The Role of the Trapezius in Stabilization of the Acromioclavicular Joint

A Biomechanical Evaluation

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Background: Acromioclavicular joint (ACJ) injuries are common, and many are adequately treated nonoperatively. Biomechanical studies have mainly focused on static ligamentous stabilizers. Few studies have quantified ACJ stabilization provided by the trapezius.

Purpose/Hypothesis: To elucidate the stabilization provided by the trapezius to the ACJ during scapular internal and external rotation (protraction and retraction). It was hypothesized that sequential trapezial resection would result in increasing ACJ instability.

Study Design: Controlled laboratory study.

Methods: A biomechanical approach was pursued, with 10 cadaveric shoulders with the trapezius anatomically force loaded to normal. The trapezius was then serially transected over 8 trials, which alternated between clavicular defects (CD) and scapular defects (SD); each sequential defect consisted of 25% of the clavicular or scapular trapezial attachment. After each defect, specimens were tested with angle-controlled scapular internal and external rotation (12°) with rotary torque measurements to evaluate ACJ stability.

Results: The mean resistance in rotary torque for 12° of scapular internal rotation (protraction) with native specimens was 7.0 ± 2.0 N·m. Overall, internal rotation demonstrated a significant decrease in ACJ stability with trapezial injury ($P < .001$). Eight sequential defects resulted in the following significant percentage decreases in rotary torque from native internal rotation: 1.5% (25% CD; 0% SD), 5.6% (25% CD; 25% SD), 5.1% (50% CD; 25% SD), 6.5% (50% CD; 50% SD), 3.8% (75% CD; 50% SD), 7.1% (75% CD; 75% SD), 6.7% (100% CD; 75% SD), and 12.3% (100% CD 100% SD) ($P < .001$). The mean resistance in rotary torque for 12° of scapular external rotation (retraction) with native specimens was 7.1 ± 1.7 N·m. External rotation did not demonstrate a significant decrease in ACJ stability with trapezial injury ($P = .596$). The 8 sequential defects resulted in decreases in rotary torque from native external rotation of 0%, 3.8%, 4.0%, 3.2%, 3.5%, 3.4%, 4.2%, and 0.7%.

Conclusion: Trapezial injury resulted in increased instability in the setting of scapular internal rotation (protraction) of the ACJ.

Clinical Relevance: These findings validate the inclusion of deltotrapezial fascial injury consideration in the modified Rockwood classification system. Repair of the trapezial insertion on the ACJ may provide improved outcomes in the setting of ACJ reconstruction.

Keywords: shoulder; trapezius; dynamic stabilizer; biomechanics; acromioclavicular joint

The surgical treatment of acromioclavicular joint (ACJ) injuries is still evolving, and the gold standard procedure has not been achieved in a reproducible manner for open or arthroscopic approaches.[2-5,10,17,18,20,23,27] Biomechanical analyses have investigated the important roles of the coracoclavicular (CC) ligaments,[4,5,18,23] acromioclavicular ligament complex (ACLC),[17,24] and coracoacromial ligament[18] in ACJ stabilization. Historically, most of these studies have focused on clavicular movement, superior and inferior translation,[18] anterior and posterior translation,[17,18] and anterior and posterior rotation.[6,24] While these investigations have increased the knowledge base of static ACJ ligamentous stabilizers, incorporating these findings into surgical reconstructions has revealed that

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further improvement of ACJ reconstructions is necessary. These studies also feature testing with clavicular movement, which differs from in vivo scapular dominant motion of the ACJ pivoting around the primarily static clavicle.

