



Repair of the entire superior acromioclavicular ligament complex best restores posterior translation and rotational stability

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Abstract

Purpose The acromioclavicular ligament complex (ACLC) is the primary stabilizer against horizontal translation with the superior ACLC providing the main contribution. The purpose of this study was to evaluate the specific regional contributions in the superior half of ACLC, where the surgeon can easily access and repair or reconstruct, for posterior translational and rotational stability.

Methods The superior half of ACLC was divided into three regions; Region A (0°–60°): an anterior 1/3 region of the superior half of ACLC, Region B (60°–120°): a superior 1/3 region of the superior half of ACLC, and Region C (120°–180°): a posterior 1/3 region of the superior half of ACLC. Fifteen fresh-frozen cadaveric shoulders were used. Biomechanical testing was performed to evaluate the resistance force against passive posterior translation (10 mm) and the resistance torque against passive posterior rotation (20°) during the following the four conditions. (1) Stability was tested on all specimens in their intact condition ($n = 15$). (2) The ACLC was dissected and stability was tested ($n = 15$). (3) Specimens were randomly divided into three groups by regions of suturing. Stability was tested after suturing Region A, Region B, or Region C ($n = 5$ per group). (4) Stability was tested after suturing additional regions: Region A + B (0°–120°), Region B + C (60°–180°), or Region A + C (0°–60°, 120°–180°, $n = 5$ per group).

Results The translational force increased after suturing Region A when compared with dissected ACLC ($P = 0.025$). The force after suturing Region A + B was significantly higher compared to the dissected ACLC ($P < 0.001$). The rotational torque increased after suturing Region A or Region B compared with dissected ACLC ($P = 0.020$, $P = 0.045$, respectively). The torque after suturing the Region A + C was significantly higher compared to the dissected ACLC ($P < 0.001$).

Conclusion The combined Region A + B contributed more to posterior translational stability than Region B + C or Region A + C. In contrast, combined Region A + C contributed more to posterior rotational stability than Region A + B or Region B + C. Based on these findings, surgical techniques restoring the entire superior ACLC are recommended to address both posterior translational and rotational stability of the AC joint.

Keywords Acromioclavicular joint dislocation · Acromioclavicular ligament complex · Translational stability · Rotational stability · Biomechanics · Cadaver study

Introduction

The best surgical procedure for acromioclavicular (AC) joint dislocations is still debated, and numerous variations of surgical procedures have been published [2]. Until 5 years ago, the procedures focused on coracoclavicular (CC) stabilization [17–19]. However, persisting posterior instability has been observed after CC stabilization without AC stabilization, and patients with posterior instability had substantially poorer clinical results [1, 18]. Furthermore, cadaveric biomechanical studies have identified the acromioclavicular

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ligament complex (ACLCLC) as the primary stabilizer preventing posterior translation and rotation [7–10]. Therefore, the recent surgical techniques have focused on both CC and AC stabilization [3, 6, 11, 12, 20, 21, 23].

Regarding the biomechanical role of the ACLCLC, Klimkiewicz et al. demonstrated that the superior part of the ACLCLC is the main contributor to overall ACLCLC restraint against posterior translation of the distal clavicle [15]. However, specific regional contributions in the superior part of ACLCLC are still unclear. Understanding the specific areal contributions for posterior stability of the ACLCLC's superior half, where the surgeon can easily access to repair, augment, or reconstruct the ACLCLC, may help to improve the development of surgical techniques for AC joint dislocation. The purpose of this study is to evaluate the different contributions of the anterior, superior, and posterior segments of the ACLCLC's superior half for posterior translational and rotational stability.

Materials and methods

Experimental design

The superior half of ACLCLC was divided into three regions; Region A (0° – 60°): an anterior 1/3 region of the superior half of ACLCLC, Region B (60° – 120°): a superior 1/3 region of the superior half of ACLCLC, and Region C (120° – 180°): a posterior 1/3 region of 1/3 of the superior half of ACLCLC (Fig. 1).

