The acromioclavicular capsule as a restraint to posterior translation of the clavicle: A biomechanical analysis

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Excessive posterior translation of the residual clavicle after distal clavicle resection can be associated with significant postoperative pain. Although the acromioclavicular capsule has been identified as the primary restraint to translation of the clavicle along this axis, the individual contributions of the anterior, posterior, superior, and inferior components of the capsular ligament have not been established. The purpose of this study was to define the relative roles of the individual acromioclavicular capsular ligaments in preventing posterior translation of the distal clavicle in normal acromioclavicular joints in a human cadaver model. Six fresh-frozen human cadaveric acromioclavicular joints were mounted on a specially designed apparatus which, when attached to a standard servohydraulic testing device, allowed translation of the distal clavicle along the anteroposterior axis of the acromioclavicular joint (ie, parallel to the articular surface). Resistance to posterior displacement was measured for standardized displacements in the five specimens and after serial sectioning of each of the acromioclavicular ligaments was performed. Sectioning of the anterior and inferior capsular ligaments had no significant effect on posterior translation at the 5% significance level. However, sectioning of the superior posterior ligaments had statistically significant effects (P < .05). These capsular structures contributed 56% ± 23% (±SEM) and 25% ± 16%, respectively, of the force required to achieve a given posterior displacement. To avoid excessive posterior translation of the clavicle after distal clavicle excision, surgical techniques that spare the posterior and superior acromioclavicular capsular ligaments should be used. (J Shoulder Elbow Surg 1999;8:119-24)

Continued pain after isolated distal clavicle excision has several potential causes including unrecognized shoulder disease, inadequate osseous resection, overzealous osseous resection, deltoid insufficiency, and anterior-posterior instability of the distal clavicle. Excessive posterior translation of the clavicle after excision arthroplasty of the AC joint is performed, but its potential negative effect on outcome has only recently been recognized.

In vitro cadaveric biomechanical testing has identified the AC joint capsule as the primary static restraint against anterior-posterior translation of the distal clavicle. More specifically, the AC capsule has been determined to provide 90% of the stability to posterior displacement of the clavicle in cadaveric ligamentous preparations. However, the relative contributions of the individual capsular ligaments (ie, anterior, posterior, superior, and inferior) to posterior stability of the distal clavicle are unknown. The purpose of this investigation was to determine the individual contributions of these capsular structures to overall posterior stability of the distal clavicle.

MATERIAL AND METHODS

Specimen preparation. Six normal fresh-frozen human cadaveric shoulders were used in this study. Two additional specimens were used to determine the effect of multiple loading cycles on the capsular structures. The specimens were unpaired, consisted of 2 males and 6 females, and ranged in age from 52 to 83 years (mean age, 68 years). Four left and 4 right shoulders were used. The specimens were stored at -20°C and allowed to thaw 24 hours before testing. Each specimen was dissected free of muscle and soft tissue, leaving intact the clavicle, scapula, AC joint capsule, coracoacromial ligament, and coracoclavicular ligaments. The humerus was disarticulated, and the position of the clavicle in relation to the scapular spine was recorded during dissection of the specimen for duplication during mechanical testing. The anteroposterior axis of the AC joint was manually determined by placing two 25-gauge needles at the anterior and posterior margins of the distal clavicle as it articulated with the acromion at the AC joint. This procedure also provided venting of the capsule to negate any effect on translations of negative intra-articular pressure. The specimen was subsequently mounted onto the testing apparatus and visually positioned in-line with these 2 needles to reproduce this axis. Scapular posi-
The MTS Machine Jig

Figure 1 Schematic drawing of testing apparatus. Clavicular portion of specimen remained fixed throughout testing conditions as scapular base was translated posteriorly through actuator displacement and pulley system.

tion was controlled by mounting an L-shaped metal extension in the plane of and parallel to the medial border of the scapula. This allowed for reproducible positioning of the scapula in relation to its medial border. The clavicle and scapular body were potted into cylindrical hollow holding frames with fast-setting epoxy cement (Dynatron/Bondo Corp, Atlanta, Ga). Throughout testing, the specimens were sprayed with a protease inhibitor solution to prevent desiccation and breakdown of the test specimens. Once testing was completed, the joints were inspected so that any specimens with significant degenerative changes of either the acromial or clavicular facets could be eliminated. None of the specimens selected for testing required elimination from the study.

