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Biomechanical Assessment of Type II Superior Labral Anterior-Posterior (SLAP) Lesions Associated With Anterior Shoulder Capsular Laxity as Seen in Throwers

A Cadaveric Study

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Background: Type II superior labral anterior-posterior lesions in throwers are often associated with anterior shoulder capsular laxity.

Hypothesis: Shoulder instability in patients with type II superior labral anterior-posterior lesions may result from the associated shoulder capsular laxity rather than the superior labral anterior-posterior lesion alone.

Study Design: Controlled laboratory study.

Methods: Six cadaveric shoulders were externally rotated to 20% beyond the maximum humeral external rotation at 60° of glenohumeral abduction, which simulated 90° of shoulder abduction, to detach the superior labrum and elongate the anterior shoulder capsular ligaments. The detached labrum was then repaired to isolate the effect of the detached superior labrum and that of the capsular laxity. Rotational range of motion was measured at 60° of glenohumeral abduction. Anterior-posterior glenohumeral translation was measured at 30° and 60° of glenohumeral abduction. Superior-inferior glenohumeral translation was measured at 0° and 60° of glenohumeral abduction.

Results: The experimentally created type II superior labral anterior-posterior lesion and capsular laxity significantly increased anterior translation at 30° (mean difference, 1.0 ± 0.8 mm; $P < .05$) and 60° (mean difference, 2.2 ± 2.0 mm; $P < .05$) of glenohumeral abduction. Subsequent superior labral anterior-posterior repair restored the anterior translation but only at 30° of glenohumeral abduction (mean difference, 0.9 ± 0.6 mm; $P < .05$).

Conclusion: Because of the anterior capsular laxity associated with type II superior labral anterior-posterior lesions, superior labral anterior-posterior repair of the peeled-back superior labrum may not restore anterior glenohumeral translation at 90° of shoulder abduction.

Clinical Relevance: Anterior shoulder capsular laxity associated with type II superior labral anterior-posterior lesions may cause anterior shoulder instability at 90º of shoulder abduction in throwers even after superior labral anterior-posterior lesion repair.

Keywords: SLAP lesion; laxity; shoulder; external rotation

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Type II superior labrum anterior-posterior (SLAP) lesions cause shoulder instability[18] and pain. In previous biomechanical studies, simulation of type II SLAP lesions by cutting the superior labrum has resulted in increased glenohumeral translation.[3,15,22] However, the increase in glenohumeral translation is subtle, suggesting that shoulder instability may not result only from the type II SLAP lesion.

Type II SLAP lesions are often associated with shoulder capsular laxity in throwing athletes.[6] Terry et al[26] showed that abnormally increased glenohumeral translation was demonstrated in 24% of patients with SLAP lesions, and Cohen et al[5] reported that a reason for postoperative failure of the SLAP repair was residual instability. Andrews and Dugas[2] reported that thermal-assisted capsular shrinkage improved long-term follow-up results after treatment of type II SLAP lesions. However, no biomechanical studies have investigated the relationship between type II SLAP lesions and anterior shoulder capsular laxity. One of the causes of the type II SLAP lesion is thought to be a peel-back mechanism. Burkhart and Morgan[4] postulated that excessive humeral external rotation may peel back the superior labrum. Our previous study showed that excessive humeral external rotation results in anterior shoulder capsular laxity,[16] suggesting that the anterior shoulder capsule may be elongated when the superior labrum is peeled back by excessive external rotation. We hypothesized that shoulder instability in patients with type II SLAP lesions may result from the associated shoulder capsular laxity and not just from the tearing injury itself. To assess this shoulder instability, glenohumeral translation and the rotational range of motion of the humerus were measured in cadaveric shoulders. The objective was to distinguish between the effects of (1) superior labral detachment and (2) anterior capsular laxity on glenohumeral translation and the rotational range of motion by evaluating the intact specimen, after excessive external rotation (superior labral detachment and anterior capsular laxity), and after SLAP repair.

