

Basic Research

What Are the Effects of Capsular Plication on Translational Laxity of the Glenohumeral Joint: A Study in Cadaveric Shoulders

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Abstract

Background Surgical treatment for shoulder instability generally involves labral repair with a capsular plication or imbrication. Good results are reported in both open and arthroscopic procedures, but there is no consensus on the

amount or location of capsular plication that is needed to achieve stability and anatomic anterior, posterior, and inferior translation of the joint.

Questions/purposes (1) What are the separate and combined effects of increasing plication magnitude and sequential additive plications in the anterior, posterior, and inferior locations of the joint capsule on glenohumeral joint translation in the anterior, posterior, and inferior directions? (2) What plication location and magnitude restores anterior, posterior, and inferior translation to a baseline level?

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Methods Fourteen cadaveric shoulders were dissected down to the glenohumeral capsule and underwent instrumented biomechanical testing. Each shoulder was loaded with 22 N in anterior, posterior, and inferior directions at 60° abduction and neutral rotation and flexion and the resulting translation were recorded. Testing was done over baseline (native), stretched (mechanically stretched capsule to imitate a lax capsule), and 5-mm, 10-mm, and 15-mm plication conditions. Individually, for each of the 5-, 10-, and 15-mm increments, plications were done in a fixed sequential order starting with anterior plication at the 3 o'clock position (Sequence I), then adding posterior plication at the 9 o'clock position (Sequence II), and then adding inferior plication at the 6 o'clock position (Sequence III). Each individual sequence was tested by placing 44 N (10 pounds) of manual force on the humerus directed in an anterior, posterior, and inferior direction to simulate clinical load and shift testing. The effect of plication magnitude and sequence on translation was tested with generalized estimating equation models. Translational differences between conditions were tested with paired t-tests.

Results Translational laxity was highest with creation of the lax condition, as expected. Increasing plication

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magnitude had a significant effect on all three directions of translation. Plication location sequence had a significant effect on anterior and posterior translation. An interaction effect between plication magnitude and sequence was significant in anterior and posterior translation. Laxity in all directions was most restricted with 15-mm plication in anterior, posterior, and inferior locations. For anterior translational laxity, at 10-mm and 15-mm plication, there was a progressive decrease in translation magnitude (10-mm plication anterior only: 0.46 mm, plus posterior: 0.29 mm, plus inferior, -0.12 mm; and for 15-mm anterior only: -0.53 mm, plus posterior: -1.00 mm, plus inferior: -1.66 mm). For posterior translational laxity, 10-mm and 15-mm plication also showed progressive decrease in magnitude (10-mm plication anterior only: 0.46 mm, plus posterior: -0.25 mm, plus inferior: -1.94; and for 15-mm anterior only: 0.14 mm, plus posterior: -1.54 mm, plus inferior: -3.66). For inferior translational laxity, tightening was observed only with magnitude of plication (anterior only at 5 mm: 0.31 mm, at 10 mm: -1.39, at 15 mm: -3.61) but not with additional plication points (adding posterior and inferior sequences). To restore laxity closest to baseline, 10-mm AP/inferior plication best restored anterior translation, 15-mm anterior plication best restored posterior translation, and 5 mm posterior with or without inferior plication best restored inferior translation.

Conclusions Our results suggest that (1) a 10-mm plication in the anterior and posterior or anterior, posterior, and inferior positions may restore anterior translation closest to baseline; (2) 10-mm anterior and posterior or 15-mm anterior plications may restore posterior translation closest to baseline; and (3) 5-mm anterior and posterior or anterior, posterior, and inferior plications may restore inferior translation closest to baseline. Future studies using arthroscopic techniques for plication or open techniques via a true surgical approach might further characterize the effect of plication on glenohumeral translation.

Clinical Relevance This study found that specific combinations of plication magnitude and location can be used to restore glenohumeral translation from a lax capsular state to a native state. This information can be used to guide surgical technique based on an individual patient's degree and direction of capsular laxity. In vivo testing of glenohumeral translation before and after capsular plication will be needed to validate these cadaveric results.

Introduction

Glenohumeral instability is generally accompanied by injury to the labrum, capsule, and glenohumeral ligaments [1, 5, 6, 9, 10, 28, 29, 42-44]. Shoulder instability is thought to involve injury to primary and secondary stabilizers of the

capsule and capsular ligaments on both sides of the joint, like in the "circle stability concept" reported by Bowen and Warren [7, 9]. In addition to superior and middle glenohumeral ligaments, the anterior and posterior bands of the inferior glenohumeral ligament are important stabilizing structures within the capsule. The anterior band is generally injured in anterior shoulder instability, but the posterior band has been shown to play an equally important role in stabilization [28]. The middle glenohumeral ligament and rotator interval have also been shown to affect the translational and rotational profile of the joint [16, 17, 21, 37, 39]. Many techniques have been developed to treat recurrent shoulder instability; some aim at addressing the labral pathology, some at the capsular/glenohumeral ligament pathology, and some at both. Initially, Neer and Foster [25] reported a humeral-based, open capsular shift technique, and later both Jobe et al. [19] and Altchek et al. [4] reported an open glenoid-based technique incorporating a labral repair.