Biomechanical testing was performed to evaluate the resistance force against passive posterior translation and the resistance torque against passive posterior rotation during the following five conditions. (1) Stability was tested on all specimens in their intact condition ($n = 15$). (2) The ACLCLC was dissected and stability was tested ($n = 15$). (3)

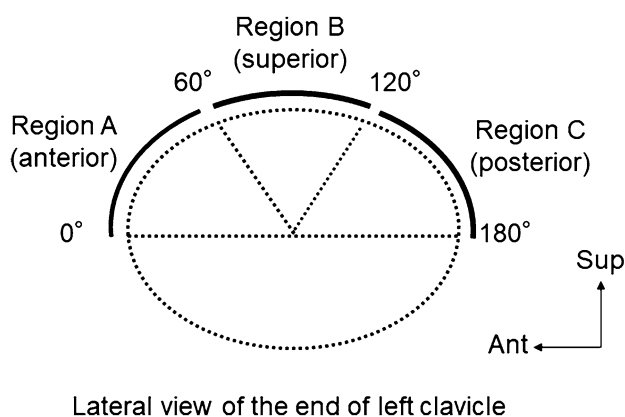


Fig. 1 Schematic of the acromioclavicular ligament complex division for suturing

Specimens were randomly divided into three groups by regions of suturing (Fig. 2). Stability was tested after suturing Region A (0° – 60°), Region B (60° – 120°), or Region C (120° – 180°) (Figs. 2, 3, $n = 5$ per group). Each region was sutured using four 2-0 FiberWire® (Arthrex Inc., Naples, FL) sutures. (5) Stability was tested after suturing an additional region: Region A + B (0° – 120°), Region B + C (60° – 180°), or Region A + C (0° – 60° , 120° – 180°) (Figs. 2, 3, $n = 5$ per group).

Specimen preparation

Fifteen fresh-frozen cadaveric shoulders were analyzed in this study (mean age of 58.4 ± 12.9). All specimens were obtained from Medcure Inc. (Portland, OR). Specimen preparation was done in accordance with previously published methods [3, 5, 22]. Each shoulder specimen was thawed overnight at room temperature and disarticulated at the glenohumeral joint. The clavicle and scapula were dissected free of all soft tissue except the ACLCLC, the CC ligaments, and the coracoacromial ligament. The scapula was trimmed and potted with plaster of Paris in a 7.6 cm (diameter) \times 7.6 cm (length) section of polyvinyl chloride (PVC) pipe. The glenoid surface was aligned parallel to the floor when the PVC pipe positioned upright. The scapula was secured to a swivel fixture on the X–Y table of a servohydraulic testing system (MTS Systems Corp). The clavicle was then trimmed to 13 cm and potted with bone cement in a 3.2 cm (diameter) \times 6.4 cm (length) section of PVC pipe, so that its long axis was centered and ran parallel within the PVC pipe. This enabled clavicular fixation to the actuator of the MTS machine with a custom aluminum clamp. The local institutional review board provided approval for the study. The Health Center's safety office and OSHA approved the purchase and disposal of cadaver specimens.

Biomechanical test setup

The pipe-cemented specimens were positioned anatomically with the scapula secured to a swivel fixture on an X–Y–Z table of a servohydraulic testing system (MTS Systems Corp). The clavicle side was attached to a custom fixture allowing anterior–posterior translation and rotation motion without moving the specimen. A pneumatic cylinder (Bimba, Monee, IL, USA) connected to 100 lb load cells (Futek, Irvine, CA, USA) was hooked to the custom fixture (parallel to the AC joint) on the clavicle side to generate an anterior–posterior translational force. This setup allowed the investigation of rotational and anterior–posterior loading during the cutting procedure without repositioning the specimen. A displacement controlled setting was used to run the test.