MATERIALS AND METHODS

A custom shoulder-testing system was developed to create laxity in human cadaveric shoulders and to measure glenohumeral translation and humeral rotation (Figure 1). The shoulder-testing system allowed 6 degrees of freedom for positioning the glenohumeral joint. Anterior-posterior and superior-inferior translations were provided by 2 translation plates. Compression distraction was applied through a lever arm and bearing system attached to the top translation plate, where the scapula box was mounted. The humeral cylinder was attached along the top arc of the shoulder-testing system. The angle of the arc could be adjusted to create various degrees of shoulder abduction. The humerus could be positioned along any point of the arc, simulating horizontal abduction or adduction. The shoulder-testing system allowed 360° of humeral rotation, which was measured with a goniometer at the distal end of the humerus.

Six fresh-frozen cadaveric shoulders with an average age of 72 years (range, 67-81 y) were used. The shoulders were screened by macroscopic and arthroscopic examinations for any signs of abnormality. The specimens were thawed for 24 hours at room temperature before testing. Each specimen was dissected of all soft tissues except the capsule and the coracoacromial ligament. The long head of the biceps was cut at the proximal musculotendinous junction. The intra-articular portion of the biceps tendon was left intact. The biceps force was simulated using a 10-N weight applied along the bicipital groove for the entire test period. The scapula was potted with the glenoid oriented parallel to the top edge of the scapular box by using plaster of Paris. The humeral shaft was transected 2 cm distal to the deltoid tuberosity for potting in PVC pipe with plaster of Paris. The shoulder was then mounted on the custom shoulder-testing system. All specimens were kept moist with 0.9% saline throughout the experiment.

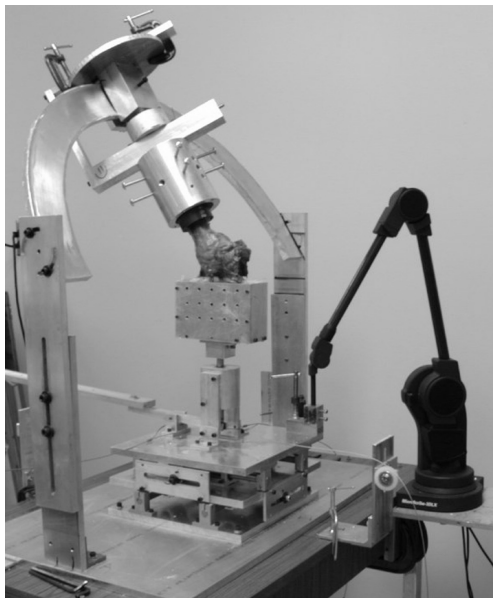

Figure 1. Custom shoulder-testing system. The shoulder-testing system permits 6 degrees of freedom of motion and the measurement of glenohumeral translations and humeral rotational range of motion.

Excessive Humeral External Rotation and SLAP Repair

The experimentally created type II SLAP lesion model[17] and experimentally created anterior shoulder capsular laxity model[16] were developed by using fresh-frozen cadaveric shoulders. To simulate the late cocking phase of throwing, the humerus was externally rotated to 20% beyond maximum external rotation at 60° of glenohumeral abduction, which represented 90° of shoulder abduction.[8,9,24] The 20% increase in maximum humeral external rotation was achieved by applying an external torque of 2.2 N·m for 1 minute and then relaxing for 30 seconds. The external torque was then increased in 0.55-N·m increments until the targeted humeral external rotation was reached. The humerus was then secured with a locking clamp in this position for 30 minutes. After this excessive external rotation of the humerus, in all specimens the anterior shoulder capsule was elongated, and the superior labrum was detached at the glenoid insertion (Figures 2 and 3). The elongated anterior capsule was observed macroscopically and had been confirmed by the authors' previous study.[16] The detached superior labrum was confirmed arthroscopically by comparing sulcus scores[17] before and after excessive external rotation.

