (inferior SSD).

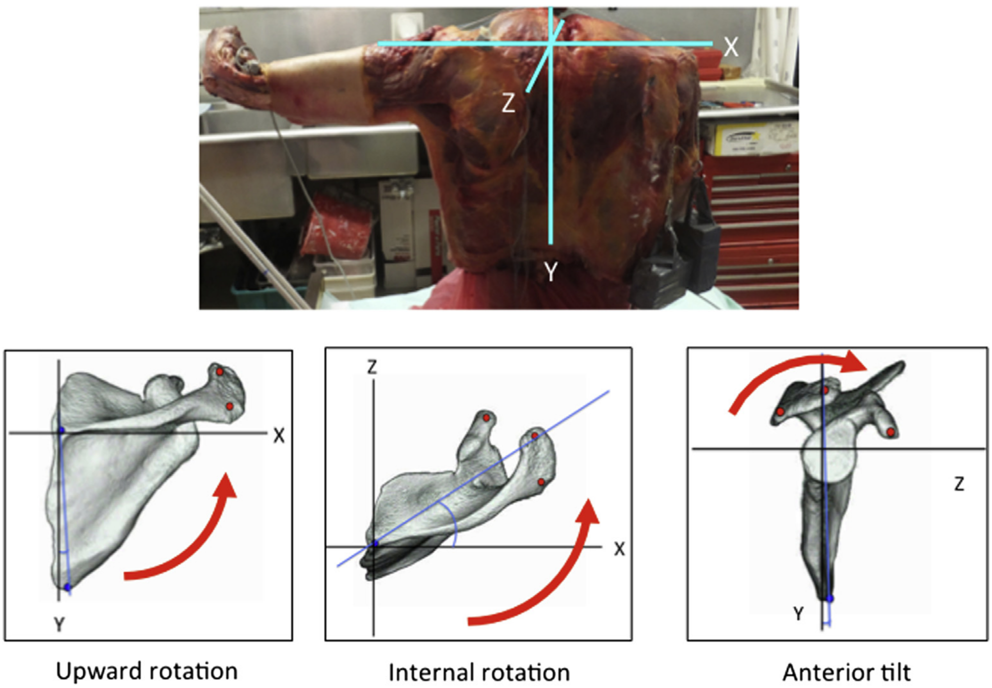

Figure 2 Schematics illustrating the scapular orientations assessed. X-axis was made by connecting the anterolateral corner of the acromion on each shoulder. Y-axis was perpendicular to both the X-axis and the floor. Z-axis was perpendicular to both the X-axis and the Y-axis.

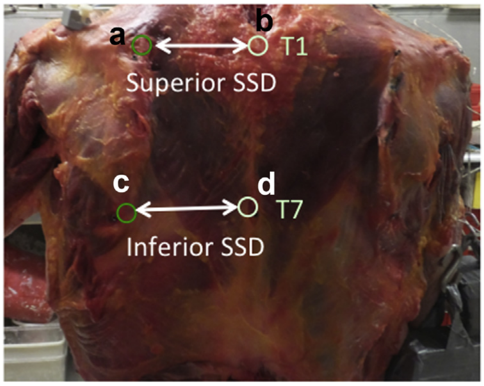

Figure 3 The scapula-spine distance (*SSD*) involved 2 specific measurements: distance from the medial edge of the scapular spine **(a)** to the spinous process of the first thoracic vertebra **(b)** (superior SSD); and distance from the inferior angle of the scapula **(c)** to the spinous process of the seventh thoracic vertebra **(d)** (inferior SSD). *Dark green circle*, scapula marking points; *green circle,* spinous process marking points.

Study design

Each specimen underwent 4 stages of experimentation. All measurements were performed on intact shoulders (stage I); shoulders with simulated posterior rotator cuff muscle tightness (stage II; Fig. 4, *A*); shoulders with simulated posterior rotator cuff muscle and capsule tightness (stage III; Fig. 4, *B*); and shoulders with simulated posterior capsule tightness (stage IV).

