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Supplementary material

Commentary and Perspective, data tables, additional images, video clips and/or translated abstracts are available for this article. This information can be accessed at <http://www.ejbs.org/cgi/content/full/88/1/179/DC1>

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ARTHROSCOPIC ANTEROINFERIOR SUTURE PLICATION RESULTING IN DECREASED GLENOHUMERAL TRANSLATION AND EXTERNAL ROTATION

STUDY OF A CADAVER MODEL

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Background: The consequences of arthroscopic plication for the treatment of anterior shoulder instability are unknown. The purpose of this study was to evaluate the effects of arthroscopic plication on glenohumeral translation, the rotational range of motion, and the positions of the glenohumeral center of rotation.

Methods: Six cadaver shoulders were tested in the intact state, after simulation of anterior instability by anterior capsular stretching, after creation of arthroscopic portals, and following a 10-mm anteroinferior arthroscopic suture plication. Capsulolabral build-up was measured to quantify the increase after plication.

Results: Stretching resulted in a significant increase, compared with the intact state, in external rotation (mean increase, 23.2° [14.3%]; $p < 0.001$) but not in glenohumeral translation (mean increase, 0.8 mm [7.4%] under a 20-N translational load; $p = 0.06$). After plication, external rotation decreased significantly (by 12.6° [6.7%], $p = 0.003$) compared with that following the stretching. After plication, the glenohumeral center of rotation was significantly shifted posteriorly at 60°, 90°, and 120° of external rotation and inferiorly at 90° and 120°. Plication also resulted in significant decreases in anterior translation (mean decrease, 61.1% under a 15-N translational load and 49.8% under a 20-N translational load; $p < 0.001$), posterior translation (mean decrease, 11.4% under a 15-N translational load and 13.1% under a 20-N translational load; $p = 0.002$ and $p < 0.001$, respectively), and inferior translation (mean decrease, 3.2% under a 20-N load; $p = 0.04$). The height of the capsulolabral “bumper” increased from 2.9 mm in the intact state to 6.4 mm following plication ($p = 0.001$).

Conclusions: Arthroscopic anteroinferior plication effectively reduces anterior translation and external rotation. Capsulolabral buildup may help limit anterior translation without affecting rotation. Plication resulted in a shift of the glenohumeral center of rotation posteriorly and inferiorly.

Clinical Relevance: Anterior translation and external rotation can be significantly restricted by arthroscopic anteroinferior suture plication.

Recurrent glenohumeral instability is a difficult problem to treat. While various open capsular tightening procedures (e.g., the Neer anterior inferior capsular

shift and the Jobe capsulolabral reconstruction) have been successful historically, the use of arthroscopic surgery to address recurrent glenohumeral instability is very appealing because of the low associated morbidity, minimal invasiveness, and ability to address the entire joint¹⁻¹⁰.

Capsular plication through a “pinch-tuck” technique, in which a pleat is formed by suturing the capsule to itself, has been used with increasing regularity¹⁻⁵. This technique



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TABLE I Primary Translation Under 15 and 20-N Applied Loads

	Primary Translation (mm)			
	Intact	Stretched	Portals	Plication
15-N load				
Anterior				
Mean	12.8	13.5	13.6	5.1*†‡
Stand. error	1.9	1.9	1.9	1.5
% Change§		5.8	6.7	-61.1*†‡
Posterior				
Mean	20.6	20.1	20.9	18.4*†‡
Stand. error	3.0	3.2	3.1	3.1
% Change§		0.9	1.7	-11.4*†‡
Superior				
Mean	1.1	1.1	0.9	1.3
Stand. error	1.0	1.2	1.4	1.0
% Change§		13.9	23.3	19.1
Inferior				
Mean	14.9	15.2	15.3	14.3
Stand. error	1.1	1.0	1.1	1.3
% Change§		2.2	3.1	-3.9
20-N load				
Anterior				
Mean	13.4	14.2	14.2	6.9*†‡
Stand. error	2.0	1.9	1.9	1.5
% Change§		7.4	7.2	-49.8*†‡
Posterior				
Mean	21.2	21.5	21.5	18.8*†‡
Stand. error	3.0	3.1	3.1	3.2
% Change§		1.2	1.3	-13.1*†‡
Superior				
Mean	1.3	1.3	1.1	1.3
Stand. error	1.3	1.6	1.7	1.6
% Change§		16.2	15.9	11.8
Inferior				
Mean	15.5	15.9	15.9	15.0†
Stand. error	1.2	1.1	1.1	1.3
% Change§		2.5	3.0	-3.2†