Testing protocol. A custom testing apparatus was manufactured which, when secured to a standard materials testing device (MTS Corporation, Minneapolis, Minn), permitted load-displacement testing of the specimens in an anteroposterior direction in the plane of the AC joint (Figure 1). A series of 2 pulleys was used to transform the actuator displacement of the MTS into AP translations. Once the specimen was positioned in the testing apparatus, all degrees of freedom except AP translation were constrained. The use of 1 degree of freedom for subsequent trials ensured the same exact path of displacement for each trial performed. During the experiment the scapular portion of the specimen was displaced, whereas the clavicle remained locked in position.

Two of the 8 specimens were used as control specimens to determine whether the forces applied throughout the testing protocol would cause plastic deformation of the capsule, which could influence the results of subsequent trials. After the joints were oriented, control specimens were preconditioned for 15 cycles in both anterior and posterior directions at 70 N. They were then displaced with 70 N of posteriorly directed force for an additional 15 cycles to reproduce the total number of testing cycles to be performed on the experimental specimens. Posterior displacement was recorded after each trial and measured in millimeters with the data acquisition software, Lab-Tech Notebook (Laboratories Technologies Corp, Wilmington, Mass). These trials were performed at a rate of 3 sec/cycle, and data were sampled at a frequency of 10 Hertz.

The 6 experimental specimens were positioned and pro-
conditioned in an identical manner as the control specimens. Intact specimens were tested for 3 cycles at 70 N of posterior force, and the translations were measured and averaged. This displacement then served as the baseline from which the specimens would be displaced after each ligament sectioning. The force required to achieve this predetermined displacement was recorded in Newtons. Ligamentous contributions were determined relative to the 70 N necessary to displace the intact specimen. Sectioning was then performed for each specimen in the sequence of anterior, superior, posterior, and inferior capsular attachments. Clavicular anatomy was used to define the anterior and posterior borders of the attached capsuloligamentous structures and provided a reference for making the cuts. After each cut was made, the specimens were tested for 3 cycles, with the average force value of these trials used for data analyses. In total, 15 testing trials were conducted for each test specimen, equaling the number of cycles in the control group.

A pilot experiment was performed in this laboratory regarding the order of sectioning in serial ligamentous sectioning studies for both translation and rotation about the AC joint. This analysis used a similar experimental design to the one used in this study with the exception of varying the order of capsular sectioning for each of the specimens tested. Twelve specimens, each representing different combinations of sequential ligamentous cuts, were used in a statistical subclass of a Latin square design (type II) to yield an unbiased estimate regarding this variable (ie, the effect of varying the order of sequential ligamentous sectioning on ligamentous contribution to posterior stability). When applied to this case of 4 separate capsular cuts, this experimental design produces an orthogonal square to ensure that each ligamentous cut follows all other ligamentous cuts with equal frequency. In doing so, this experimental design has similar power in analyzing the effect of the order of cutting each ligament as the more exhaustive type I experimental design, which requires all 24 possible randomizations of the 4 cuts. This design revealed no statistically significant difference (at the 5% significance level) on overall ligament contribution regardless of the order of sectioning (analysis of variance [ANOVA]: P = .1702). On the basis of these results, the order of sectioning for this study arbitrarily began anteriorly and was followed by sectioning the superior, posterior, and inferior portions of the capsule.

Data analysis. All data were analyzed with the statistical analysis program Statview II (Abacus Concepts, Inc, 1992-93) on a Macintosh personal computer. For each of the 2 control specimens, the mean posterior translation at 70 N of force was recorded. In addition, the percentage variation in posterior displacement for each of the 15 load cycles for each specimen was calculated and compared relative to the mean translation for all 15 trials.