Simulated posterior rotator cuff muscle tightness and posterior capsule tightness

To create the posterior muscle tightness model (Fig. 4, *A*), the shoulder was locked at 45° of abduction, and two 4.5-mm Corkscrew suture anchors (Arthrex) were inserted at the center of the infraspinatus and teres minor insertions on the greater tuberosity. No. 2 FiberWires extending from the Corkscrews were passed through 2 bone tunnels at the scapular origins of the infraspinatus and teres minor muscles. The lengths of the infraspinatus and teres minor muscles were then measured in maximum scapular internal rotation by measuring the length of No. 2 FiberWire from anchor insertion on the greater tuberosity to bone tunnel at the scapular origins of the infraspinatus and teres minor muscles. To simulate posterior muscle tightness in stage II, the No. 2 FiberWires from the infraspinatus and teres minor muscles were tied at the scapular origins of the muscles as the shoulder was held in the rotation position at which the muscle length between the humeral and scapular insertions was 90% of the length in maximum shoulder internal rotation at 45° of abduction. The 90% of the length was determined on the basis of a pilot study to simulate pathologic condition as seen in throwing athletes.

For stage III, a 10-mm posteroinferior capsular plication was performed to simulate posteroinferior capsular tightness (Fig. 4, *B*). The posteroinferior capsule was cut in a superior-inferior direction at the glenoid side from the 6- to 9-o'clock positions in the right shoulder (3- to 6-o'clock positions in the left shoulder) and in a medial-lateral direction at the 7:30-o'clock position (4:30-o'clock position in the left shoulder). Two 2.8-mm metal FASTak anchors (Arthrex) with No. 2 FiberWire were inserted at the 7- and 8-o'clock positions on the glenoid in the right shoulder (4- and 5-o'clock positions in the left shoulder). Finally, the posteroinferior capsule was plicated with No. 2 FiberWire 1 cm in the superior-inferior direction. For stage IV, the No. 2 FiberWires of infraspinatus and teres minor muscles were removed to simulate the isolated posterior capsule tightness model.

Shoulder range of motion

We measured the shoulder range of motion, including glenohumeral and scapulothoracic motions, to confirm the glenohumeral internal rotation deficit induced by the simulated posterior rotator cuff muscle tightness, simulated posterior capsule tightness, or both. The maximum humeral rotation angle was calculated by using position data for the 2 markers on the forearm rod. The specimens were preconditioned using torque wrench with ten 5-s cycles of 1.1 Nm of torque in external and internal rotation to measure the range of motion accurately. The maximum external and internal rotations were then measured with 2.2 Nm of torque.

Data analysis

All measurements were performed twice at each position, and the averages of the values were taken for data analysis. Repeated-measures analysis of variance was performed to compare scapular rotations or SSDs. Fisher post hoc analysis was performed to identify the differences between the experimental stages of intact, posterior muscle tightness, posterior capsule tightness, and tightness of both when a significant main effect was found. Data were presented as means $\pm$ standard deviation, and the significance level was set at .05.

Results

Shoulder range of motion

Compared with the intact state, maximum shoulder internal rotation angle decreased significantly after the creation of isolated posterior rotator cuff muscle tightness ($P < .001$), both posterior muscle and capsule tightness ($P < .001$), or isolated posterior shoulder capsule tightness ($P < .001$) at 0°, 45°, and 90° of shoulder abduction (Table I). Only at 90° of shoulder abduction did maximum shoulder external rotation angle decrease significantly with both posterior muscle and capsule tightness and with posterior shoulder capsule tightness alone (Table I).