The deltoid and trapezial muscles are dynamic stabilizers of the ACJ. The trapezius is of particular interest because of its attachments to the clavicle, ACLC, and scapula.[8,19] However, underlying mechanisms of trapezial dynamic stabilization of the ACJ are largely unknown.[10,17,18,22,26] Sahara et al[25] demonstrated in a 3-dimensional kinematic analysis of the ACJ using magnetic resonance imaging that during abduction, the trapezius played a critical role through attachment to the distal end of the clavicle and providing posterior translation. Furthermore, the upper and middle trapezial fibers (C3-T1) are responsible for elevation and lateral rotation of the clavicle and scapula.[13,14] This is achieved though the transverse orientation of the trapezial fibers exerting a horizontal force, medially causing clavicular superior rotation at the sternoclavicular joint (SCJ).[13] At the ACJ, these transverse trapezial fibers likely also stabilize movement between the clavicle and scapula.

Normally during ACJ movement, the clavicle is insignificant and primarily stabilizes the scapula,[21] while the scapula is responsible for most of ACJ movement, abduction and adduction, and protraction and retraction. Internal and external rotation of the scapula occur during shoulder protraction and retraction, respectively, allowing for approximately 15 to 18 cm of scapular translation in the lateral plane.[16] During these movements, the trapezius is attached to both the clavicle and the scapula and is expected to provide ACJ stability by restriction of internal rotation of the scapula. Therefore, trapezial injury likely results in less horizontal stability between the clavicle and scapula, specifically presenting with increased instability with internal rotation of the scapula. This is of noteworthy clinical importance, considering that trapezial injury can occur with ACJ injuries (ie, Rockwood types 4 and 5).

The purpose of this study was to elucidate the stabilization provided by the trapezius to the ACJ during scapular internal and external rotation. It was hypothesized that sequential trapezial resection will result in increasing ACJ instability.

METHODS

Specimen Preparation and Testing

Institutional review board approval was not required for the study, as deidentified specimens do not constitute human participant research. We obtained 10 shoulder specimens (7 male, 3 female; mean age ± SD, 67.0 ± 5.7 years) from MediCure and calculated the bone mass densities of the distal clavicle (0.25 ± 0.05 g/cm^2) using a GE Lunar Prodigy Advance Bone Densitometer. Specimens were prepared and potted (clavicle and scapula) in a routine fashion, as previously described,[6] with the most medial 3 inches of the clavicle potted and the most inferior 3 inches of the scapula potted in bone cement. All soft tissue was removed from the clavicle and scapula, except for the intact trapezius, deltoid, biceps, triceps, ACJ capsule, and CC ligaments.[24] The ACJ capsule and CC ligaments were kept intact to isolate the effects of the trapezius seen at the ACJ. All specimens were thawed overnight at room temperature before testing. The clavicle was fixated in anatomic alignment, as it is normally fixed anatomically during ACJ movement, with the scapula mounted to the MTS actuator (MTS Systems Corp) (Figure 1). This approach was pursued to simulate protraction (internal rotation) and retraction (external rotation) in a reproducible and consistent manner as it occurs in vivo, with the scapula contributing most of ACJ movement and the clavicle predominantly acting as a stabilizer.

Two polyester straps were sutured to the clavicular and scapular spine fibers of the upper and middle trapezius, which were weight-loaded during testing and suspended on a pulley system. The clavicular fibers of the upper trapezius connect to vertebrae C3-C6, and scapular spine middle trapezial fibers connect to vertebrae C7-T1.[13] Therefore, the pulleys for clavicular and scapular trapezial loading were oriented at 18° and 11° relative to the muscle insertion on the x-axis, respectively, each with 8.9 N of loaded force, equating to approximately 10% of the potential trapezial fiber force.[13] Trapezial force was calculated based on the fibers accounting for approximately 6.4 cm^2 multiplied by a force coefficient of 35 N/cm^2, equating to an approximate trapezial muscle fiber force of 224 N ([8.9 N × 2 trapezial straps]/224 N = 8%). Similarly, because of the inverted nature of the testing approach, the humerus was loaded in a neutral position of 20° of abduction with 25 N of force to account for the average arm (consisting of 6% of total body weight).