Subsequently, arthroscopic techniques for labral repair and/or capsular plication have been reported [11, 18, 20, 23, 32, 49]. Each of these techniques has shown good results, but currently there is controversy over the style and amount of plication needed to restore physiologic rotation and translation of the glenohumeral joint [12, 13, 18, 33]. Concerns about capsule overtightening, limiting ROM, or overconstraining the glenohumeral articulation further complicate decision-making [6, 14, 39, 46]. Previous studies have attempted to quantify capsular volume reduction after plication [15, 22, 24, 31, 36, 47]. These studies show a sequential decrease in volume with plication as expected; however, the clinical correlation is difficult to interpret. Anterior translation has been the focus of studies on the effect of capsular plication, because this is the most common direction of instability [3, 35, 37-39, 45, 46]. Anteroinferior plication is shown to decrease anterior translation as expected [3, 35, 37-39, 45, 46]. However, the effect of posterior plication on anterior translation has not shown consistent results with some studies showing additive benefits on reducing anterior translation and some showing no effect [11, 14, 30, 34], and there are few studies on the evidence of the effect of anterior, posterior, or inferior plication on posterior and inferior translation [8, 26, 34]. Our goal is to add to the literature on the effect of plication in all three locations and directions of translation.

Therefore, we asked: (1) What are the separate and combined effects of increasing plication magnitude and sequential additive plications in the anterior, posterior, and inferior locations of the joint capsule on glenohumeral joint translation in the anterior, posterior, and inferior directions? (2) What plication location and magnitude restores anterior, posterior, and inferior translation to a baseline level?

Materials and Methods

A biomechanical study using cadaveric specimens was conducted. Fourteen shoulder specimens were tested with the same protocol at a single time point. Each specimen served as its own control. The specimens were procured from an anatomic donation organization (Anatomy Gifts Registry, Hanover, MD, USA) as fresh-frozen cadavers and were evaluated structurally with CT and clinically with ROM by an orthopaedic surgeon (SWM). The cohort consisted of shoulders from nine males and five females (12 white and two black) with an average age of 56 ± 11 years (range, 33–66 years).

Experimental Setup

After being fully thawed to room temperature, all pericapsular tissues were dissected from the specimens by a single experienced orthopaedic surgeon (SWM). The rotator cuff tendinous insertions were left intact to keep the capsule unviolated. The rotator interval was then loosely closed with a single suture using Vicryl® 2.0 (Ethicon Inc, Bridgewater, NJ, USA) to act as a ripstop to prevent further stretching or tearing open of the interval during the rotational and translational forces during the creation of a lax state and the subsequent testing. The capsule was then vented with an 18-gauge angiocatheter at the rotator interval to prevent a reseal suction phenomenon during testing. Retroreflective motion tracking marker clusters were rigidly attached to the humerus and scapula. Humerus and scapula bony landmarks were identified and logged in the motion analysis software with a spatial pointer with a calibrated tip. A dynamic 5-second circumduction trial was used to calculate the effective glenohumeral joint center of rotation. The trajectory and distance of movement of each marker, corresponding to the translation of the humerus on the glenoid, was recorded with a calibrated motion analysis system (Motion Analysis Corp, Santa Rosa, CA, USA) accurate to 0.2 mm.

The humerus was cut at the midshaft; the shaft was fixed in a cylindrical tube and the scapula was set in a square frame. Plaster of Paris was poured around each bone and allowed to harden. The humeral and scapular fixtures were attached to a glenohumeral laxity testing device (Fig. 1) designed to allow translational load-response testing in a variety of positions.

Each shoulder underwent translational glenohumeral laxity testing in a fixed position of 60° abduction in the scapular plane with neutral axial rotation to represent a common position of load and shift testing clinically. A 44-N (10 pounds) load was applied cyclically five times along three directions (anterior, posterior, and inferior) selected randomly. The load was applied manually to the scapula

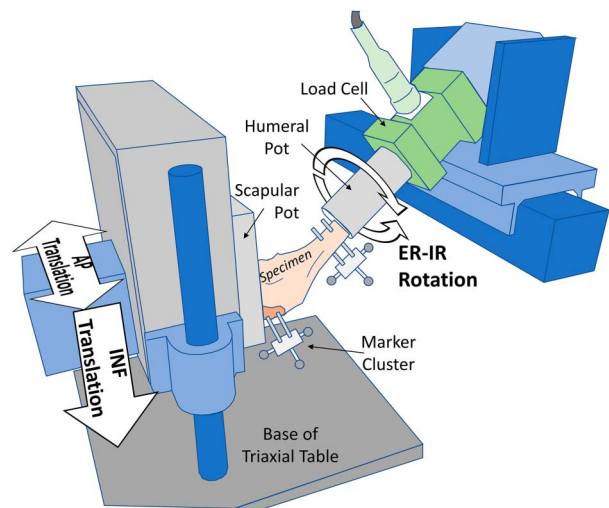


Fig. 1 Schematic of the glenohumeral laxity device and testing degrees of freedom from the oblique view is shown. The triaxial base allowed the scapula to translationally float in three directions (only the vertical cylinder bearing is shown). The load cell was mounted in series and aligned with the anatomic humerus long axis. INF = inferior; ER-IR = external rotation–internal rotation. Reprinted from *Journal of Shoulder and Elbow Surgery*, Kraszewski AP, Mayer SW, Kontaxis A, Hillstrom HJ, Sheikhzadeh A, Russell P, Mapping glenohumeral laxity: effect of capsule tension and abduction in cadaveric shoulders, 2017, with permission from Elsevier.

potting frame with a calibrated spring scale by a single rater (APK) and the joint returned to center after each cycle.