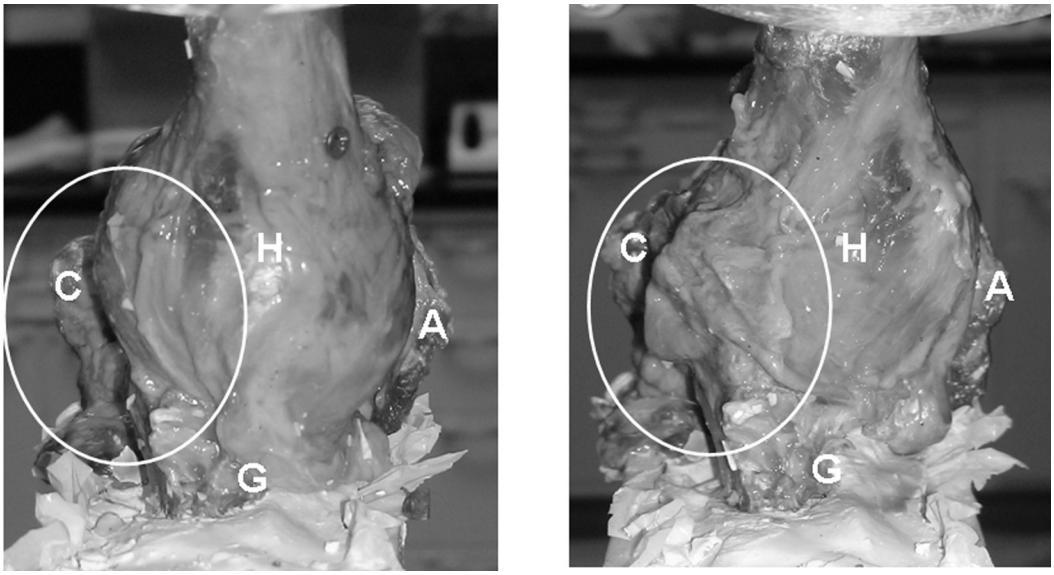

Figure 2. Inferior view of the anterior shoulder capsule. Left image: Before excessive humeral external rotation. Right image: After excessive humeral external rotation. The stretched anterior shoulder capsule was macroscopically observed. A, acromion; C, coracoid; G, glenoid; H, humerus.

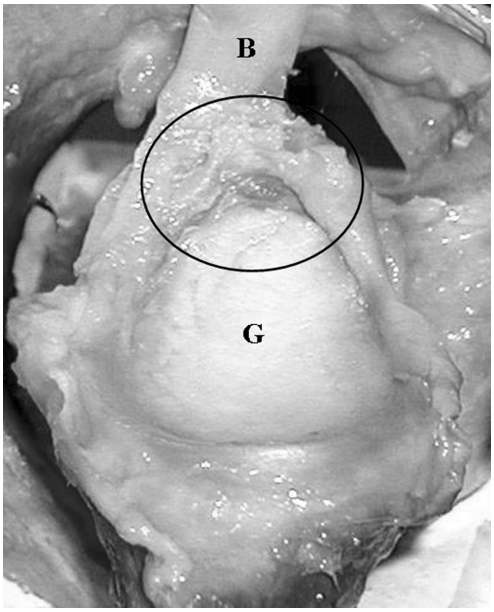

Figure 3. The superior labrum detachment after excessive humeral external rotation. B, biceps long head; G, glenoid.

To isolate the separate effects of anterior capsular elongation and superior labral detachment, the detached superior labrum was repaired arthroscopically by the same investigator in all specimens. A posterior portal measuring 5 mm was made with an 11 blade. After the arthroscope was introduced into the glenohumeral joint, a second 5-mm working portal was made behind the biceps tendon with an 11 blade. Our previous study confirmed that these 2 small portals do not affect the glenohumeral translation and rotational range of motion.[23] Two fully threaded 2.8-mm-diameter titanium suture anchors (FASTak II Suture Anchor; Arthrex Inc, Naples, Fla) with polyester sutures with a long chain polyethylene core (No. 2 FiberWire; Arthrex Inc) were placed at the glenoid edge. After we ensured adequate bony purchase of the anchors, a Suture Lasso (Arthrex Inc) was used to penetrate the superior labrum. Under direct arthroscopic visualization, the detached superior labrum was repaired with a sliding knot (Tennessee slider) and tightened to the glenoid rim with 3 alternating half hitches. The integrity of the knot and repair was then examined with a probe. The elongated anterior shoulder capsule was not plicated during the repair; therefore, any change remaining after superior labral repair was considered to have resulted from elongation of the anterior shoulder capsule.