*A significant difference between the plicated and intact states. †A significant difference between the plicated and stretched states. ‡A significant difference between the plicated state and the state after creation of the portals. §Compared with intact state.

combines access to the entire capsule with the ability to perform specific and individualized procedures on limited areas of the capsule or the glenohumeral ligaments. Furthermore, the capsule is not damaged, as it may be following thermal capsulorrhaphy¹¹⁻¹⁵.

Biomechanical studies have been carried out to assess the reduction in glenohumeral translation and rotation following formal open capsular shifts¹⁶⁻¹⁸ as well as thermal treatment of the capsule^{19,20}. The purpose of this study was to evaluate the effects of a glenoid-based arthroscopic suture capsulorrhaphy on the glenohumeral range of rotation, translation, and center of rotation as well as to as-

sess the change in the depth of capsulolabral complex.

Materials and Methods

Specimens

Six fresh-frozen cadaver shoulders (mean age at the time of death, seventy-one years; range, sixty-two to seventy-nine years) were thawed and prepared for testing. All specimens were seen to be normal, with no evidence of a rotator cuff tear or limitation of the range of motion, both macroscopically and radiographically. Each specimen was dissected to an intact glenohumeral capsule, and all muscles were removed. The humerus was sectioned 2 cm distal to the deltoid tuberosity and

was mounted in polyvinyl chloride pipe with plaster of Paris. The scapula was potted with plaster of Paris and mounted on the shoulder testing system.

Shoulder Testing System

The shoulder testing system (jig) has been described in detail previously (Fig. 1)^{21,22}. The testing apparatus allowed six degrees of freedom for glenohumeral positioning. Translation in both the anterior-posterior and superior-inferior directions could be measured independently or in combination. The scapular box was mounted onto a bearing and lever-arm system, attached to the top translation plate, that allowed application of a joint compressive force. The humerus was mounted to the jig in the plane of the scapula. Glenohumeral abduction and humeral rotation were fully adjustable through the humeral mount. Translational forces could be applied in the anterior, posterior, superior, or inferior direction and were recorded with MicroScribe 3DLX positional sensor (Immersion, San Jose, California).

Specimens were mounted in 60° of glenohumeral abduction for the entirety of the testing. The scapula was potted with plaster of Paris, with the anterior-posterior and superior-inferior planes of the glenoid in line with an aluminum box.

Glenohumeral abduction was measured as the angle formed between the superoinferior axis of the glenoid and the axis of the humerus. Sixty degrees of glenohumeral abduction was assumed to represent 90° of total shoulder abduction, which simulated the 90° of abduction achieved in the clinical situation when the total abduction equals the sum of glenohumeral and scapulothoracic abduction. For the purpose of clarity, abduction will be referred to as total shoulder abduction, and the position used for testing was therefore 90° of total shoulder abduction. Glenohumeral translations were measured with the humerus secured in 90° of external rotation. Ninety degrees of external rotation was estimated by aligning the biceps tendon with the anterior edge of the acromion^{19,20}. Neutral rotation was defined as 90° of internal rotation from that point. A compressive force of 22 N was applied^{18,23}. The specimen was vented with a 19-gauge needle and lubricated with 2 mL of normal saline solution between each phase of testing.