Scapular rotation

Intact state

Scapular upward rotation increased with increasing shoulder abduction angle in maximum internal rotation, neutral rotation, and maximum external rotation ($P < .05$; Table II). Both internal rotation and anterior tilt of the scapula decreased significantly with increasing shoulder abduction

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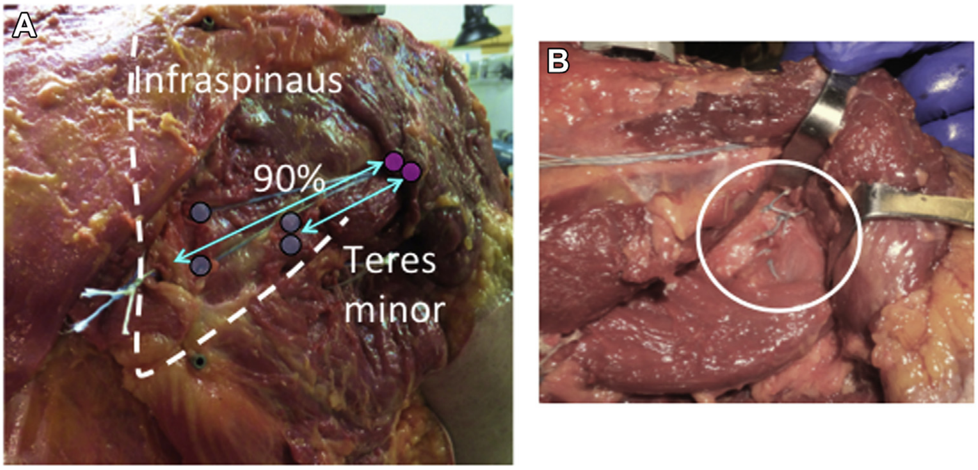

Figure 4 Posterior shoulder tightness models. (**A**) To create a posterior muscle tightness model, the shoulder was locked at 45° of abduction, and two 4.5-mm Corkscrew suture anchors (Arthrex) were inserted at the center of the infraspinatus and teres minor insertions on the greater tuberosity (●). No. 2 FiberWires extending from the Corkscrews were passed through 2 bone tunnels at the scapular insertions of the infraspinatus and teres minor muscles (●). The lengths of the infraspinatus and teres minor muscles were then measured in maximum shoulder internal rotation. To simulate posterior muscle tightness in stage II, the No. 2 FiberWires attached to the infraspinatus and teres minor muscles were tied at the scapular origins of the muscles by holding the shoulder in a position of rotation in which the muscle length between the humeral and scapular insertions was 90% of the length in maximum shoulder internal rotation at 45° of abduction. The ▬▬ shows the scapular body. (**B**) In stage III, the posteroinferior capsule was plicated 1 cm in a superior-inferior direction with two No. 2 FiberWires from two 2.8-mm metal FASTak anchors.

angle in maximum internal rotation, neutral rotation, and maximum external rotation ($P < .05$; Tables III and IV).

Effects of posterior shoulder tightness

Scapular upward rotation

Compared with the intact state, tightness of the infraspinatus and teres minor significantly decreased scapular upward rotation under maximum shoulder internal rotation at 45° ($P <$ .05) or 90° ($P < .001$) of shoulder abduction (Fig. 5). Posterior capsule tightness alone did not significantly change upward rotation compared with the intact condition ($P = .09$ to .96). Combined posterior capsule tightness and tightness of infraspinatus and teres minor significantly increased scapular upward rotation in neutral shoulder rotation at 0° ($P < .05$) or 45° ($P < .05$) of shoulder abduction or maximum external shoulder rotation at 45° of shoulder abduction ($P < .05$).

Scapular internal rotation

Posterior capsule tightness alone significantly increased scapular internal rotation in both maximum shoulder internal rotation (Fig. 6) and external rotation (Fig. 7) at 0° ($P < .01$), 45° ($P < .05$), or 90° ($P < .01$) of shoulder abduction. Even in neutral shoulder rotation, scapular internal rotation increased significantly after the creation of posterior capsule tightness at 0° ($P < .01$) or 90° ($P < .01$) of shoulder abduction. Tightness of infraspinatus and teres minor alone did not significantly change scapular internal rotation compared with the intact stage ($P = .62$ to .89).