Translational laxity tests were conducted across two experimental factors: capsule state and plication sequence. Capsule state contained five levels: baseline, stretched, 5 mm, 10 mm, and 15 mm. Plication sequence consisted of three levels (anterior; anterior and posterior; and anterior, posterior, and inferior) repeated within the last three capsule state levels (designated I, II, and III, respectively) (Fig. 2).

Baseline served as the control condition representing the physically unaltered capsule. Preconditioning was done before testing in the baseline capsule state through 10 cycles in both internal and external rotation at 30° of abduction in the scapular plane, rotating at $5^\circ/\text{s}^{-1}$ [41]. A complete cycle started at neutral rotation, proceeded until 1.0 N·m torque was reached, and then returned to neutral. The stretched condition was created by applying a constant 5.0-N·m torque for 30 minutes in internal and external rotation separately. The glenohumeral joint was fixed in 40° of abduction in the scapular plane and neutral flexion [3].

The last three levels of state represented conditions of plication repair with incremental magnitude. Plication sutures were first spaced 5 mm apart, then 10 mm, and lastly 15 mm. Within each magnitude level were three plication sequence levels. First was anterior suture of the capsule at the 3:00 position (Sequence I). A second level of plication posteriorly

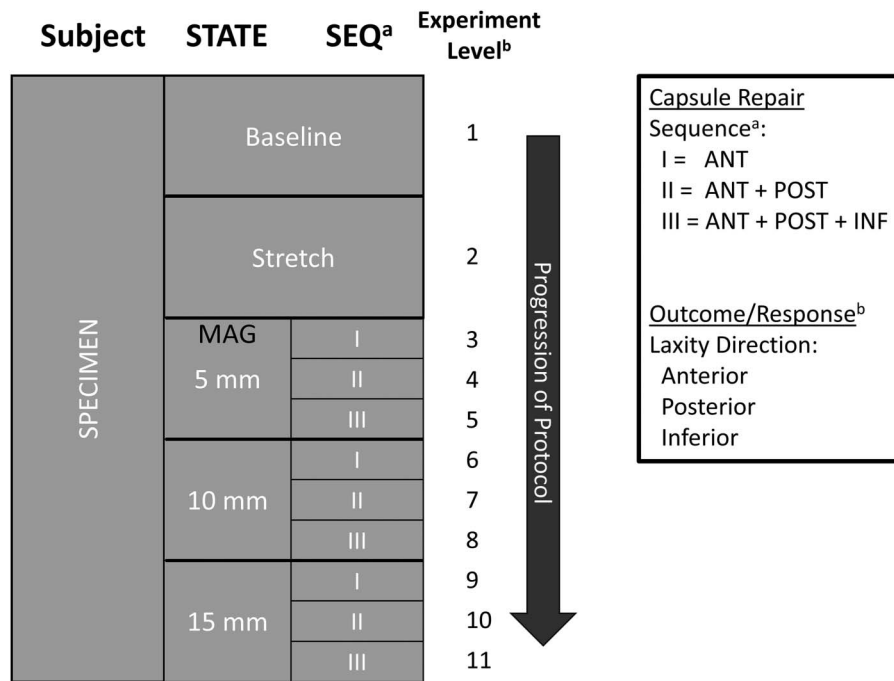


Fig. 2 Diagram showing the experimental design and protocol. Each specimen (first column) was tested across two fixed-order within-subject conditions, STATE (second column) and SEQ (third column). The last three levels of STATE were the capsule repairs, MAG. The SEQ levels were repeated within each MAG level, and each SEQ plication was done in a fixed sequence and additively. A total of 11 experimental levels (fourth column) was tested, where the measured outcome per level was glenohumeral translation with laxity direction order randomized. The chronologic progression of testing is depicted by the dark vertical arrow. ANT = anterior; POST = posterior; INF = inferior.

at 9:00 was added (Sequence II). Lastly, a third plication inferiorly at 6:00 was added (Sequence III). Capsular volume was taken up additively such that Sequence II included anterior and posterior plications, and Sequence III included all three plications, until starting the next magnitude level.

Plications were performed on the external capsule with the shoulder in 50° of abduction in the scapular plane and neutral rotation. In each plication region, three parallel sutures were placed starting 10 mm from the glenoid rim, proceeding laterally with 5 mm between each suture. Each plication was performed using a horizontal mattress-type suture configuration with the plication oriented north to south (superior to inferior). Magnitude and spacing were measured with a 1-mm gradation metric ruler. A single experienced orthopaedic surgeon (SWM) performed all repairs using #2 Ethibond-Extra (Ethicon Inc, Somerville, NJ, USA).