Each specimen was attached to the servohyrdralic testing system (MTS Systems) and calibrated to neutral by zeroing axial displacement, axial force, and rotary torque. Specimens remained in the testing setup for the entirety of the defect trials and were not removed in an effort to maintain a standardized testing approach. The servohydraulic testing system was used to apply and record the necessary rotational torque applied to the scapula in order to obtain

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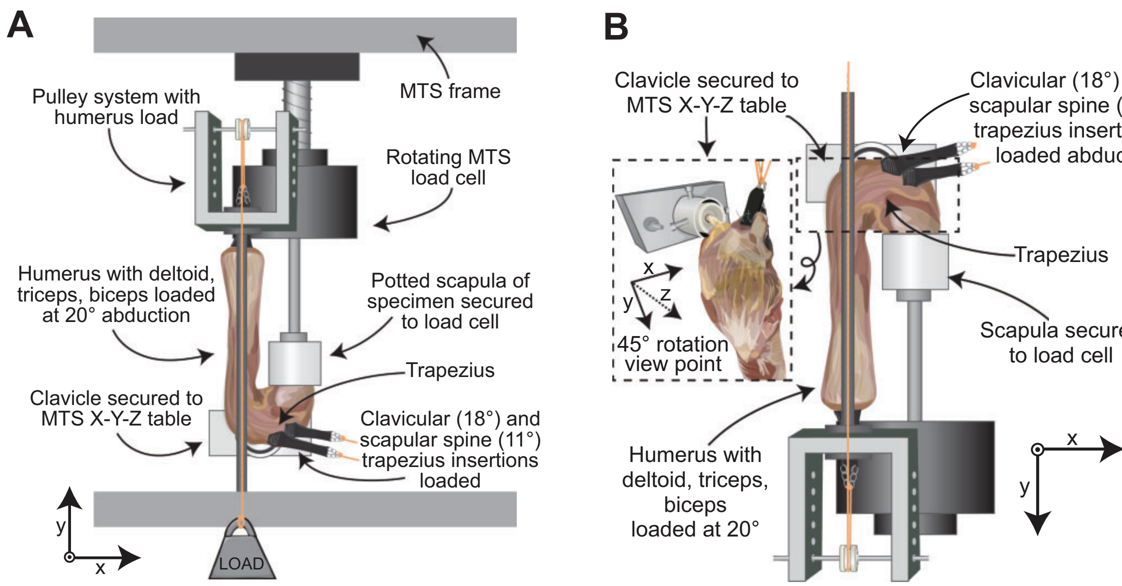


Figure 1. (A) Study setup illustration featuring posterior view of a right shoulder specimen with clavicle fixated, scapula attached to the Material testing system, humerus loaded to neutral, and trapezial clavicular and scapular muscle fibers loaded at their native anatomic angle. (B) Additional illustration inverted for greater appreciation of testing setup.

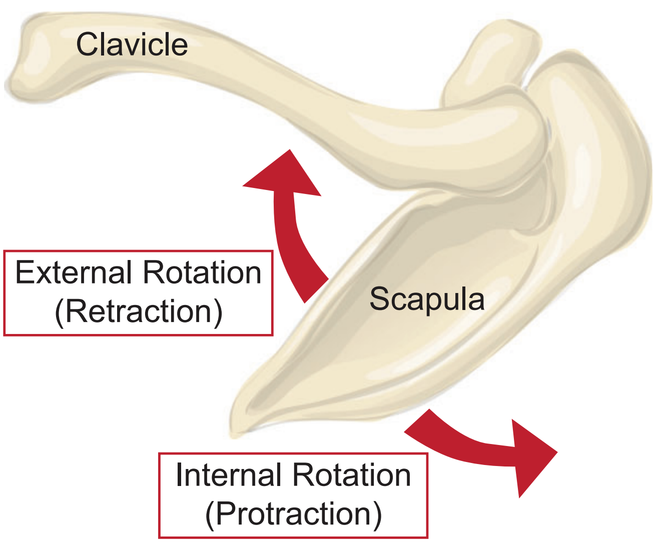


Figure 2. Illustration demonstrating scapular internal rotation (protraction) and external rotation (retraction).