Table I Shoulder range of motion (degrees)

	Intact	Muscle tightness	Muscle and capsule tightness	Capsule tightness
Maximum internal rotation angle				
0° shoulder abduction	93 (12)	54 (15)*	50 (16)*,†	66 (21)*
45° shoulder abduction	83 (16)	57 (17)*	48 (16)*,†	62 (21)*
90° shoulder abduction	51 (21)	42 (14)*	30 (15)*,†,‡	39 (21)*
Maximum external rotation angle				
0° shoulder abduction	43 (10)	43 (7)	41 (7)	42 (8)
45° shoulder abduction	56 (15)	56 (15)	57 (13)	56 (15)
90° shoulder abduction	62 (18)	60 (19)	57 (18)*	55 (20)*,‡

The values are given as the mean (standard deviation).
* Significantly smaller than the intact states ($P < .001$).
† Significantly smaller than capsule tightness ($P < .001$).
‡ Significantly smaller than muscle tightness ($P < .001$).

Table II Scapular upward rotation (degrees)

	Intact	Muscle tightness	Muscle and capsule tightness	Capsule tightness
0° shoulder abduction				
Maximum internal rotation	2.1 (1.1)	1.4 (1.1)	2.1 (1.3)	2.5 (1.5)
Neutral rotation	2.6 (1.6)	2.3 (1.4)	3.3 (1.6)*	3.2 (1.7)
Maximum external rotation	2.2 (2.0)	1.8 (1.7)	2.9 (1.7)	2.6 (1.9)
45° shoulder abduction				
Maximum internal rotation	7.4 (1.3)	4.8 (2.0)†	7.2 (1.9)	6.7 (2.4)
Neutral rotation	6.0 (1.8)	5.1 (2.6)	7.4 (2.0)*	6.0 (2.8)
Maximum external rotation	6.8 (2.5)	6.3 (3.2)	8.3 (2.7)*	6.8 (3.4)
90° shoulder abduction				
Maximum internal rotation	17.4 (5.6)	15.5 (5.9)‡	16.9 (5.2)	16.8 (4.8)
Neutral rotation	14.8 (5.9)	14.0 (5.8)	15.1 (4.9)	14.8 (4.6)
Maximum external rotation	17.7 (6.4)	17.2 (6.1)	18.0 (6.2)	17.5 (5.7)

The values are given as the mean (standard error).
* Significantly larger than the intact states ($P < .05$).
† Significantly smaller than the intact states ($P < .05$).
‡ Significantly smaller than the intact states ($P < .001$).

Table III Scapular internal rotation (degrees)

	Intact	Muscle tightness	Muscle and capsule tightness	Capsule tightness
0° shoulder abduction				
Maximum internal rotation	55.5 (7.8)	55.3 (8.7)	56.3 (8.2)	57.2 (7.3)*
Neutral rotation	52.8 (7.9)	52.9 (8.5)	53.6 (8.3)*	54.0 (8.1)*
Maximum external rotation	49.4 (8.5)	49.4 (8.9)	50.4 (8.6)*	50.5 (8.8)*
45° shoulder abduction				
Maximum internal rotation	52.2 (7.2)	51.9 (8.4)	52.7 (8.2)	53.7 (7.0)†
Neutral rotation	50.9 (7.4)	51.1 (8.3)	50.8 (7.7)	51.6 (7.4)
Maximum external rotation	47.6 (9.0)	47.7 (9.3)	48.2 (8.6)	48.7 (8.6)†
90° shoulder abduction				
Maximum internal rotation	45.7 (8.2)	45.6 (7.9)	46.8 (6.9)†	47.4 (6.4)*
Neutral rotation	47.1 (8.8)	47.2 (8.7)	47.4 (8.3)	47.8 (8.3)*
Maximum external rotation	43.8 (10.2)	44.0 (10.3)	46.3 (9.2)*	46.7 (9.1)*

The values are given as the mean (standard deviation).
* Significantly larger than the intact states ($P < .01$).
† Significantly larger than the intact states ($P < .05$).