Before advancing to the next magnitude, all sutures from the previous round of testing were removed and the location of plication was planned and remeasured such that the new sutures would encompass the location of the holes from previous plications and new suture holes would be created to prevent stretching of any holes and falsely increasing capsular laxity (Fig. 3).

Outcome Measures

Recorded marker data were verified and then imported into Visual3D™ software (C-Motion, Germantown, MD, USA) for signal processing. Marker trajectories were smoothed with a low-pass Butterworth filter using a 3.0-Hz cutoff frequency. Bony landmarks taken from CT were used to create specimen-specific scapula and humerus anatomic segment definitions (Fig. 4) [48]. Translational laxity was calculated as the displacement of the humerus center of rotation with respect to the glenoid center of rotation at 44 N force calculated in the scapular anatomic frame: anterior (+X), posterior (-X), and inferior (-Y). Laxity values from the last three cycles of each trial were averaged for analysis.

Statistical Analysis

Generalized estimating equations (GEE) with repeated factors were used for analysis. Plication magnitude and sequence were entered as categorical within-subject variables with translation as the dependent variable. A linear link function (analysis of variance model) was used along

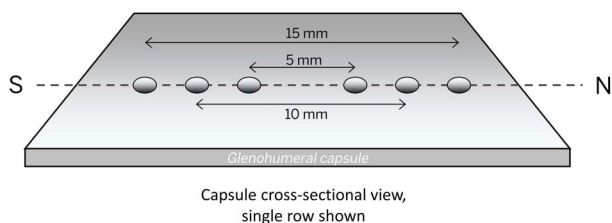


Fig. 3 Plication suture hole spacing is shown. Shown is a cross-sectional representation of the glenohumeral capsule and suture holes of a single row. Holes are shown as small shaded circles. The holes shared a common center where previous suture holes were taken up in subsequent plications. The dotted line depicts north-to-south orientation.

with an unstructured correlation matrix. Tested model main effects were Magnitude, Sequence, and their interaction, Magnitude x Sequence. Separate models were run for anterior, posterior, and inferior translation. An intercept parameter was included in each model.

Repeated-measures contrasts were also performed separately for anterior, posterior, and inferior translation. Paired comparisons were done across all combinations of capsule state and plication sequence levels including baseline and stretched for 11 experimental levels in all. Baseline and stretched levels, separately, served as references for the contrasts. Statistical significance level was set

at $\alpha = 0.05$. Statistics were done in SPSS software (IBM, Armonk, NY, USA).

Results

In general, glenohumeral laxity responded similarly across experimental conditions by increasing from intact to lax and then decreasing while progressing in magnitude and plication sequence (Fig. 5). Increasing plication magnitude decreased translation in anterior, posterior, and inferior laxity, but adding to the plication sequence (anterior, plus posterior, plus inferior) decreased anterior and posterior translations but not inferior translation. The interaction effect between plication magnitude and sequence was significant in anterior and posterior translation, but not inferior (Table 1). We observed decreasing laxity across plication magnitudes at different rates: a faster decline that corresponded with added sequence (Fig. 5). For anterior translational laxity, at 10-mm and 15-mm plication, there was a progressive decrease in translation magnitude (10-mm plication anterior only: 0.46 mm, plus posterior: 0.29 mm, plus inferior, -0.12 mm; and for 15-mm anterior only: -0.53 mm, plus posterior: -1.00 mm, plus inferior: -1.66 mm) (Fig. 6). For posterior translational laxity, 10-mm and 15-mm plication

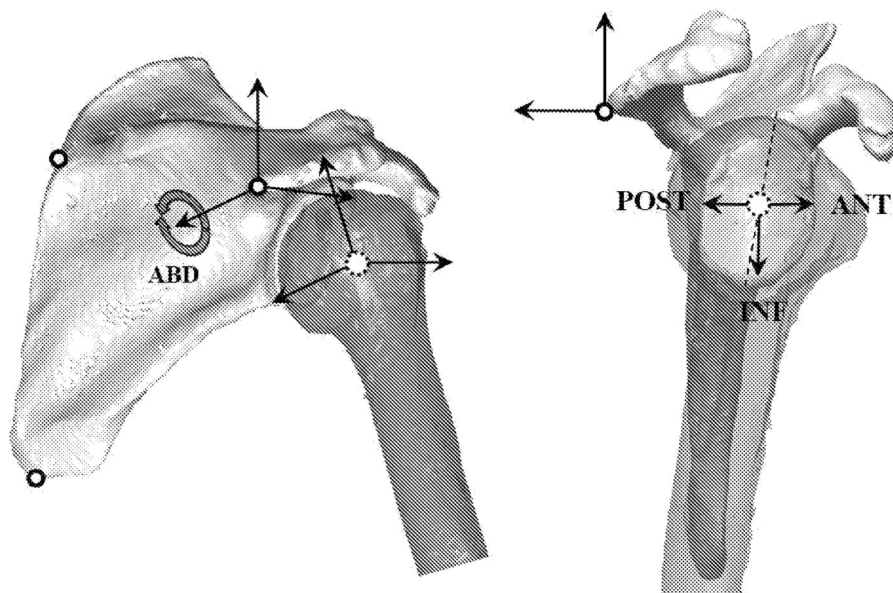


Fig. 4 Shoulder segment anatomic coordinate frames and testing degrees of freedom from an oblique view (left) and lateral-to-medial view (right) are shown. The scapular coordinate system was based on bony landmarks (left): acromion angle, root of spine, and inferior angle. Glenohumeral kinematics were calculated as the translational motion of the humeral head center of rotation (COR; dotted circle) with respect to the scapula (right) offset to the glenoid COR. Dotted line indicates the superoinferior axis of the glenoid. ABD = abduction; POST = posterior; ANT = anterior; INF = inferior.