Three sets of specific measurements were obtained for each of the following specimen conditions: intact, after anterior capsular stretching, after creation of the arthroscopic portals, and following an anteroinferior arthroscopic suture capsulorrhaphy. The three measurements were the rotational range of motion, the position of the glenohumeral center of

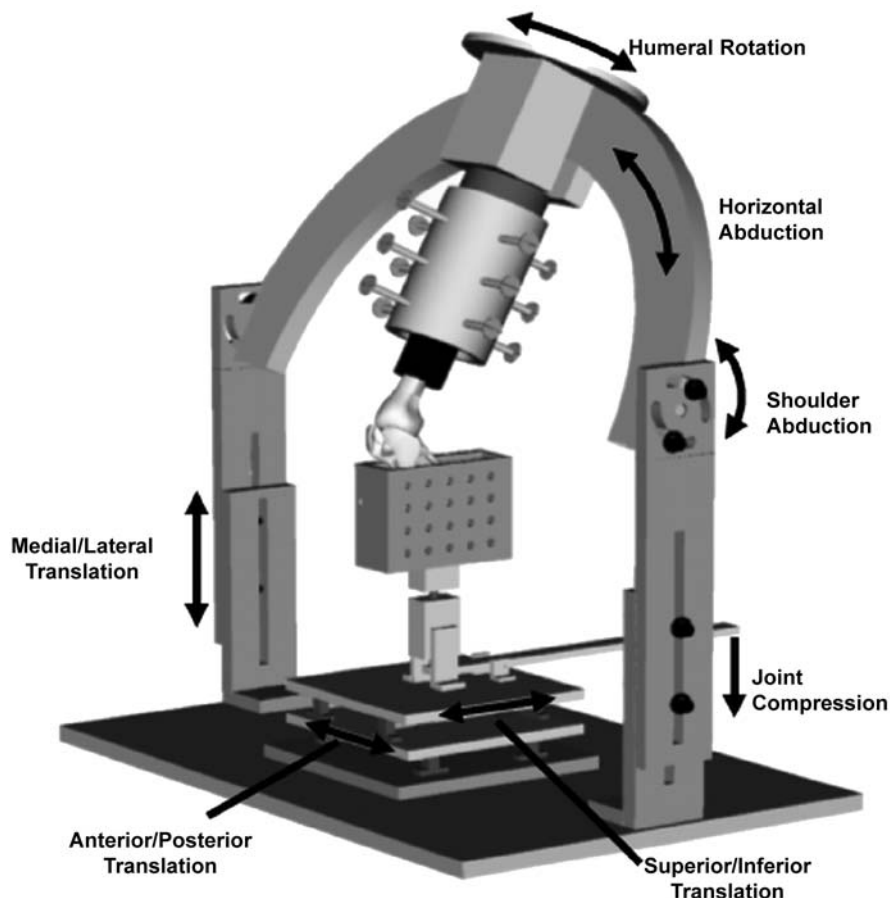


Fig. 1

Shoulder testing system, which allows six degrees of freedom and full access to the shoulder.



Fig. 2
After an anchor is placed medial to the labrum and its position is marked with a needle, a second needle is passed 10 mm directly lateral to the first, marking the position for the plication suture.

rotation (humeral shift), and the humeral head translation. The humeral head was unrestricted in all translational planes at all stages of testing.

Rotational Range of Motion

The specimens were preconditioned with ten cycles of 1.1 Nm of torque in external and internal rotation lasting five seconds each. The rotational range of motion was then measured with application of 2.2 Nm of torque. The total range of rotation, external rotation, and internal rotation were recorded with a 360° goniometer built into the jig.

Glenohumeral Center of Rotation

The glenohumeral center of rotation was calculated by measuring and comparing the humeral head position with respect to the glenoid at maximum internal rotation; 60°, 90°, and 120° of external rotation; and maximum external rotation. All measurements were made with application of a 22-N compressive force to the glenoid and were referenced from the 90° external rotation position. The measurements were made during two successive trials. Since the maximum raw internal and external rotation angles were different for all specimens, these positions were excluded from the analysis. Data were normalized to the intact 90° external rotation position.