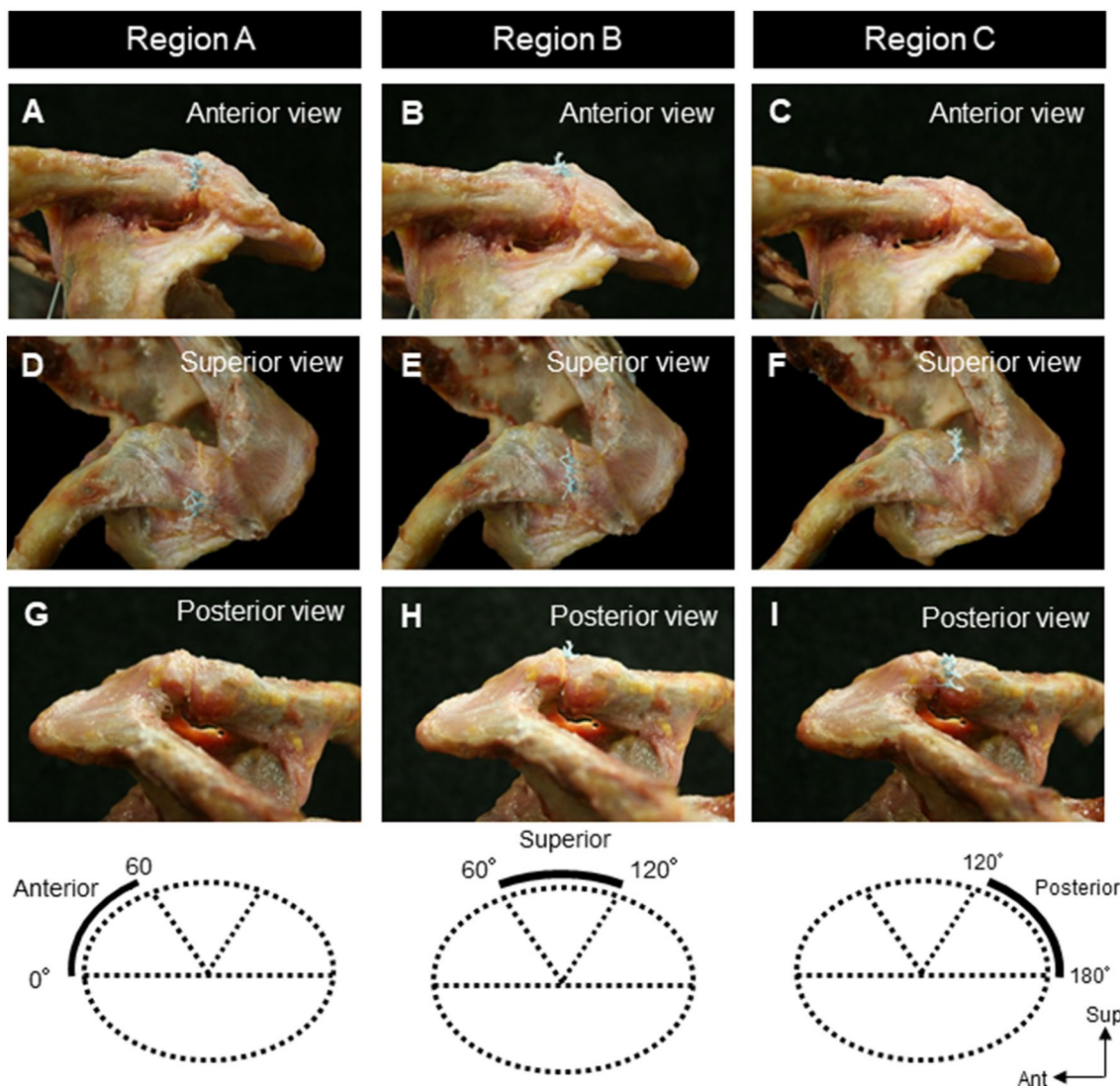


Fig. 2 Representative pictures and schemas of suturing ACLC's superior half. **a, d, g** Combinations of anterior, superior, and posterior views of suturing Region A (0° – 60°). **b, e, h** Combinations of ante-

rior, superior, and posterior views of suturing Region B (60° – 120°). **c, f, i.** Combinations of anterior, superior, and posterior views of suturing and Region C (120° – 180°)

Translational testing

The clavicle was translated anteroposterior with respect to the acromion. A linear displacement of 10 mm in the anterior and posterior directions was applied. This distance has been described in prior studies as native AC joint motion without disturbing the AC joint capsule or the CC ligaments [3, 4, 6]. Fifteen cycles were analyzed after preconditioning with five cycles of reduced distances (5 mm of displacement). The required force to achieve the designated displacement was recorded by load cells. The values of the last cycle were used for analysis.

Rotational testing

The attached translational actuator was released, so the potted clavicle could be fixed with its long axis in line with the shaft of the MTS actuator. The clavicle was rotated about its long axis 20° posterior and 20° anterior at a rate of 5° per second, as was done in a previous study [3]. Anterior rotation was designated as the superior aspect of the clavicle moving anteriorly, and posterior rotation was designated as posterior movement of the superior aspect of the clavicle. Ten cycles were completed after preconditioning with five cycles of reduced distances (10° of displacement). The