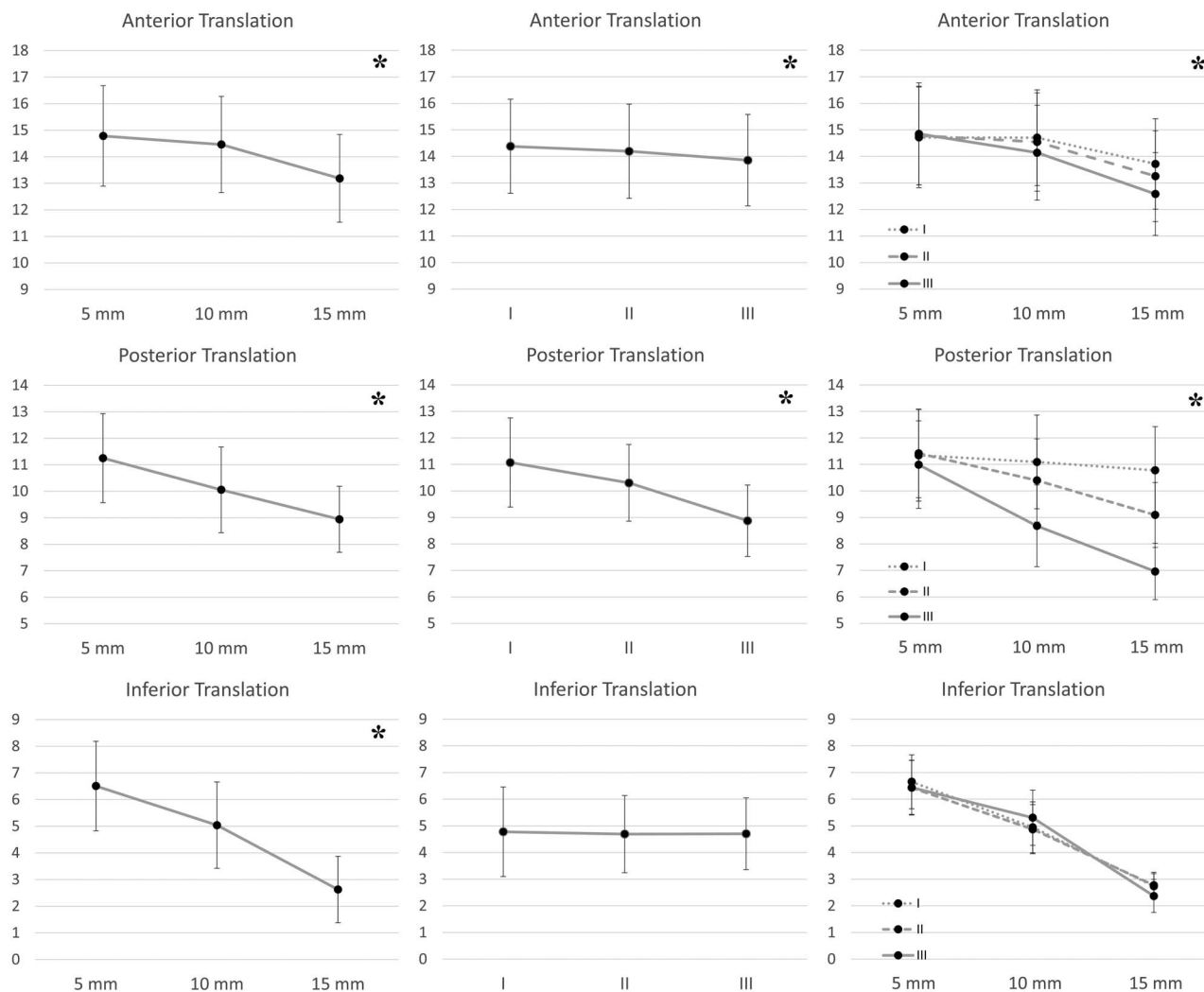


Fig. 5 Plots of glenohumeral laxity against each modeled effect are shown. Each row of plots is a separate laxity direction (top = anterior, middle = posterior, bottom = inferior) and each column of plots is a generalized estimating equation (GEE) model effect term (left = MAG, middle = SEQ, right = MAG x SEQ). Within each plot the translational values (vertical axis) are plotted against the effect levels. Values are shown as the marginal mean ± 1.0 standard error. The interaction plots (MAG x SEQ, third column) show three lines instead of one, and their divergence indicates an increasing restriction of plication magnitude across plication sequence. *Statistically significant effect (p < 0.05).

also showed progressive decrease in magnitude (10-mm plication anterior only: 0.46 mm, plus posterior: -0.25 mm, plus inferior: -1.94 mm; and for 15-mm anterior only: 0.14 mm, plus posterior: -1.54 mm, plus inferior: -3.66 mm) (Fig. 6). For inferior translational laxity, tightening was observed only with magnitude of plication (anterior only at 5 mm: 0.31 mm, at 10 mm: -1.39, at 15 mm: -3.61) but not with additional plication points (adding posterior and inferior sequences) (Fig. 6).