Translation

With a constantly applied compressive force of 22 N, transla-

tional forces were applied in the anterior, posterior, superior, or inferior direction, and glenohumeral translation was measured. With the scapula free to translate in all directions, the anterior-posterior plane was preconditioned with a 10-N force that alternated between anterior and posterior application, ten times each. The anterior and posterior translational measurements were recorded with a 15-N force applied for two trials each. The superior-inferior plane was preconditioned, and then superior and inferior translations were measured similarly. The process was then repeated with application of a 20-N force.

Creation of Anterior Laxity

A 20% increase in maximum external rotation was achieved with a gradual increase in the torque applied to the anterior aspect of the glenohumeral capsule through the jig. Pilot testing of the current batch of specimens showed that attempted stretching with more than a 20% increase in maximum external rotation risked capsular rupture and/or labral avulsion. A 3.3-Nm rotational force was applied for one minute and then relaxed for thirty seconds. External rotation was gradually increased through 0.5-Nm increments until the rotational goal was reached. Rotation was then fixed at this point for thirty minutes. The capsule was vented, the joint was lubricated, and the rotational range of motion, position of the glenohumeral center of rotation (humeral shift), and translation were measured as previously described.

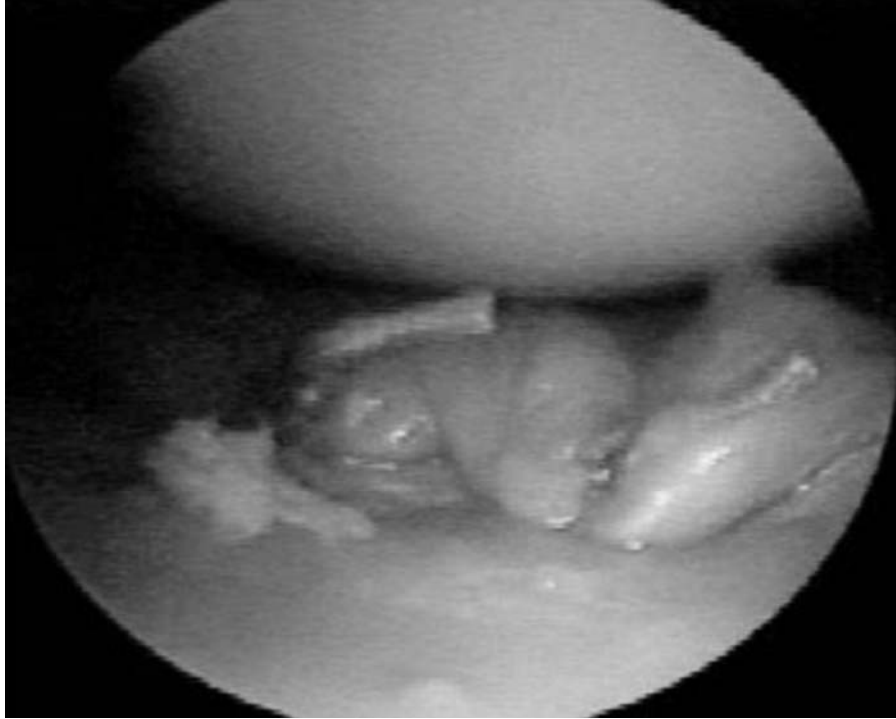


Fig. 3
Final plication with the sutures tied arthroscopically.

Creation of Arthroscopic Portals

A standard posterior viewing portal (5 mm) was created in the capsule 2 cm inferior and 1 cm medial to the posterolateral tip of the acromion. Under arthroscopic control, anterosuperior and anteroinferior portals (5 mm) were made in the rotator interval. The anteroinferior portal was placed at a location that corresponded to the superior border of the subscapularis tendon, allowing effective placement of anchors, passage of sutures, and knot-tying. To ensure that the portals did not affect the biomechanical parameters, the testing sequence was then repeated exactly as described above.