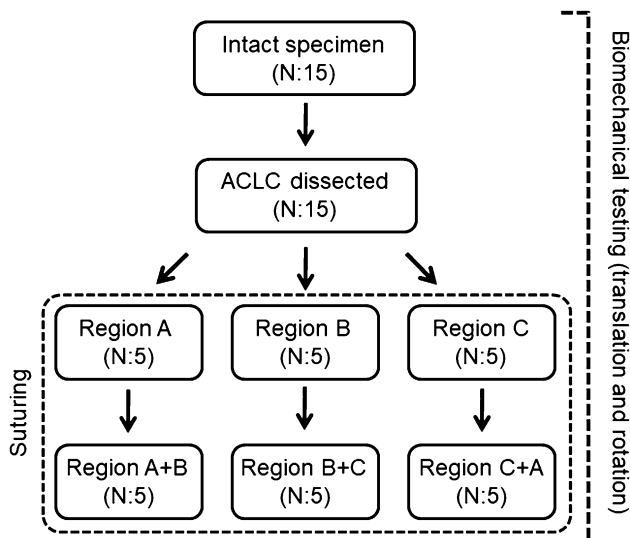


Fig. 3 Flowchart demonstrating the tested groups and biomechanical testing

required force to achieve the designated displacement was recorded by the MTS machine. The values of the last cycle were used for analysis.

The UConn Health Institutional Review Board (IRB) confirmed that the use of de-identified cadaveric specimens does not constitute human subject research.

Statistical analysis

Assuming a standard deviation of 30 N in translation force and 0.4 N-m of torque across the testing conditions with a correlation of 0.5 among the repeated measures We assumed by as. A sample size of ten specimens would provide 80% power at an alpha level of 0.05 to detect a 20 N difference in translation and a 2 N-m difference in torque. Descriptive statistics were calculated using mean and standard deviation or frequency and proportion where appropriate. Differences in posterior translational force and rotational torque with different suturing conditions were analyzed with a one-way repeated-measure ANOVA. Following a significant ANOVA, differences between the intact and suturing conditions were evaluated with Dunnett’s method for multiple comparisons. An alpha level of 0.05 was set for all comparisons.

Results

Posterior translational force

The resistance force against posterior translation in the intact condition significantly decreased after dissection of

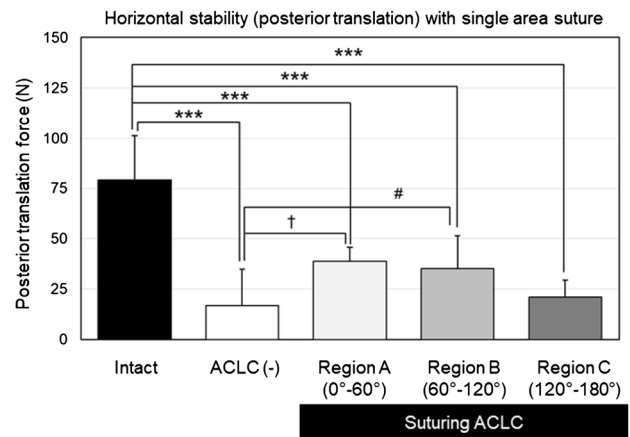


Fig. 4 Posterior translational force (N) during the 10 mm displacement of distal clavicle with intact condition of ACLC, after dissection of overall ACLC (ACLC-), suturing Region A (0°–60°), Region B (60°–120°), and Region C (120°–180°) with remaining intact coracoclavicular ligaments. The error bars indicate the standard deviation. *** $P < 0.001$ compared with the intact condition. † $P < 0.05$ compared with the dissected ACLC. # P between 0.05 and 0.1 compared with the dissected ACLC

the ACLC ($P < 0.001$, Fig. 4). Suturing Region A (0°–60°), Region B (60°–120°), or Region C (120°–180°) yielded a significantly lower resistance force for posterior translation compared to the intact condition ($P < 0.001$, Fig. 4). The resistance forces increased after suturing Region A when compared with complete dissection of the ACLC ($P = 0.025$, Fig. 4).