Table IV Scapular anterior tilt (degrees)

	Intact	Muscle tightness	Muscle and capsule tightness	Capsule tightness
0° shoulder abduction				
Maximum internal rotation	56.4 (6.4)	58.1 (6.4)*	55.0 (6.4)	54.4 (7.3)†
Neutral rotation	54.7 (7.5)	55.3 (7.9)	53.4 (7.4)†	53.7 (7.9)
Maximum external rotation	56.5 (8.1)	57.1 (8.4)	55.1 (7.8)†	55.8 (8.0)
45° shoulder abduction				
Maximum internal rotation	51.9 (7.7)	54.7 (7.6)‡	51.7 (7.3)	52.4 (8.6)
Neutral rotation	50.2 (8.0)	51.1 (8.4)	48.4 (7.7)†	50.3 (8.6)
Maximum external rotation	47.6 (8.8)	48.1 (9.2)	45.6 (8.3)†	47.6 (9.1)
90° shoulder abduction				
Maximum internal rotation	42.3 (11.7)	44.0 (11.6)	42.8 (12.0)	43.3 (11.8)
Neutral rotation	39.4 (10.7)	40.4 (10.6)	39.6 (10.8)	39.8 (10.5)
Maximum external rotation	33.2 (11.0)	33.6 (10.9)	32.5 (11.6)	33.2 (11.2)

The values are given as the mean (standard deviation).
* Significantly larger than the intact states ($P < .05$).
† Significantly smaller than the intact states ($P < .05$).
‡ Significantly larger than the intact states ($P < .01$).

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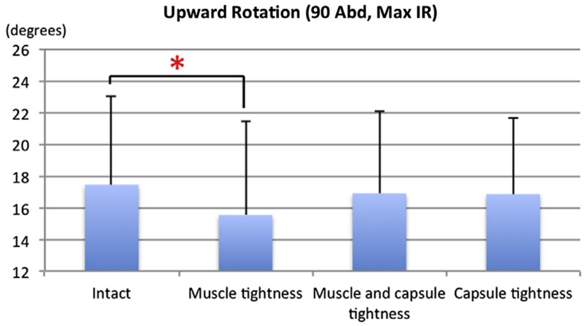

Figure 5 Scapular upward rotation in maximum shoulder internal rotation (*IR*) at 90° of shoulder abduction (*Abd*). *$P < .05$.

Combined posterior capsule tightness and tightness of infraspinatus and teres minor significantly increased scapular internal rotation in neutral ($P < .01$) or maximum external ($P < .01$) shoulder rotation at 0° shoulder abduction; this was also the case in both maximum internal ($P < .05$; Fig. 6) and external ($P < .01$; Fig. 7) shoulder rotation at 90° of shoulder abduction.

Scapular anterior tilt

Tightness of infraspinatus and teres minor significantly increased scapular anterior tilt in maximum shoulder internal rotation at 0° ($P < .05$; Fig. 8) or 45° ($P < .01$) of shoulder abduction. Posterior capsule tightness alone significantly decreased anterior tilt in maximum shoulder internal rotation at 0° shoulder abduction ($P < .05$; Fig. 8). Combined posterior capsule tightness and tightness of infraspinatus and teres minor significantly decreased anterior tilt in neutral shoulder rotation and maximum shoulder external rotation at 0° ($P < .05$) or 45° ($P < .05$) of shoulder abduction.

SSD

Intact state

In maximum internal shoulder rotation ($P < .00001$) or neutral rotation ($P < .0001$), the superior SSD significantly decreased with increasing shoulder abduction angle (Table V), whereas the inferior SSD did not change significantly

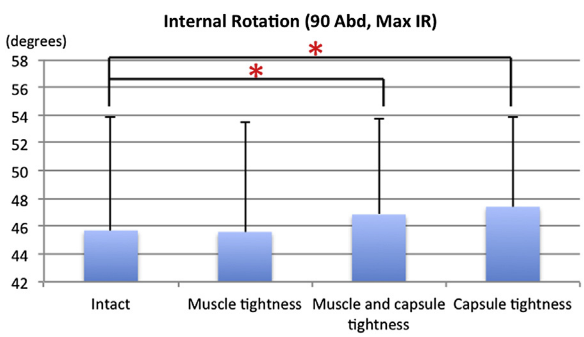

Figure 6 Scapular internal rotation in maximum shoulder internal rotation (*IR*) at 90° of shoulder abduction (*Abd*). *$P < .05$.