12° of internal and external rotation on the ACJ at 5° per second. Internal and external rotation were set at 12° as previous biomechanical studies have demonstrated a maximum of 20° of internal and external ACJ rotation.[1,11] Internal and external rotational testing was cycled 30 times, and the force values in each testing event were used for analysis.

Experimental Design

A standardized cadaveric testing protocol was developed to compare scapular internal rotation (protraction) and external rotation (retraction) in the setting of various degrees of trapezial muscle defects on the clavicular and scapular spine insertion fibers (Figure 2). A total of 10 nonpaired fresh-frozen cadaveric shoulders were utilized (7 male; age, 67.0 ± 5.7 years; bone mass density, 0.25 ± 0.05 g/cm^3). The torque (in N·m) required to achieve 12° of scapular internal and external rotation was recorded for intact specimens as well as the 8 sequential trapezial defect trials (Figure 3). The trapezial defect trials alternated between clavicular defects (CD) and scapular defects (SD); each sequential defect consisted of 25% of the clavicular or scapular trapezial attachment: 25% CD with 0% SD, 25% CD with 25% SD, 50% CD with 25% SD, 50% CD with 50% SD, 75% CD with 50% SD, 75% CD with 75% SD, 100% CD with 75% SD, 100% CD with 100% SD. Trapezial defects for both clavicular and scapular spine insertions were started laterally at the acromion and progressed medially to the end of the muscle insertion. Trapezial muscle attachments were anatomically force loaded to normal (further explained below); however, the 100% CD and 100% SD trials did not feature any trapezial load as the trapezial attachment was fully transected. To reduce the effect of variation among specimens, each native specimen was considered its own control with the proportional trapezial defects based on an individual specimen's length of trapezial insertion.

Statistical Analysis

A priori power analysis was performed, and on the basis of previous studies, a standard deviation of 0.75 N·m of torque across the testing conditions was assumed, with a correlation of 0.5 among the repeated measures. Therefore, to obtain a power of 80% at an alpha level of .05 to detect a

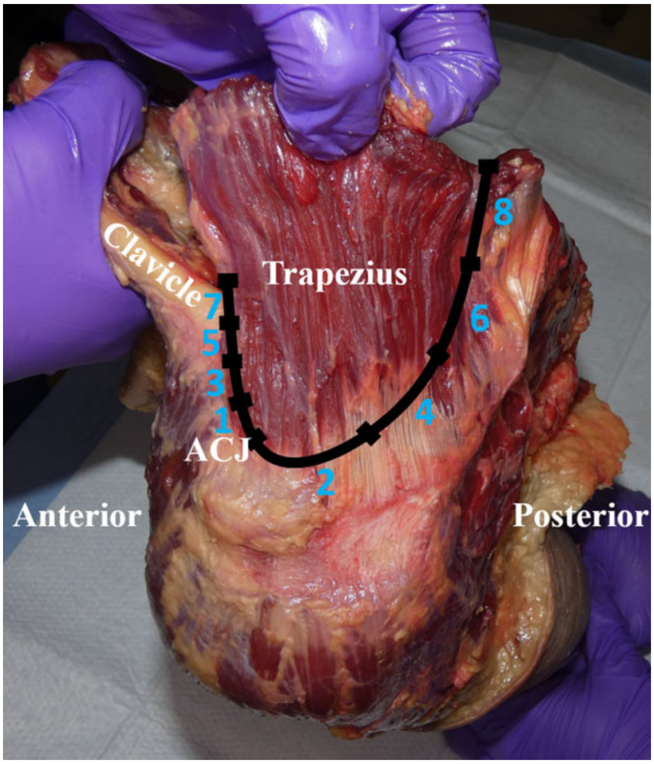


Figure 3. Superior view of left shoulder specimen depicting 8 sequential trapezial defects at clavicular and scapular spine attachment sites. Blue numbers indicate the order of alternating clavicular and scapular spine trapezial transections.