To restore laxity closest to baseline, 10-mm AP/inferior plication best restored anterior translation (to -0.12 mm of baseline), 15-mm anterior plication best restored posterior translation (to 0.14 mm of baseline), and 5-mm posterior with or without inferior plication best

restored inferior translation (to 0.09 mm of baseline) (Fig. 6). Laxity in all directions was most restricted with 15-mm anterior, posterior, and inferior plication. Conditions having a substantial observed difference from either baseline or lax conditions occurred least frequently in the anterior direction, followed by posterior, and lastly inferior.

Discussion

The role of the glenohumeral ligaments in joint stability is well explained [6-10, 17, 27-29, 40, 43, 44]. In cases of

Table 1. Output of each GEE model effect term for each laxity direction

Laxity direction [†]	GEE model effect (p value)		
	MAG	SEQ	MAG x SEQ
Anterior	0.045*	0.003*	0.003*
Posterior	0.004*	< 0.001*	< 0.001*
Inferior	< 0.001*	0.789	0.553

*Statistically significant (p < 0.5);

[†]results for model intercept not shown; GEE = generalized estimating equation; MAG = magnitude; SEQ = sequence.

atraumatic shoulder instability, capsular plication is often performed to restore the native mechanical stability of the joint. Clinical studies have shown good results with both open and arthroscopic techniques; however, it is difficult to determine if anatomic joint mechanics are restored [2, 3, 12]. Given the potential for recurrent instability with too little plication or overconstraint of the glenohumeral joint

with too great a plication, a plication level that restores the native joint mechanics as closely as possible is ideal. Our study aimed to determine the effect of sequentially larger plications in three locations along the capsule on translation of the humeral head as well as the most advantageous combination of plications from among those tested to restore anatomic joint translation.

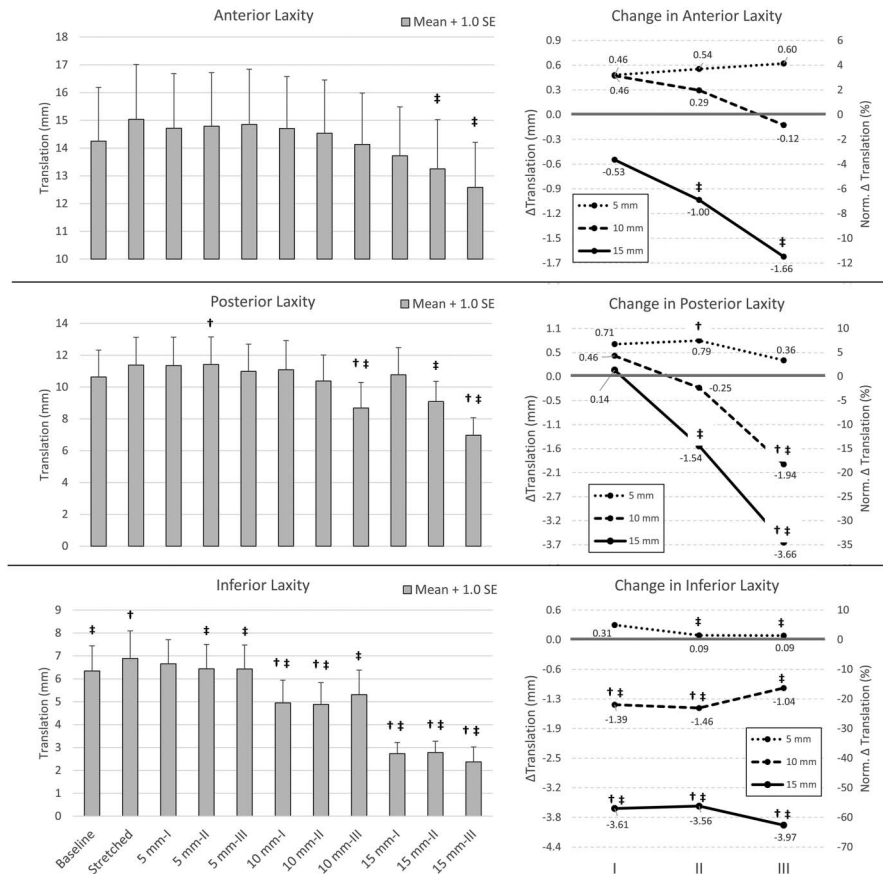


Fig. 6 Glenohumeral laxity is demonstrated. The left bar graphs are the average translation laxity values + 1.0 standard error per STATE level. The right line graphs are the average (left vertical axis) and normalized average (right vertical axis) change (Δ) in laxity with respect to baseline; values are given per plication sequence (I, II, and III) on the horizontal axis; plication magnitudes are shown with different lines: small dash = 5 mm, large dash = 10 mm, and solid line = 15 mm. Single dagger (†) and double dagger (††) indicate significant differences with respect to baseline and stretched conditions.