Humeral Rotational Range of Motion and Glenohumeral Translation

Rotational range of motion and glenohumeral translations (anterior, posterior, superior, and inferior) were measured in intact shoulders; shoulders after creation of the type II SLAP lesion and capsular laxity by excessive humeral external rotation; and shoulders after repair of the detached superior labrum. Before each measurement of rotational range of motion and glenohumeral translations, the glenohumeral joint was vented with a 19-gauge needle and then lubricated with 5 mL of 0.9% saline to eliminate the effect of negative pressure in the capsule. A compressive force of 22 N perpendicular to the glenoid and a biceps tensile force of 10 N were applied for the entire test period.

The humeral rotational range of motion was quantified by the 360° goniometer attached to the top of the testing system. The goniometer degree measurements were inscribed on a stationary circular plate in 1° increments, making the precision of the measurement 0.5°. As the humerus was rotated from maximum internal to maximum external rotation, the amount of rotation could be measured from a reference point on the rotating plate with respect to the goniometer.

The glenohumeral joint capsule was preconditioned with 10 cycles of external and internal rotation at a torque of 1.1 N·m, each cycle lasting 5 seconds. The humeral rotational range of motion at 60° of glenohumeral abduction was then measured with 2.2 N·m of torque, with both translation plates free. Ninety degrees of humeral external rotation was defined as the position where the bicipital groove was aligned with the anterior edge of the acromion.[1,16,23]

The starting position was determined by applying 22 N of joint compressive force to the glenoid to center the humeral head and thus establish a reproducible starting position. The amount and direction of translation relative to the starting position were quantified by using a desktop 3D digitizing system (Microscribe 3DLX; Immersion Corp, San Jose, Calif). The accuracy of this device was determined to be 0.30 mm by the manufacturer. To measure glenohumeral translation, first a reference plane and coordinate system were defined (x = anterior-posterior; y = superior-inferior; z = compression-distraction). A predetermined point on the baseplate on the glenoid side of the testing system was measured with the humeral head centered in the glenoid. Because the glenoid translates with respect to the humeral head, to quantify humeral translation with respect to the glenoid, a translational force was applied in the direction opposite to the direction being measured. Before translation measurements began, the capsule was preconditioned with 10 cycles of 10-N force in the anterior-posterior direction and then with 10 cycles of the same force in the superior-inferior direction. Forces of 15 N and 20 N were then applied with both translation plates unlocked, permitting 3 degrees of freedom of movement. Anterior and posterior glenohumeral translations were measured at 60° of glenohumeral abduction and 90° of humeral external rotation, 60° of glenohumeral abduction and humeral neutral rotation, and 30° of glenohumeral abduction and humeral neutral rotation. Superior and inferior glenohumeral translations were measured at 60° of glenohumeral abduction and 90° of humeral external rotation, 60° of glenohumeral abduction and humeral neutral rotation, and 0° of glenohumeral abduction and humeral neutral rotation. Here, neutral rotation of the humerus was defined as the bisected position of total rotational range of motion.

Statistical Analysis

All measurements were performed twice and the averages calculated. Statistical analyses were performed by using a repeated measures analysis of variance followed by a Tukey post hoc test for comparison of humeral rotational range of motion and glenohumeral translations (1) between intact, (2) after creation of the type II SLAP lesion and capsular laxity by excessive humeral external rotation, and (3) after repair of the detached superior labrum. Data are shown as means ± standard deviations (SDs) of the mean. Significance was set at $P < .05$.

RESULTS

There was a significant increase in humeral external rotational range of motion after excessive external rotation (mean difference, 20.8° ± 5.2°; $P < .0001$) and a significant decrease after superior labrum repair compared with after excessive external rotation (mean difference, 4.0° ± 1.8°; $P < .05$). Humeral internal rotational range of motion did not change significantly after excessive external rotation but decreased significantly after repair of the detached superior labrum (mean difference, 2.5° ± 1.0°; $P < .05$) (Table 1).