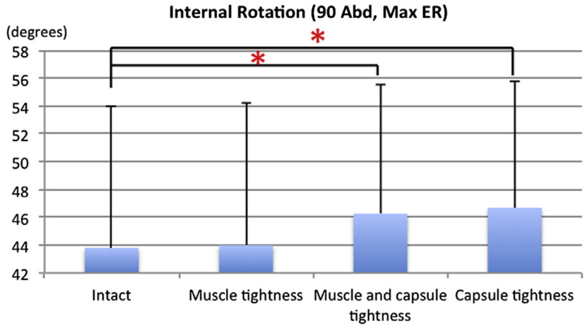

Figure 7 Scapular internal rotation in maximum shoulder external rotation (*ER*) at 90° of shoulder abduction (*Abd*). *$P < .05$.

with increasing shoulder abduction ($P = .20$ to .64; Table VI). In maximum shoulder external rotation, the superior SSD decreased significantly ($P < .001$) and the inferior SSD increased significantly ($P < .01$) with increasing shoulder abduction angle.

Effects of posterior shoulder tightness

Posterior capsule tightness alone significantly increased the superior SSD in maximum external ($P < .05$) or internal ($P < .01$) shoulder rotation at 90° of shoulder abduction (Table V). It also significantly increased the inferior SSD in maximum external rotation ($P < .05$) at 90° of shoulder abduction (Table VI). Tightness of infraspinatus and teres minor alone significantly decreased the inferior SSD in maximum shoulder internal rotation at 0° ($P < .05$) or 45° ($P < .01$) of shoulder abduction (Table VI). Combined posterior capsular tightness and tightness of infraspinatus and teres minor significantly increased both the superior ($P < .01$) and inferior ($P < .05$) SSD in maximum shoulder external rotation at 90° of shoulder abduction (Tables V and VI).

Discussion

An earlier clinical study showed that 95% of posterosuperior labral tears were accompanied by prominence of the medial scapular border resulting from increased scapular internal

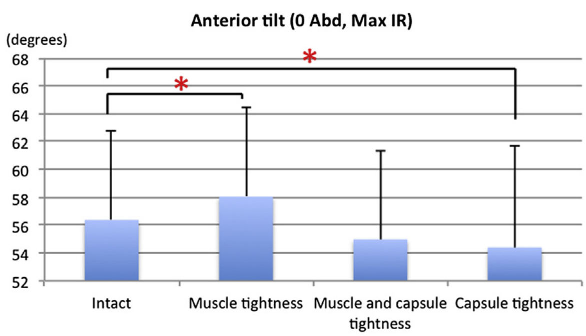

Figure 8 Scapular anterior tilt in maximum shoulder internal rotation (*IR*) at 0° of shoulder abduction (*Abd*). *$P < .05$.

Table V Superior scapula-spine distance (mm)

	Intact	Muscle tightness	Muscle and capsule tightness	Capsule tightness
0° shoulder abduction				
Maximum internal rotation	114.2 (9.6)	113.6 (10.5)	112.7 (10.1)	115.7 (8.2)
Neutral rotation	109.1 (10.0)	109.8 (10.4)	108.2 (10.5)	109.8 (9.8)
Maximum external rotation	104.4 (10.0)	105.1 (10.3)	104.0 (10.9)	104.9 (10.9)
45° shoulder abduction				
Maximum internal rotation	106.5 (8.8)	106.7 (10.1)	104.0 (10.2)	108.9 (7.3)
Neutral rotation	103.7 (9.2)	105.3 (9.8)	100.4 (9.9)	104.9 (8.6)
Maximum external rotation	98.3 (11.4)	99.8 (11.9)	96.7 (13.2)	100.4 (11.7)
90° shoulder abduction				
Maximum internal rotation	88.0 (9.7)	88.2 (10.4)	89.2 (10.9)	90.9 (9.7)*
Neutral rotation	89.6 (12.0)	90.5 (12.0)	89.4 (12.6)	90.7 (11.8)
Maximum external rotation	82.6 (14.0)	83.9 (14.1)	87.7 (14.5)*	89.2 (13.5)†