Any trends throughout these 15 cycles indicating plastic deformation from 1 cycle to the next (ie, changes in the shape of the force-displacement curve or increasing amounts of translation from 1 trial to the next) were also recorded.

For each of the test specimens, the force necessary to achieve the baseline posterior clavicular displacement was measured for the intact specimen and after sequential sectioning of the anterior, superior, posterior, and inferior capsular ligaments. The total contribution of the AC capsule to posterior stability of the distal clavicle was defined as the

Figure 2 Graph of 1.5 consecutive trials on 1 control specimen at 70 N. Note reproducibility of curve over 15 testing sequences with no change in either pattern of force-displacement curves or sequential increase in translation for given force over 15 trials.
percentage difference between the intact specimen (ie, 70 N) and the specimen after all 4 ligaments had been sectioned. The relative contributions of each individual ligament were determined as a percentage of the AC capsular contribution as a whole with the use of the decreases in developed force during posterior clavicular displacement with sequential ligament sectioning. Statistical significance of the individual ligament contributions was determined with Fisher’s post-hoc repeated measures ANOVA test with significance set at the 5% level.

RESULTS

Mean posterior displacements for each of the 2 control specimens were 7.1 ± 0.1 mm and 9.1 ± 0.1 mm. The maximum deviation from the mean over these 15 trials was approximately 2% from the mean translation for each specimen. Furthermore no increasing trend was seen in the displacement measured or the shapes of the load displacement curves obtained between successive cycles over the 15 trials tested that might suggest the presence of plastic deformation (Figure 2).

The relative ligamentous contributions to posterior stability of the test specimens were anterior 7% ± 3%, superior 56% ± 9%, posterior 25% ± 7%, and inferior 11% ± 6% (Tables I and II). The contribution of the superior portion of the AC capsule was statistically significant relative to the intact specimen and all other sectioning conditions (P < .05) (Figure 3). The posterior AC capsule also was significant relative to the intact specimen (P < .05) but not when compared with all other ligaments. The anterior and inferior portions of the capsule did not achieve significance in resisting posterior displacement when compared with the intact specimen (P > .05). The overall contribution of the AC capsule to resisting a posteriorly directed force was 57% ± 13% (range 23% to 98%). The remaining resistance to displacement in this plane was thought to be caused by the coracoclavicular ligaments and the testing apparatus.

DISCUSSION

The importance of the AC and coracoclavicular ligaments in maintaining stability and function of the AC joint has long been recognized. Cadenat recognized the importance of ligamentous stability to the AC joint in reference to subluxation and dislocation. Urist, in 1946, studied the roles of the AC and coracoclavicular ligaments in providing stability for the AC joint in the laboratory setting. Through serial sectionings of the AC capsule, coracoclavicular ligaments, and trapezius and deltoid insertions, he concluded that the AC ligament was an important stabilizer of the distal clavicle. After sectioning of the AC capsular ligaments was performed, the distal clavicle could be completely dislocated anteriorly and posteriorly. Superior dislocation of the clavicle did not occur until the coracoclavicular ligament had also been divided. These observations have been confirmed by Rockwood et al, who concluded that the AC ligaments control anterior-posterior translation of the distal clavicle and the coracoclavicular ligaments control superior-inferior translation.

The work of Fukuda et al has provided further scientific insight into the stability issue at this joint. Through the use of a similar apparatus that was used in this study, load-displacement testing was performed on human cadaver AC joints to determine the contributions of the AC ligaments, the trapezoid ligament,
and the conoid ligament to AC stability at both small and large displacements. At small displacements the AC capsular ligaments provided the primary restraint to both posterior (89%) and superior (68%) translation of the distal clavicle. At large displacements the conoid ligament was the primary restraint to superior (62%) translation, whereas the AC ligaments remained the primary restraint to posterior (90%) translation of the distal clavicle. Although the overall importance of the AC capsular ligaments was confirmed in this cadaveric study, the relative contributions of the individual capsular ligaments (ie, anterior, posterior, superior, and inferior) was not studied.