Arthroscopic Suture Plication

Two capsular pleats were created with the use of suture anchors in the anteroinferior quadrant of the capsule by the same investigator in all specimens. Suture anchors were used to eliminate the potential variability in labral tissue quality in the specimens. Under arthroscopic control, a 2.8-mm titanium suture anchor (FASTak; Arthrex, Naples, Florida) with number-2 braided polyester suture was placed as inferiorly as possible just medial to the leading edge of the labrum (at the 5 o'clock position, referenced to a right shoulder). A 22-gauge needle was passed through the capsule, from outside in, under the labrum at the level of the suture anchor, parallel to the face of the glenoid. A second needle was passed, from outside in, through the capsule, 10 mm medial to the first needle with the capsule on stretch (Fig. 2). Unlike what might be tried clinically, no attempt was made to place the medial needle more inferiorly in order to achieve an inferior-to-superior shift as

well. One limb of the suture in the anchor was passed through the capsule at the point marked by the second needle with use of a Suture Lasso (Arthrex). The same procedure (second anchor) was then performed at or below the superior border of the anteroinferior glenohumeral ligament. Arthroscopic knots were then tied, starting with the inferior anchor, to complete the capsulorrhaphy (Fig. 3). The testing procedure was then repeated exactly as previously described.

Measurement of Capsulolabral Buildup

Once the testing on the plicated specimens was complete, the capsule was divided at its humeral insertion. With use of a ruler, the depth of the normal, intact labrum was measured inferior to the plication and between the two anchors.

Data Analysis

Each measurement was performed twice, and the results were averaged. A normalized humeral rotational range of motion and normalized glenohumeral translations were expressed as percentages of the rotational range of motion and the translations of the intact specimens. Repeated-measures analysis of variance was used to compare the normalized humeral rotational range of motion, the normalized glenohumeral translations, and the glenohumeral center of rotation among the shoulder conditions. When a significant difference was identified, comparisons of all pairs were performed with the Tukey-Kramer post hoc test. Capsulolabral depth was analyzed with a paired t test. All data are shown as mean values and the standard error of the mean, with significance determined at $p < 0.05$.