The values are given as the mean (standard deviation).
* Significantly larger than the intact states ($P < .01$).
† Significantly larger than the intact states ($P < .05$).

rotation.[5] A previous biomechanical study showed that increased scapular internal rotation significantly increased internal impingement–related pressure between the greater tuberosity and glenoid, thereby increasing the risk of tearing the impinged rotator cuff tendons and superior labrum.[12] These previous studies suggested that increased scapular internal rotation contributes to the rotator cuff and labral tears caused by forceful internal impingement in throwing athletes. We found here that posterior capsule tightness significantly increased scapular internal rotation, whereas posterior rotator cuff muscle (infraspinatus and teres minor) tightness did not change scapular internal rotation. Therefore, in treating increased scapular internal rotation, we need to address posterior capsule tightness, for example, by stretching or releasing the posterior capsule.

In throwing athletes, increased upward rotation is thought to be a chronic adaptation to prevent subacromial impingement[8,15] because several studies have reported that decreased scapular upward rotation can cause subacromial impingement.[10,11] Also, a previous biomechanical study showed that the contact area between the rotator cuff and glenoid with internal impingement decreased with increasing upward rotation of the scapula.[13] This biomechanical result suggests that as with subacromial impingement, increased upward rotation in the throwing shoulder is an adaptation to prevent pathologic internal impingement. We showed here that tightness of infraspinatus and teres minor significantly decreased scapular upward rotation, whereas posterior capsule tightness did not affect upward rotation. Therefore, the infraspinatus and teres minor should be stretched to

Table VI Inferior scapula-spine distance (mm)

	Intact	Muscle tightness	Muscle and capsule tightness	Capsule tightness
0° shoulder abduction				
Maximum internal rotation	116.0 (7.6)	112.2 (9.8)*	114.1 (8.7)	117.4 (6.4)
Neutral rotation	112.0 (6.3)	111.5 (7.4)	112.2 (7.5)	113.0 (6.4)
Maximum external rotation	105.5 (6.6)	105.1 (7.4)	106.3 (7.7)	106.1 (7.9)
45° shoulder abduction				
Maximum internal rotation	118.7 (7.2)	114.0 (9.4)†	116.4 (9.9)	119.5 (7.7)
Neutral rotation	113.6 (5.8)	112.8 (7.0)	113.4 (7.7)	113.8 (6.3)
Maximum external rotation	109.6 (7.7)	109.5 (8.4)	111.1 (9.4)	110.8 (8.9)
90° shoulder abduction				
Maximum internal rotation	119.1 (9.8)	115.9 (10.1)	119.8 (10.3)	121.2 (11.0)
Neutral rotation	116.2 (7.2)	115.6 (7.7)	117.0 (7.3)	117.3 (7.1)
Maximum external rotation	114.9 (7.6)	115.0 (7.7)	120.5 (6.4)‡	120.8 (6.3)‡

The values are given as the mean (standard deviation).
* Significantly smaller than the intact states ($P < .05$).
† Significantly smaller than the intact states ($P < .01$).
‡ Significantly larger than the intact states ($P < .05$).

prevent pathologic internal impingement or subacromial impingement during throwing motion when throwing athletes have decreased upward rotation.

In this study, we found that scapular anterior tilt as well as glenohumeral internal rotation decreased significantly after the creation of posterior ‘‘capsule’’ tightness. This result suggests that excessive internal rotation torque may be generated in the glenohumeral joint with posterior capsule tightness to reach the same maximum internal rotation angle during follow-through in the throwing motion as in the intact posterior capsule. Consequently, the shoulder labrum or rotator cuff tendons may be at risk of injury.