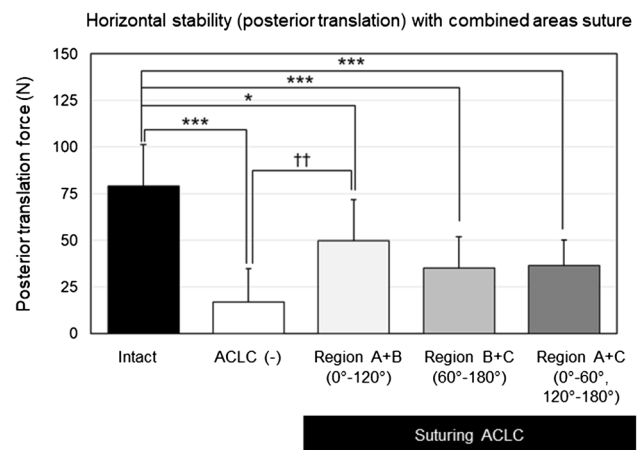


Fig. 5 Posterior translational force (N) during the 10 mm displacement of distal clavicle with intact condition of acromioclavicular ligament complex (ACLC), after dissection of ACLC (ACLC-), suturing Region A + B (0°–120°), Region B + C (60°–180°), and Region A + C (0°–60°, 120°–180°) with remaining intact coracoid clavicular ligaments. The error bars indicate the standard deviation. * $P < 0.05$ and *** $P < 0.001$ compared with the intact condition. †† $P < 0.01$ compared with the dissection of all capsule condition

Suturing Region A + B (0°–120°) significantly increased the resistance force compared to complete dissection of the ACLC ($P=0.004$, Fig. 5). There was no significant difference in resistance force between the complete dissection of the ACLC and suturing Region B + C (60°–180°) or Region A + C (0°–60°, 120°–180°) (n.s., respectively, Fig. 5).

Posterior rotational torque

The resistance torque against posterior rotation significantly decreased after complete dissection of the ACLC ($P < 0.001$, Fig. 6). Suturing Region A, Region B, or Region C yielded a significantly lower resistance torque for posterior rotation compared to the intact condition ($P = 0.006$, $P = 0.004$, $P < 0.001$, respectively, Fig. 6). The resistance torque after suturing Region A or Region B increased when compared with complete dissection of the ACLC ($P = 0.020$, $P = 0.045$, respectively, Fig. 6).

The resistance torque after suturing Region A + C significantly increased when compared to the completely dissected ACLC ($P < 0.001$, Fig. 7). There were no significant differences in resistance torque between the dissected ACLC and suturing Region A + B or Region B + C (n.s., respectively, Fig. 7).

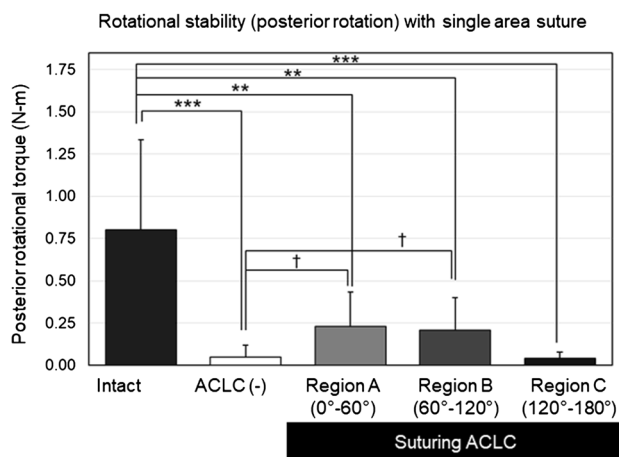


Fig. 6 Posterior rotational torque (N-m) during the 20 degree rotation of distal clavicle with intact condition of acromioclavicular ligament complex (ACLC), after dissection of ACLC (ACLC-), suturing Region A (0°–60°), Region B (60°–120°), and Region C (120°–180°) with remaining intact coracoclavicular ligaments. The error bars indicate the standard deviation. ** $P < 0.01$ and *** $P < 0.001$ compared with the intact condition. † $P < 0.05$ compared with the dissected condition

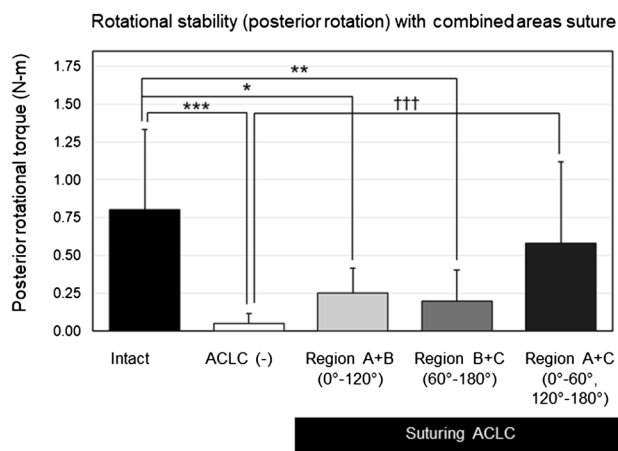


Fig. 7 Posterior rotational torque (N-m) during the 20 degree rotation of distal clavicle with intact condition (Intact) of acromioclavicular ligament complex (ACLC), after dissection of ACLC (ACLC-), suturing Region A + B (0°–120°), Region B + C (60°–180°), and Region A + C (0°–60°, 120°–180°) with remaining intact coracoclavicular ligaments. The error bars indicate the standard deviation. * $P < 0.05$, ** $P < 0.01$, and *** $P < 0.001$ compared with the intact condition. ††† $P < 0.01$ compared with the dissection of the ACLC