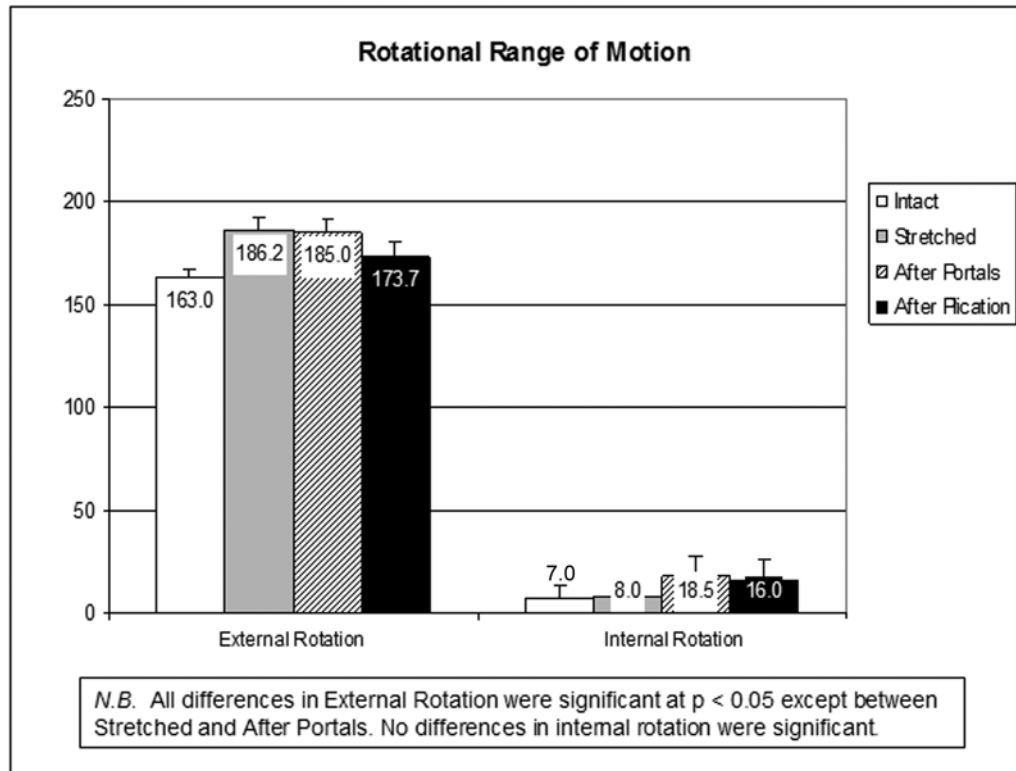


Fig. 4-A
Rotational range of motion, with standard error bars.

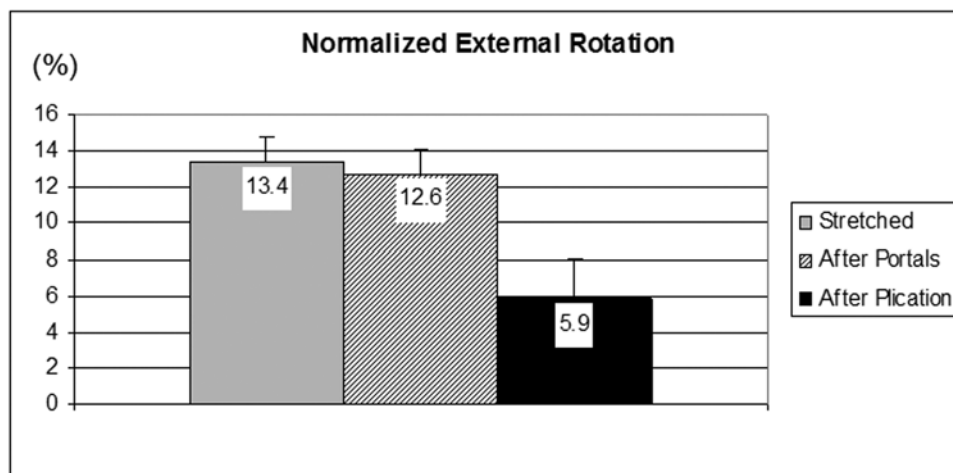


Fig. 4-B
Normalized external rotation, with standard error bars.

Results

The rotational range-of-motion data are depicted in Figures 4-A and 4-B. The intact specimens had an average of $163^\circ \pm 3.9^\circ$ of external rotation and $7^\circ \pm 16^\circ$ of internal rotation. Stretching resulted in a significant increase (of 23.2° [14.3%], $p < 0.001$) in external rotation, to a mean of $186.2^\circ \pm 6.3^\circ$, and no significant change in internal rotation. One specimen had a large increase in internal rotation during stretching

(from 28° to 63°) because the anterior laxity allowed the humeral head to subluxate past the coracoid process. This accounted for a large change in the overall mean internal rotation after stretching, but this change was not significant. The change in glenohumeral translation after stretching was not significant (mean increase, 0.8 mm [7.4%] under a 20-N translational load; $p = 0.06$). Creation of the arthroscopic portals did not change the rotational measurements significantly.

After plication, external rotation decreased by 12.6° ($p = 0.003$), to a mean of $173.7^\circ \pm 7.1^\circ$, but it was still 10.67° greater than, or 106.4% of, that in the intact specimens ($p = 0.006$).