Flatow et al2,7,8 emphasized the role of the AC ligaments in controlling anterior-posterior translation of the distal clavicle in the clinical setting. They further recognized the destabilizing effect that disruption of the AC capsule could have in patients undergoing excision of the distal clavicle for degenerative and traumatic conditions affecting the AC joint. In addition, they recognized in these studies that excessive postoperative anterior-posterior translation of the distal clavicle may have a negative effect on outcome and recommended intracapsular excision of the distal clavicle to preserve these capsular ligaments and their stabilizing effect.

Blazar et al3 studied the effect of postoperative anterior-posterior translation on clinical outcome on 17 patients who underwent either arthroscopic or open distal clavicle excision for isolated AC arthropathy. Anterior, posterior, and total anterior-posterior translations were measured with standardized axillary stress radiographs and were correlated to postoperative pain scores. Total anterior-posterior and posterior translation had significant negative effects on postoperative pain. Most of the increased anterior-posterior translation in this patient cohort was the result of increased posterior as opposed to anterior translation. Blazar's study further supports excessive posterior instability of the distal clavicle as a significant source of postoperative pain after distal clavicle excision.

Our results indicate that the superior and posterior AC ligaments are the most important contributors to the overall AC capsuloligamentous restraint against posterior translation of the distal clavicle (56% ± 9% and 25% ± 7%, respectively). These findings are supported by previously reported anatomic observations that the superior portion of the AC capsule is the thickest portion of the capsule and that this thickening is most prominent posteriorly.4,9,11,12 Our data substantiate the concept that preservation of the AC capsular ligaments during distal clavicle excision, especially the superior and posterior ligaments, is important to minimize postoperative posterior translation of the clavicle.

This study has several limitations that are common with cadaveric biomechanical models. Testing was performed on isolated osseoligamentous preparations of the AC joint. Consequently, the effects of other articulations of the shoulder girdle (ie, sternoclavicular, gleno-humeral, scapulothoracic, and subacromial) on AC translations were not studied. In addition, the influence of the dynamic stabilizers of the AC joint (ie, deltoid, trapezius) was not studied. The testing apparatus also

### Table I: Force required to achieve given posterior displacement

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Translation (mm)</th>
<th>Intact (N)</th>
<th>Anterior cut (N)*</th>
<th>Superior cut (N)*</th>
<th>Posterior cut (N)*</th>
<th>Inferior cut (N)*</th>
<th>Total contribution (N)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>13.91</td>
<td>70</td>
<td>71.3±0.9</td>
<td>40.8±0.4</td>
<td>39.1±0.4</td>
<td>39.5±0.7</td>
<td>30.5</td>
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<td>2</td>
<td>7.52</td>
<td>70</td>
<td>65.9±0.6</td>
<td>53.9±0.4</td>
<td>50.8±0.6</td>
<td>47.3±1.2</td>
<td>22.7</td>
</tr>
<tr>
<td>3</td>
<td>9.06</td>
<td>70</td>
<td>65.2±1.0</td>
<td>53.1±1.4</td>
<td>44.5±0.8</td>
<td>29.8±0.2</td>
<td>40.2</td>
</tr>
<tr>
<td>4</td>
<td>7.96</td>
<td>70</td>
<td>68.9±0.5</td>
<td>60.8±1.0</td>
<td>55.0±0.8</td>
<td>54.4±0.3</td>
<td>15.6</td>
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<tr>
<td>5</td>
<td>6.32</td>
<td>70</td>
<td>69.8±2.0</td>
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</tr>
<tr>
<td>6</td>
<td>10.51</td>
<td>70</td>
<td>65.9±0.5</td>
<td>18.4±0.4</td>
<td>3.9±0.1</td>
<td>1.1±0.4</td>
<td>68.9</td>
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* SEM.