TABLE 1
Rotational Range of Motion Reported as the Mean and Standard Deviation in Degrees[a]

	Intact, deg	Excessive External Rotation, deg	Superior Labrum Repair, deg
External rotation	141.5 ± 15.1	162.3 ± 17.0[b]	158.3 ± 17.5[c]
Internal rotation	3.7 ± 28.3	4.0 ± 28.4	1.5 ± 28.8[c]

[a]Increase in external rotation after excessive external rotation was the effect of type II SLAP lesion and anterior capsular laxity. Increase in external rotation remaining after superior labral repair was considered to have resulted from elongation of the anterior shoulder capsule.
[b]$P < .05$.
[c]$P < .0001$.

The increases in glenohumeral translations were similar between 15 N and 20 N of translational force applied (Table 2). After experimental creation of the type II SLAP lesion and anterior capsular laxity, anterior glenohumeral translation significantly increased in all 3 positions (60° of glenohumeral abduction and 90° of external rotation: mean difference, 2.4 mm ± 1.7 mm at 15 N and 2.2 mm ± 2.0 mm at 20 N; 60° of glenohumeral abduction and neutral rotation: mean difference, 1.5 mm ± 2.2 mm at 15 N and 1.5 mm ± 1.9 mm at 20 N; and 30° of glenohumeral abduction and neutral rotation: mean difference, 1.2 mm ± 1.0 mm at 15 N and 1.0 mm ± 0.8 mm at 20 N; $P < .05$). After superior labral repair, anterior glenohumeral translation significantly decreased only at a position of 30° of glenohumeral abduction and humeral neutral rotation (mean difference, 1.0 mm ± 0.5 mm at 15 N and 0.9 mm ± 0.6 mm at 20 N; $P < .05$).

Inferior glenohumeral translation significantly increased in all 3 positions after experimental creation of the type II SLAP lesion and anterior capsular laxity (60° of glenohumeral abduction and 90° of external rotation position: mean difference, 1.5 mm ± 1.2 mm at 15 N and 1.5 mm ± 1.1 mm at 20 N; 60° of glenohumeral abduction and neutral rotation position: mean difference, 0.7 mm ± 0.6 mm at 15 N and 0.7 mm ± 0.7 mm at 20 N; and 0° of glenohumeral abduction and neutral rotation position: mean difference, 1.1 mm ± 0.8 mm at 15 N and 1.3 mm ± 0.8 mm at 20 N; $P < .05$). After superior labrum repair, inferior glenohumeral translation was significantly decreased at 60° of glenohumeral abduction and humeral neutral rotation (mean difference, 0.8 mm ± 0.4 mm at 15 N and 0.7 mm ± 0.4 mm at 20 N; $P < .05$) and at 0° of glenohumeral abduction and humeral neutral rotation (mean difference, 1.3 mm ± 0.8 mm at 15 N and 1.3 mm ± 0.8 mm at 20 N; $P < .01$). Posterior and superior glenohumeral translations were not changed significantly.

TABLE 2
Anterior and Inferior Glenohumeral Translation[a]