The glenohumeral center of rotation was similar for the intact specimens, the specimens tested after stretching, and those tested after creation of the portals. Following plication, the center of rotation shifted posteriorly by a mean of 5.3 ± 1.6 mm ($p = 0.002$) at 60° of external rotation, by a mean of 7.6 ± 2.5 mm ($p = 0.002$) at 90° , and by a mean of 9.7 ± 3.5 mm ($p < 0.001$) at 120° . It shifted inferiorly by a mean of 5.3 ± 1.8 mm ($p = 0.01$) at 90° of external rotation and by a mean of 7.0 ± 2.6 mm ($p = 0.005$) at 120° .

Translational changes are shown in Table I. Stretching did not result in significant changes in any of the translation measurements, and there were no changes in translation following portal creation compared with the stretched or intact states. Following plication, anterior translation decreased significantly (compared with the intact state) by 7.7 mm (61.1%) ($p < 0.001$), to a mean of 5.1 ± 1.5 mm, under a 15-N load, and by 6.5 mm (49.8%) ($p < 0.001$), to a mean of 6.9 ± 1.5 mm, under a 20-N load. Posterior translation decreased significantly by 2.2 mm (11.4%) ($p = 0.002$), to a mean of 18.4 ± 3.1 mm, under a 15-N load, and by 2.4 mm (13.1%) ($p < 0.001$), to a mean of 18.8 ± 3.2 mm, under a 20-N load. Inferior translation decreased significantly by 0.5 mm (3.2%) ($p = 0.04$), to 15.0 ± 1.3 mm, under a 20-N load.

Following plication, the depth of the capsulolabral “bumper” was significantly increased ($p = 0.001$) by 3.5 mm (131.9%), to a mean of 6.4 ± 0.7 mm, compared with that of the normal labrum (2.9 ± 0.4 mm).

Discussion

Our results suggest that, following stretching of the anterior aspect of the shoulder capsule, anterior translation can be consistently reduced by >60% by the use of two arthroscopic plication stitches sutured to anchors in the anteroinferior aspect of the capsule without overly constraining the rotational range of motion. This observed reduction in translation was at least equal to that reported in studies of similar design that were performed to evaluate open capsulorrhaphies^{16-20,22,24}. In addition, the loss of external rotation that we observed was among the smallest reported. The authors of only one of the studies of open capsulorrhaphy attempted to simulate capsular laxity by stretching the capsule²². In one other study, by Speer et al.¹⁶, open glenoid-based shifts were performed in an instability model. That model involved the creation of a Bankart lesion and was not a model of anteroinferior capsular laxity. While Speer et al. reported a mean decrease in translation of 9.8 mm, they found a mean 32.7° loss of external rotation. We identified only one study involving suture plication in which the investigators quantified the effects of a simulated capsular contracture²⁵. In that study, a 10-mm medial-to-lateral midcapsular plication resulted in a mean 45.7° (34.4%) decrease in external rotation.

In a study of the same model as was used in the current investigation, Remia et al.²² compared an open glenoid-based

shift with an open humerus-based shift. They reported a significant increase in anterior and inferior translation after stretching of the capsule to 30% beyond maximum external rotation ($p < 0.05$). Capsulorrhaphy with a glenoid-based shift decreased anterior translation by a mean of 7.4 mm. Total rotation was decreased by a mean of 10° .

Recently, arthroscopic capsulorrhaphy with thermal energy has been evaluated in cadaver models. Tibone et al.^{19,26} assessed the effects on translation of an anteroinferior (“3-6 o’clock”) laser-assisted capsuloplasty and radiofrequency-induced capsular shrinkage. The authors reported a significant decrease in both anterior and posterior translation ($p < 0.05$).

In the present study, a 10-mm glenoid-based capsular plication resulted in decreases in translation similar to, if not in excess of, those reported following open shifts or thermally induced capsuloplasties. A possible explanation for the large effect seen in our study is the use of anchors on the glenoid face medial to the intact labrum. By shifting to this anchor position, the capsule must traverse the entire breadth and depth of the labral tissue. Furthermore, some direct comparisons have shown open glenoid-based shifts to result in a greater loss of translation than humerus-based shifts^{16,18,24}. However, the loss of external rotation that we found was on par with that demonstrated in other biomechanical studies and was less than that reported following glenoid-based medial-to-lateral shifts. There are several possible explanations for these findings.