### Table II: Relative capsular contributions to posterior stability

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Intact (%)</th>
<th>Anterior capsule (%)</th>
<th>Superior capsule (%)</th>
<th>Posterior capsule (%)</th>
<th>Inferior capsule (%)</th>
<th>Total contribution (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100</td>
<td>0</td>
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<td>5.3</td>
<td>0</td>
<td>43.5</td>
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<tr>
<td>2</td>
<td>100</td>
<td>18.1</td>
<td>32.6</td>
<td>13.9</td>
<td>15.4</td>
<td>22.7</td>
</tr>
<tr>
<td>3</td>
<td>100</td>
<td>0.3</td>
<td>38.5</td>
<td>50.1</td>
<td>11.1</td>
<td>90.3</td>
</tr>
<tr>
<td>4</td>
<td>100</td>
<td>7.7</td>
<td>51.8</td>
<td>37.1</td>
<td>3.4</td>
<td>22.2</td>
</tr>
<tr>
<td>5</td>
<td>100</td>
<td>11.9</td>
<td>30.1</td>
<td>21.5</td>
<td>36.5</td>
<td>57.4</td>
</tr>
<tr>
<td>6</td>
<td>100</td>
<td>6.0</td>
<td>68.9</td>
<td>21.2</td>
<td>3.9</td>
<td>98.4</td>
</tr>
</tbody>
</table>

Average ± SEM 100±0 7.3±2.8 56.1±9.4* 24.9±6.6* 11.4±5.5 57.4±12.7

* Denotes statistical significance.
introduces several limitations to interpreting motion at this joint with dynamic influences aside. Translations along the superior-inferior and medial-lateral axes were constrained. This allowed for generation of load-displacement data along the same displacement path during all displacement cycles. However, it represents a simplification of in vivo loading conditions. In addition, the pulley system and translation table both introduced low levels of friction in the system (approximately 5% of the total force administered at these translations). Although this friction may have underestimated the total absolute contribution of the AC joint, its effects were even less significant when relative contributions on the same specimen were compared.

In vivo forces across the AC joint are unknown. Our specimens were tested at 70 N. This is an arbitrary number that is between the 10 N and 90 N loads used by Fukuda et al.9 Fukuda et al demonstrated that there was little to no difference in AC capsular contribution to posterior stability at 10 N and 90 N. In addition, none of our control specimens underwent plastic deformation. Therefore all specimens were tested on the same "elastic," albeit arbitrary, portion of their load-displacement curves.

This study was performed on normal AC joints. Resection of the distal clavicle, even if the resection is intracapsular, is likely to result in increased posterior translation. The ability of the AC capsular ligaments to resist posterior translation is undoubtedly enhanced by the capsuloligamentous tension developed as a result of articular contact between the clavicle and the acromion and by the "bulk" effect of the distal clavicle. Therefore extrapolation of our data to the situation in which the distal clavicle is absent but the capsule has been preserved should be done with caution. It may not be possible to prevent an increase in posterior translation of the clavicle after distal clavicle excision is performed. However, it seems reasonable to assume that preservation of the capsular ligaments, especially the superior and posterior ligaments, will minimize this increase.

The goal of resection arthroplasty of the AC joint (ie, distal clavicle excision) is to decrease pain associated with motion or contact between the clavicle and the acromion.11,12,17 Intracapsular excision to preserve the capsular ligaments requires removal of less bone than has been commonly recommended by many authors.2,8,12,17,20,21 Although the anterior-posterior stability gained by preservation of the capsular ligaments during intracapsular resection of the distal clavicle is probably desirable, further study is required to determine whether the conservative clavicle excision required to preserve the capsular ligaments will prevent painful contact between the clavicle and the acromion and provide long-term results that are comparable to or better than the results obtained with traditional amounts of bone resection.

REFERENCES