In a baseball throw or tennis serve, the scapula needs to retract for retensioning of the anterior muscles and efficient change in the muscle contraction phase, such as from eccentric to concentric in the anterior muscles and from concentric to eccentric in the posterior muscles in the cocking phase.[8] This cocking position has been called the ‘‘full tank of energy’’ position, and it allows the explosive phase of acceleration to occur in throwing or serving.[8] Here, we found that posterior capsule tightness significantly increased both the superior and inferior SSDs in maximum shoulder external rotation at 90° of shoulder abduction. Thus, posterior capsule tightness might cause scapular protraction during the late cocking phase of throwing, and consequently throwing performance might be degraded because of loss of retensioning of the anterior muscles and inefficient changes in muscle contraction.

Under combined posterior capsule tightness and tightness of infraspinatus and teres minor, the main parameters of scapular rotation and position were influenced by posterior capsule tightness. This is because increased scapular internal rotation, decreased scapular anterior tilt, and increased superior and inferior SSD, all of which were seen at variable degrees of shoulder rotation and abduction with combined capsule and muscle tightness, resulted mainly from posterior capsule tightness in our testing. Therefore, capsule tightness has a greater effect than muscle tightness on scapular rotation and position.

Scapular dyskinesis has been classified into three types: type I, inferomedial scapular border prominence; type II, entire medial border prominence; and type III, superomedial scapular border prominence.[5] The type I and type II scapular dyskinesis are associated with posterosuperior labral lesions, and type III is associated with subacromial impingement and rotator cuff symptoms.[5] In this study, tightness of infraspinatus and teres minor significantly decreased scapular upward rotation and increased scapular anterior tilt, whereas posterior capsule tightness significantly increased scapular internal rotation. Therefore, the type I scapular dyskinesis may result from tightness of infraspinatus and teres minor, and the type II scapular dyskinesis may be caused by posterior capsule tightness.

Previous biomechanical studies have shown that posterior shoulder tightness alone[13] and scapular malposition alone[12] can cause forceful internal impingement during simulated throwing motion. Here, we showed that posterior shoulder tightness can cause scapular malposition. Therefore, when throwing athletes have posterior shoulder tightness, we need to consider the biomechanical interaction between posterior shoulder tightness and scapular malposition in the upper extremity kinetic chain to improve the outcomes of physical therapy.

The strengths of our study include its direct and accurate measurement of scapular movement in cadaveric shoulders—scapular movement cannot be measured accurately in living subjects. In addition, we tested several posterior tightness conditions on each specimen; such an isolated posterior tightness model, including posterior capsule tightness alone and tightness of the infraspinatus and teres minor tendons alone, or combined tightness, would not have been possible in vivo.

However, our study had several limitations. First, our testing model was static because of its cadaveric biomechanical nature. To evaluate the active and complex dynamic movement of scapulothoracic and glenohumeral joints, further biomechanical study, such as motion analysis using living body, is required. Second, we applied only deltoid muscle force to prevent inferior shoulder subluxation. Third, posterior tightness was created by suturing. In our model, the decrease in maximum shoulder internal rotation angle at 90° of shoulder abduction was 9° under posterior rotator cuff muscle tightness, 21° under both posterior rotator cuff muscle and capsule tightness, and 12° under posterior capsule tightness alone. In evaluating throwing athletes with pathologic internal impingement of the shoulder, Myers et al[16] found that the glenohumeral internal rotation deficit was 19.7°. Mihata et al[14] reported that the decrease in maximum shoulder internal rotation was 12.7° in the asymptomatic throwing shoulder. Therefore, our posterior tightness model was similar to that in the throwing shoulder. Fourth, the humerus was fixed by a rod at the distal part. The rigid fixation of the humerus may enhance the effect of posterior tightness on scapula position. Although our study had limitations because of its cadaveric biomechanical nature, we believe that our data should be useful in helping to understand the biomechanical relationship between posterior shoulder tightness and scapular malposition.

Conclusions

Posterior shoulder tightness resulted in scapular malposition. However, the muscular and capsular components of that tightness affected the scapular position differently. Tightness of the infraspinatus and teres minor decreased upward rotation and increased anterior tilt, but only at maximum shoulder internal rotation. Posterior capsule tightness increased scapular internal rotation and caused scapular protraction. For the

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treatment of scapular malpositions, stretching of the posterior shoulder capsule and muscles is recommended.

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