Our plication was performed in a direct medial-to-lateral direction with no attempt to advance the capsule superiorly. It is therefore not surprising that we saw small (0.5-mm) decreases in inferior translation following plication. Although small, these changes were consistent and significant. It is reasonable to suggest that, when the capsule is advanced from inferior to superior as well in the clinical setting, the change in inferior translation would be greater. Furthermore, the medial-to-lateral direction of the shift is not parallel to the major orientation of the anteroinferior glenohumeral ligament and does not result in a linear decrease in its length. The linear capsular tensioning is appreciated most when the arm is in abduction and external rotation, and it may have a greater effect on translation than it does on external rotation.

The buildup of the capsulolabral bumper that was created after plication also may have helped to prevent anterior translation without restricting external rotation. Loss of the anterior aspect of the labrum has been shown to decrease stability in abduction by up to 65%²⁷⁻³⁰, whereas reconstruction has been found to restore the lost stability³⁰. These data support the role of the anteroinferior aspect of the labrum as a restraint to anterior translation. We believe this to be the primary reason for the comparatively small decrease in external rotation noted in our study.

Plication resulted in a posterior-inferior shift of the humerus on the glenoid throughout the arc of motion. This shift has been implicated in the development of capsulorrhaphy arthropathy and has been associated with nonanatomic procedures such as the Putti-Platt and Magnuson-Stack reconstructions.

tions³¹⁻³³. Remia et al.²² noted the same finding after an open capsular shift in this model; however, that procedure has not been associated with the development of degenerative osteoarthritis. We hypothesized that, in external rotation, the larger portion of the humeral head is delivered into the anterior pouch against the retensioned anterior glenohumeral ligament. This could force the center of rotation posteriorly and result in the above findings. Additionally, the built-up capsulolabral complex may prevent the humeral head from gliding anteriorly and result in a posterior shift.

This study and its results are limited by a number of factors. We used a static testing model that enabled us to evaluate only the effect of the osseous, labral, and capsular tissues on biomechanical and kinematic parameters. No loads were applied to any of the muscle-tendon units in an attempt to simulate their contribution to stability. Second, we reported results that are a snapshot in time immediately following plication in a cadaver model. Cadaver capsular tissue may not accurately represent the clinical situation in an active, healthy shoulder with laxity. Therefore, no conclusions can be drawn, on the basis of these data, regarding the possible fixation strength, longevity, or healing potential following this surgical procedure. Finally, the laxity model that we employed did not result in significant changes in anterior translation after the stretching procedure. Previous investigators utilizing this model achieved higher degrees of translation by stretching to 30% beyond maximal external rotation^{21,22}. Pilot tests and our experience with the model revealed that degrees of stretching resulted in an unacceptably high rate of capsular and labral damage. In order to preserve the capsular integrity of the samples and to be consistent with regard to our methods, we decided to stretch to 20% beyond maximum external rotation. We did achieve significant increases in external rotation in all specimens but this did not translate into a significant increase in anterior, inferior, or posterior translation. We do not believe that this affected the validity of our results since the change in translation is a more sensitive and important measure of the effectiveness of this procedure.

In conclusion, arthroscopic anteroinferior plication of 10 mm effectively reduced anterior and posterior glenohumeral

translation in a cadaver model of anterior shoulder instability. The humeral head shifts posteriorly and inferiorly on the glenoid surface throughout the arc of motion following plication. Despite this significant tightening of the shoulder joint, loss of external rotation was similar to that reported following open capsular shift procedures performed on similar models. While it remains difficult to extrapolate from this static snapshot in time to the clinical situation, it appears that humeral translation and rotation can be significantly restricted with use of arthroscopic plication techniques. ■

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