	Intact	Excessive External Rotation	Superior Labrum Repair
60° abduction, 90° external rotation			
Anterior translation, mm			
15 N	8.4 ± 3.7	10.8 ± 4.0[b]	10.3 ± 4.2
20 N	9.3 ± 3.6	11.5 ± 4.5[b]	10.9 ± 4.2
Inferior translation, mm			
15 N	10.8 ± 3.3	12.4 ± 3.9[b]	11.7 ± 3.8
20 N	11.7 ± 3.6	13.2 ± 3.7[b]	12.6 ± 3.6
60° abduction, neutral rotation			
Anterior translation, mm			
15 N	13.4 ± 6.6	14.9 ± 7.8[b]	14.6 ± 7.8
20 N	14.1 ± 6.8	15.6 ± 7.6[b]	15.2 ± 7.6
Inferior translation, mm			
15 N	9.0 ± 2.7	9.7 ± 2.8[b]	9.0 ± 2.7[c]
20 N	9.6 ± 2.8	10.3 ± 2.8[b]	9.6 ± 2.7[c]
30° abduction, neutral rotation			
Anterior translation, mm			
15 N	20.3 ± 5.5	21.5 ± 5.9[b]	20.5 ± 5.8[c]
20 N	21.0 ± 5.4	22.1 ± 5.8[b]	21.2 ± 5.8[c]
0° abduction, neutral rotation			
Inferior translation, mm			
15 N	21.0 ± 11.2	22.1 ± 11.3[b]	20.9 ± 11.5[c]
20 N	22.2 ± 10.3	23.5 ± 10.0[b]	22.2 ± 10.5[c]

[a]The values are reported as the mean and standard deviation in millimeters.
[b]$P < .05$ for the difference between intact and SLAP with capsular laxity after excessive external rotation.
[c]$P < .05$ for the difference between SLAP with capsular laxity and capsular laxity remaining after superior labrum repair.

DISCUSSION

The type II SLAP lesion, which is a common injury in throwing athletes, causes shoulder instability as well as shoulder pain.[18] According to previous biomechanical studies, a type II SLAP lesion results in increased glenohumeral translation.[3,15,22] However, this increase in translation is subtle, suggesting that the shoulder instability may not result only from the type II SLAP lesion.

Type II SLAP lesions are often associated with shoulder capsular laxity in throwing athletes. Andrews and Dugas[2] reported that thermal-assisted capsular shrinkage improved their long-term follow-up results after treatment of type II SLAP lesions. However, there have been no biomechanical investigations of type II SLAP lesions in relation to shoulder capsular laxity. Here, we developed an experimentally created type II SLAP lesion model[17] and anterior shoulder capsular laxity model by using cadaveric shoulders.[16] By excessive humeral external rotation at 60° of glenohumeral abduction, which simulated the late cocking phase of the throwing motion, detachment of the superior labrum and elongation of the anterior shoulder capsule were simultaneously created in cadaveric shoulders. We believe that the cadaveric type II SLAP lesion model is based on a peel-back mechanism, which was postulated by Burkhart and Morgan,[4] and that the cadaveric anterior shoulder capsular laxity model is similar to the attenuation of anterior-inferior capsuloligamentous restraint caused by overhead activity.[13]

In this model, excessive humeral external rotation simulating the late cocking phase of throwing motion resulted in simultaneous detachment of the superior labrum and elongation of the anterior shoulder capsular ligaments. Then, to isolate the effects of the detached superior labrum and the capsular laxity on rotational range of motion and glenohumeral translation, only the detached superior labrum was repaired. The difference between the intact model data and the excessive external rotation data represented the effects of both elongation of the anterior shoulder capsular ligaments and detachment of the superior labrum; the difference between the excessive external rotation data and the SLAP repair data represented the superior labrum detachment effect; and the difference between the intact data and the SLAP repair data represented the effect of stretching of the anterior shoulder capsular ligaments.

After the application of excessive external rotation force, the external rotation at 60° of glenohumeral abduction, anterior translation at both 60° and 30° of glenohumeral abduction, and inferior translations at both 60° and 0° of glenohumeral abduction increased significantly. The SLAP repair partly restored external rotation and restored anterior translation only at 30° of glenohumeral abduction and inferior translation at 0° of glenohumeral abduction. Therefore, detachment of the superior labrum resulted in a slight increase in external rotation and an increase in anterior and inferior translations at low glenohumeral abduction. Anterior and inferior translation at 60° of glenohumeral abduction and 90° of external rotation were not restored by the SLAP repair, meaning that anterior and inferior translation at 60° of glenohumeral abduction, which was simulated at 90° of shoulder abduction, and 90° of external rotation were increased by the stretching of the anterior shoulder capsular ligaments.