We recognize several limitations to this study. First, many of the specimens were advanced in age with possible unknown previous injuries to the shoulder and capsule not detectable with CT or dissection. Second, we did not simulate dynamic muscular forces across the shoulder, which may change translation compared with *in vivo*. Next, we are not able to draw conclusions about the effect of a single location of plication other than the anterior position as a result of the sequential and additive nature of the study design. Testing was also performed in a single position and plane, possibly limiting the applicability our conclusions to this glenohumeral position. Additionally, our methodology did not include testing of rotational changes, which is another important part of decision-making when performing a capsular plication. Our results are limited to time zero analysis and we are unable to provide information on the role of capsular healing or further changes over time. We chose a capsular-based plication technique for this study, which is less common than other described techniques. The rotator interval was closed in all specimens for homogeneity but may have produced translational consequences. We expected that these changes would be similar across specimens.

This study is comparable to others in specimen age, sample size, and technique of translational testing. Dynamic stability through muscular contraction is minimal during routine clinical laxity tests. Despite time zero analysis, this information could be used clinically to decide the best plication for individual patterns of instability from among those tested. Rotator interval closure created more homogeneity of capsule morphology and was performed before any translational testing. Additionally, previously collected pilot data suggested interval closure had no effect on translation in our model. Our capsular-based plication was chosen to isolate capsular effect without confounding factors of labral repair. As such, we feel that this study provides additional insight into the systematic effect of plication magnitude and location sequence on translation. To our knowledge this has not been previously reported.

We found translation decreased in all three directions with increasing magnitude of plication although each direction responded to a different degree (Fig. 5). Additionally, there was an interaction between magnitude and plication location for anterior and posterior translation, but not inferior. Compared with previous studies, we found it required anterior and posterior or anterior, posterior, and inferior 15-mm plication to decrease anterior translation, whereas two other studies each found that anterior translation was decreased with two anteriorly based 10-mm capsular or capsulolabral plications. We also found 10-mm anterior, posterior, and inferior plications or 15-mm anterior/posterior or anterior/posterior/inferior plication decreased posterior translation, whereas both other studies reported posterior translation had not decreased [30, 38]. A

third study performed two anterior 10-mm capsulolabral plications and found anterior and posterior translation decreased below the lax state, again dissimilarly to our results [3]. This study also evaluated inferior translation, which did not decrease, unlike our study in which inferior translation decreased with 5-mm anterior/posterior or anterior/posterior/inferior translation and all 10- and 15-mm plication. Peltier et al. was the only previous report, which included the effect of a two-level (ANT and ANT + POST) sequence on anterior and posterior translation. Similar to our results, the addition of posterior plication decreased anterior translation further than anterior plication alone [30]. Dissimilarly, neither location decreased posterior translation. Each of these three studies utilized similar positioning of the glenohumeral joint (60° of abduction and neutral rotation), but they report plications of 10 mm, whereas our study included plications of 5, 10, and 15 mm. Each study utilized a different type, location, and number of plications, which may account for differing results (Fig. 7). These results support the circle stability concept, which states that an injury to both the anterior and posterior capsular structures occurs with anterior shoulder instability, and thus injury on both sides of the joint is necessary to produce instability, and repair of both sides may be necessary to restore stability [9]. Interestingly, plication magnitude and sequence progression showed an interdependent (covariate) change; increased loss of translational laxity was observed with progression in the plication sequence for a given magnitude. A lack of covariate change in inferior translation may be the result of the fixed plication sequence order with inferior sutures performed last. This information is important to consider in preoperative planning where knowledge of this multiplicative effect between plication magnitude and number of sites may improve the desired decrease of glenohumeral translation and may aid in decreasing the risk of joint overtightening. It is unknown if our observations would change with a different sequence order; thus, this remains open to future investigation.

Addressing our second objective, our study found anterior translation was restored closest to baseline with 10 mm in anterior/posterior (+0.29 mm) or anterior/posterior/inferior (-0.12 mm) plication. Posterior translation was restored closest to baseline with 10-mm anterior/posterior (-0.25 mm) and 15-mm anterior plication (+0.14 mm). Posterior translation decreased furthest below baseline with 10-mm anterior/posterior/inferior (-1.94 mm) and 15-mm anterior/posterior (-1.54 mm) or anterior/posterior/inferior (-3.66 mm) plications. Finally, inferior translation was restored using 5-mm anterior/posterior (+0.09 mm) or anterior/posterior/inferior (+0.09 mm) plications. All 10-mm and 15-mm plications decreased inferior translation compared with baseline (-1.04 mm to -3.97 mm). Alberta et al. found less anterior translation than baseline (6.9 mm