1.0-N·m difference in torque, 10 specimens were included. Differences in rotational torque across testing conditions were analyzed with a 1-way repeated-measures analysis of variance. After a significant analysis of variance, differences among conditions were evaluated with the post hoc Bonferroni correction for multiple comparisons. $P < .05$ was considered statistically significant.

RESULTS

Of the 10 specimens included in this study, 1 specimen experienced a scapular fracture resulting in exclusion. The final results include data from 9 specimens.

Scapular Internal Rotation (Protraction)

The mean resistance in rotary torque for 12° of scapular internal rotation with native specimens was 7.0 ± 2.0 N·m. After the 8 sequential defects, the rotary torque changed as follows: 6.9 ± 2.0, 6.6 ± 2.0, 6.6 ± 2.0, 6.5 ± 2.0, 6.7 ± 2.0, 6.5 ± 2.1, 6.5 ± 2.2, and 6.1 ± 2.2 N·m ($P < .001$ for the difference between all trials overall). Sequential changes in rotary torque requirements relative to native form can be observed in Figure 4. Overall, when progressing from the native condition to 100% clavicular and scapular trapezial defects, there was a 12.3% decrease in rotary torque requirements for 12° of scapular internal rotation.

Scapular External Rotation (Retraction)

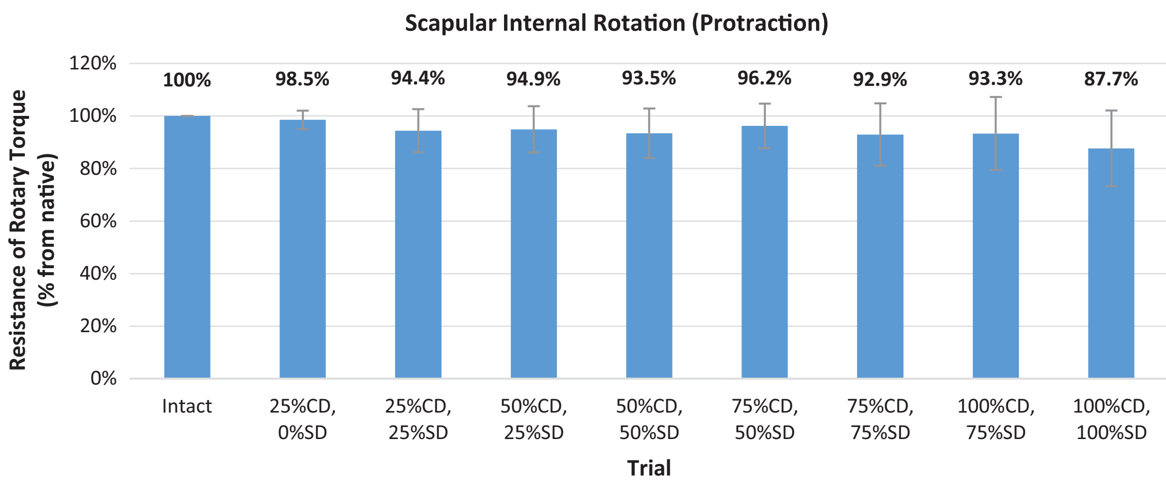
The mean resistance in rotary torque for 12° of scapular external rotation with native specimens was 7.1 ± 1.7 N·m. After the 8 sequential defects, rotary torque changed as follows: 7.2 ± 1.5, 6.8 ± 1.7, 6.8 ± 1.6, 6.9 ± 1.5, 6.9 ± 1.5, 6.7 ±1.6, 6.8 ±1.6, and 7.1 ± 1.7 N·m ($P = .596$ for the difference between all trials overall). Sequential changes in rotary torque requirements relative to the native form can be observed in Figure 5. Overall, when progressing from the native condition to 100% clavicular and scapular trapezial defects, there was a 0.7% decrease in rotary torque requirements for 12° of scapular external rotation.