In the current study, anterior glenohumeral translation at 60° of glenohumeral abduction and 90° of external rotation increased by 2.2 mm after excessive external rotation and decreased by 0.6 mm after SLAP repair. On the other hand, our previous study showed that the arthroscopic creation of a type II SLAP lesion with a periosteal elevator resulted in an increase in anterior glenohumeral translation by 0.6 mm at 60° of glenohumeral abduction and 90° of external rotation.[23] Therefore we believe that the increase in anterior glenohumeral translation by excessive external rotation resulted from the increased anterior capsular laxity as well as the type II SLAP lesion.

The superior glenohumeral ligament and superior shoulder capsule attached to the superior labrum[19] are tight at 0° and 30° of glenohumeral abduction and loose at 60° and 90° of glenohumeral abduction.[7] The anterior band of the inferior glenohumeral ligament is a primary restraint to humeral external rotation at 90° of shoulder abduction.[27,28] The anteroinferior capsule is tight at 60° and 90° of glenohumeral abduction and loose at 0° and 30° of glenohumeral abduction.[7,20] Therefore, detachment of the superior labrum may be responsible for the increased

glenohumeral translation at low glenohumeral abduction (0° to 30°), and elongation of the anterior band of the inferior glenohumeral ligament may be responsible for the increased translation at high glenohumeral abduction (60° to 90°).

There are several limitations to this study. First, the number of suture anchors may not have been sufficient. Two suture anchors were used to repair the experimentally created type II SLAP lesion. The "sulcus score,"[17] which represents the size and severity of type II SLAP lesions, of the superior labral detachment produced in this study by excessive external rotation was 3.3 ± 0.6. Our previous study showed that rotational range of motion and glenohumeral translations were completely restored after repair of a type II SLAP lesion, whose sulcus score was 4, with 2 suture anchors.[23] Therefore, we believe that the 2 suture anchors we used would in fact have been sufficient. Second, no muscle force except the biceps force was applied during testing; however, instead of muscle force, a compression force of 22 N was applied. According to previous cadaveric studies, 22 N of compression force is sufficient to measure glenohumeral translation and rotational range of motion in cadaveric shoulders.[1,11,16,17,23] Third, obviously the feeling of shoulder instability experienced by patients cannot be identified in cadaveric studies. However, patients with shoulder instability usually have increased glenohumeral translation[12,21,29]; moreover, humeral rotational range of motion has been shown to be correlated with glenohumeral translation.[16] Because increased shoulder laxity may cause shoulder instability, glenohumeral translation and humeral rotational range of motion were measured here. Fourth, the stretched anterior capsule was not plicated after SLAP repair. In a study of the same model as the current investigation, an arthroscopic anteroinferior plication reduced anterior translation at 60° of glenohumeral abduction.[1] Therefore the arthroscopic anteroinferior suture plication may be useful for anterior capsular laxity associated with type II SLAP lesion. Because the loss of external rotation was observed after arthroscopic anteroinferior capsular plication,[1] careful attention should be paid to the amount of capsule included in the plication for throwing athletes.[14] Finally, the effect of biceps force in throwing motion is still unclear because only one condition of biceps force was investigated in this study. A previous electromyographic study showed that biceps muscle activity was only 30% of maximum muscle strength at the late cocking phase.[10] However, a cadaveric study by Rodosky et al[25] showed that the long head of the biceps contributes to anterior stability of the glenohumeral joint by increasing the shoulder's resistance to torsional forces in the abducted and externally rotated position. Therefore the biceps force may have some effect on glenohumeral stability.

According to Mileski and Snyder,[18] some patients with type II SLAP lesions have signs of shoulder instability as well as symptoms of pain. Because the increased anterior glenohumeral translation at 60° of glenohumeral abduction was not restored by our SLAP repair, anterior shoulder capsular laxity, which has the same origin, that is, excessive external rotation, as the type II SLAP lesion, may cause anterior shoulder instability at 90° of shoulder abduction in throwers. In cases of peeled-back superior labrum, as seen in throwers, the associated anterior capsular laxity should be addressed if anterior instability is present at 90° of shoulder abduction.

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