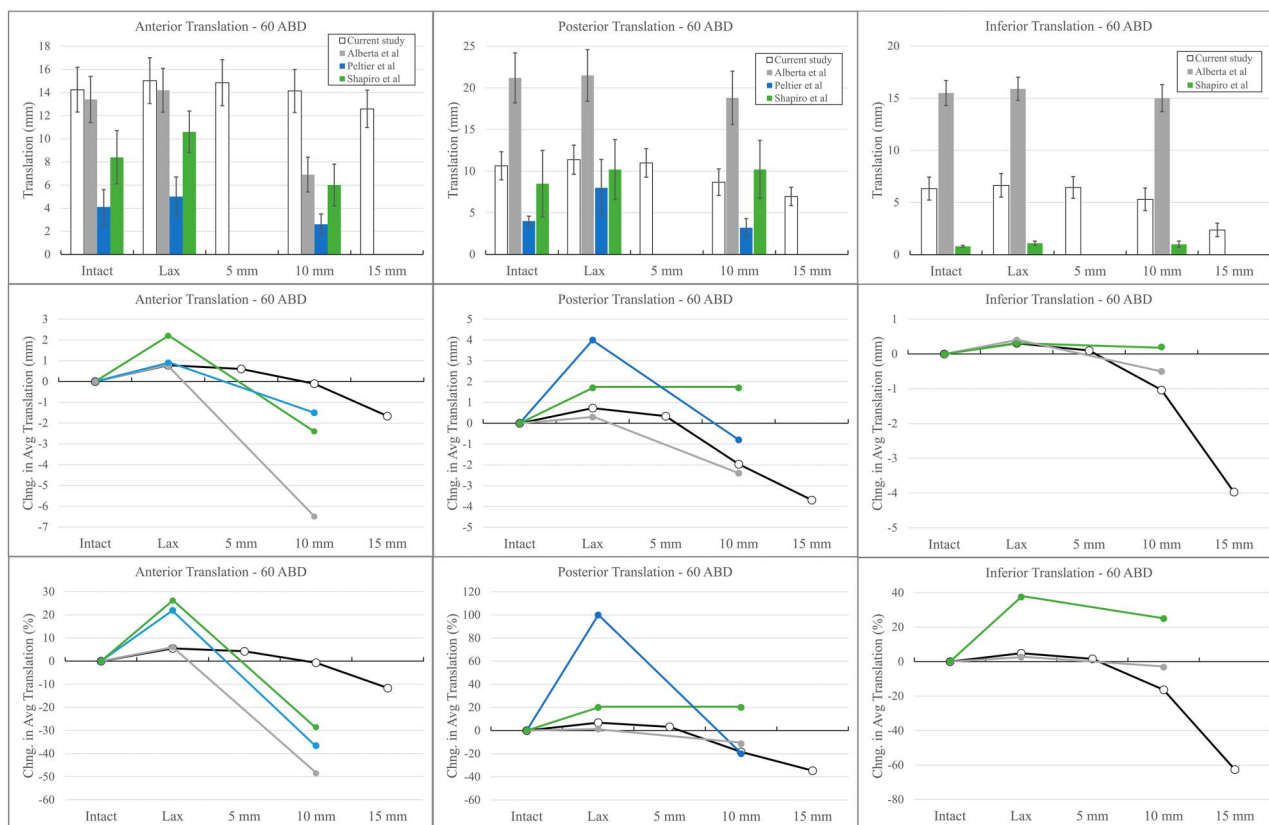


Fig. 7 Comparison of glenohumeral laxity across comparable studies is shown. Shown are the laxity results from this study and three others that tested laxity in 60° elevation per capsule condition. Each direction is in a separate column, and in rows top to bottom are the average raw translation, change in translation, and normalized change in translation. As a result of the range in experimental methodologies among our work and comparable studies, incremental steps of capsular plication magnitude past the stretched (lax) condition are Level 1, Level 2, and Level 3. ABD = abduction.

with 20-N force) with two 10-mm anterior plications [3]. However, Shapiro et al. also used two 10-mm anterior plications and found no decrease in anterior translation [38]. Peltier et al. also reported two 10-mm anterior plications did not decrease anterior translation with 25-N force. Addition of posterior plications also did not decrease anterior translation [30]. Compared with previous studies, conflicting results are also seen among those examining the ability of plication to restore baseline posterior translation. One study reported that posterior translation remained 5 to 6 mm greater than baseline after two 10-mm anterior plications [38]. However, another reported that posterior translation decreased 2.2 to 2.4 mm below baseline with the same plication configuration [3]. Peltier et al. reported posterior translation was not different than baseline, even with posterior plication added [30]. Shapiro et al. was the only study to quantify inferior translation and reported restoration 0.4 mm above baseline with two 10-mm anterior plications [38].

Based on our results, 10-mm plication in the combined AP or AP/inferior positions may restore anterior translation

closest to baseline; 10-mm combined AP or 15-mm anterior plications may restore posterior translation closest to baseline; and 5-mm combined AP or AP/inferior plications may restore inferior translation closest to baseline. Our results may be used to help guide surgeons in individualizing surgical plans based on the direction of translational instability of each patient. Future studies that may expand on these findings could utilize arthroscopic or open surgical approaches with intact musculature or test translation and rotation of specimens in multiple degrees of glenohumeral abduction and rotation as well as follow clinical outcomes in patients after utilization of these individualized techniques.

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