DISCUSSION

The most important finding of this study was that sequential trapezial injury resulted in increased instability of the ACJ. Specifically, it was observed that trapezial injury resulted in a significantly decreased rotary torque required for scapular internal rotation (protraction) of the ACJ. There was no significant difference observed in rotary torque requirements for scapular external rotation (retraction).

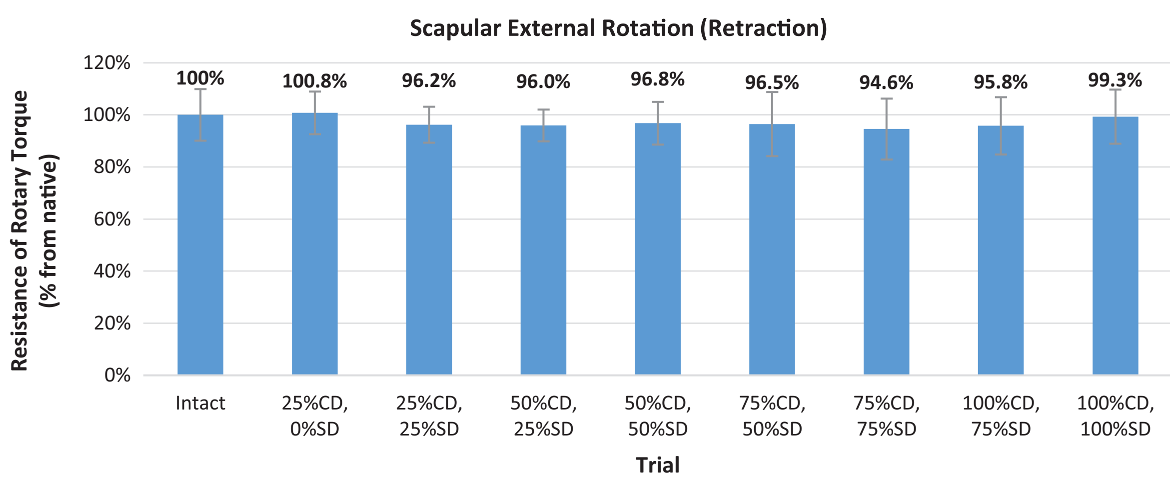
This study serves as among the first biomechanical investigations to test and quantify the functional dynamic stabilization of the trapezius on the ACJ, while the CA and CC ligaments were intact. The upper and middle trapezial fibers are transversely oriented and displace a horizontal medial force on the SCJ to achieve scapular elevation and upward rotation.[13] Additionally, it has been accepted that these transverse fibers secondarily provide dynamic stabilization to the ACJ.[8,19] In this study, angle-controlled rotation of the scapula (internal and external) with a static clavicle was used to reproducibly mimic protraction and retraction as it occurs in vivo. This approach allows for the most functional analysis of dynamic trapezial support. It was seen that 25% clavicular upper trapezial and 25% scapular middle trapezial injury resulted in a 5% decrease in stability, which progressed to a 12% decrease in stability after 100% trapezial injury. It is likely that complex movements, such as external rotation (protraction), in the setting of trapezial injury may be contributing to unsatisfactory reduction results after ACJ reconstruction. Radiographic studies demonstrating rates of loss of reduction ranged from 30% to 53% after surgical management of ACJ injuries.[7,9,12,15] While unaddressed trapezial injury in the setting of ACJ repair may not fully account for these discrepancies, it is believed that there is a certain degree of effect that needs to be further characterized.

The modified Rockwood classification system of ACJ injuries acknowledges the role of dynamic stabilization from the trapezius and deltoid by accounting for the degree of deltotrapezial fascial injury as part of the classification system.[22] In ACJ injury types 1 and 2, the deltotrapezial fascia is intact, in types 3A and 3B there is mild injury to the deltotrapezial fascia, and in types 4 and 5 there is injury to the deltotrapezial fascia.[22] This incremental increase in severity of deltotrapezial injuries with additional clinical



Rotary Torque, N·m	7.0 ± 2.0	6.9 ± 2.0	6.6 ± 2.0	6.6 ± 2.0	6.5 ± 2.0	6.7 ± 2.0	6.5 ± 2.1	6.5 ± 2.2	6.1 ± 2.2

Figure 4. Mean percentage of rotary torque for 12° of scapular internal rotation in correlation with the intact (native) condition across sequential defect (SD) ($P < .001$). CD, clavicular defect.



Rotary Torque, N·m	7.1 ± 1.7	7.2 ± 1.5	6.8 ± 1.7	6.8 ± 1.6	6.9 ± 1.5	6.9 ± 1.5	6.7 ± 1.6	6.8 ± 1.6	7.1 ± 1.7

Figure 5. Mean percentage of rotary torque for 12° of scapular external rotation in correlation with the intact (native) condition across sequential defect (SD) ($P = .596$). CD, clavicular defect.

findings and the increasing radiographic CC distance increase the severity of the ACJ injury Rockwood classification. This is because of the deltotrapezial fascia acting as a static and dynamic stabilizer of the ACJ via transmission from the trapezius and deltoid muscles.[19] The current study supports that trapezial injury at the ACJ may specifically contribute to increased ACJ instability. However, it should be acknowledged that in vivo deltotrapezial fascial injuries may differ from the transection featured in this biomechanical study. This may be especially true for the SD featured in this study, as few sources, if any, have reported trapezial injury resulting in separation of the muscle body from the scapular spine.

Currently, ACJ reconstruction surgical techniques do not feature reconstitution of the trapezial insertion on the clavicle. A recent study by LeVasseur et al[19] highlighted the possible importance of either maintaining or repairing trapezial insertion to the ACJ during reconstructions to enhance stability. Considering that this current study demonstrated the increased instability of the ACJ in internal rotation with trapezial injury, future advancements in ACJ reconstruction may benefit from repairing the trapezial insertion on the ACJ. This consideration may also be similarly applied to reconstitution of the anterior deltoid to the distal clavicle during ACJ reconstruction in an effort to obtain increased ACJ stabilization. Additionally, this study may support the benefit of early surgery for Rockwood type 5 ACJ injuries with the ability to repair the trapezial fascia.

Limitations

There are several limitations to this study. First, this in vitro biomechanical evaluation attempts to replicate trapezial force on the ACJ but is achieved through force loading rather than actual muscle innervation that occurs in vivo. Furthermore, the internal and external rotation of the scapula achieved through this study may not fully account for the full degree of anterior and posterior translation of the acromion on the clavicle that occurs in vivo during protraction and retraction. Additionally, the magnitude and direction of forces applied in this testing model certainly do not represent all stresses that the ACJ may be exposed to in vivo; there are many scapular stabilizer muscles that may compensate and provide resistance to scapular motion with limited ability to account for all of them in a dynamic manner during biomechanical testing. Finally, there was variation between baseline stability of native specimens as measured by the methods in this study. In an attempt to minimize this effect on variation among specimens, the percentage in relation to the native specimen was chosen to be a reported outcome measure so that each specimen would act as its own control.

CONCLUSION

Trapezial injury resulted in increased instability of the ACJ specifically in the setting of scapular internal rotation. These findings validate the inclusion of deltotrapezial fascial injury being considered in the grading of ACJ injuries as outlined by the modified Rockwood classification system. Repair of the trapezial insertion on the ACJ may provide improved outcomes in the setting of ACJ reconstruction. Further investigations are warranted to assess the trapezius and other dynamic stabilizers in the stabilization of remaining scapular movements involving the ACJ.

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