Discussion

The most important finding of the present study was each segment of the ACLC’s superior has different contributions for posterior translational and rotational stability of AC joint. The resistance forces against posterior translation increased after suturing Region A and when compared with complete dissection of the ACLC (Fig. 4). Moreover, the resistance force after suturing Region A + B significantly increased compared to complete dissection of the ACLC. Furthermore, there was no significant difference in resistance force between the complete dissection of the ACLC and suturing Region B + C and Region A + C (Fig. 5). Klimkiewicz et al. reported the superior part of the ACLC was the main contributor to the overall ACLC’s posterior translational stability [15]. However, there are some differences in the method of segmentation between the current study and Klimkiewicz’s study. The present study focused on the superior half of ACLC and divided it into three regions (Region A, B, and C), due to the clinical relevance for repair or augmentation. Klimkiewicz et al. sectioned the overall ACLC into four segments (anterior, superior, posterior, and inferior) with reference to clavicular anatomy. The authors reported that the contribution of the superior segment of the ACLC to posterior translational stability was statistically significant relative to all other sectioning conditions. Sectioning the posterior ACLC was only significant relative to the native condition, but not when compared with all the other ligaments. In an anatomical study of the AC ligament, Nakazawa et al. reported the ACLC is divided into two parts

(superoposterior and anteroinferior bundles) and has several anatomical variations (categorized into three types) [16]. These anatomic variations may have further contributed to the different results between the studies. Based on the present findings, Region A and Region B may contribute more than the Region C to the resistance force against posterior translation.

For posterior rotational stability, we demonstrated that the resistant torque after suturing Region A + C significantly increased compared to the dissected ACLC. In contrast, there was no significant difference in resistance torque between the dissection of the ACLC and suturing Region A + B or Region B + C. To our knowledge, this is the first study to analyze the regional contribution of the superior half of the ACLC to rotational stability. Kippe et al. compared the posterior rotational torque after a Weaver–Dunn reconstruction to native shoulders [14]. Following the technique, which does not reconstruct the ACLC, the resistance torque against posterior rotation was decreased about 85% or more when compared with native shoulders. The present study also demonstrated that the resistance torque against posterior rotation decreased about 94% after dissection of the ACLC. Furthermore, the resistance force against posterior translation decreased about 79% after dissection of the ACLC when compared to the intact condition. These findings suggest that the ACLC is more important for posterior rotational stability than posterior translational stability.

Based on the present findings, repair or reconstruction of the entire superior ACLC is required to restore both posterior translational and rotational stability of the AC joint. In chronic case, reconstruction of the entire superior ACLC may be needed, due to the limited healing potential of the acromioclavicular ligaments. Beitzel et al. biomechanically compared four techniques for AC reconstruction in addition to CC stabilization (modified anatomic CC ligament reconstruction, intramedullary, transacromial, and 8-turn) [3]. The modified anatomic CC ligament reconstruction, which wraps the entire AC joint using a semitendinosus tendon, was the most stable method with regard to clavicle translation and rotation. However, this technique has several limitations to require a long tendon, tendon-to-bone attachment, and surgical invasion due to access to the inferior part of the AC joint. Therefore, our study focused on the superior half of the AC joint and analyzed the individual contributions of different regions for posterior translational and rotational stability. Recently, another modified anatomic CC ligament reconstruction method was reported [13]. This technique reconstructed the superior ACLC with a semitendinosus tendon after CC ligament reconstruction and repaired the ruptured anterior and posterior ACLC with suture anchors. At midterm follow-up, 93% of patients had two-dimensional radiographic stability and three-dimensional dynamic clinical stability; therefore, restoring the superior ACLC

may also optimize the clinical outcome after AC repair or reconstruction.

The present study has several limitations. (1) The in vitro nature of biomechanical evaluation can be a limiting factor in the application of the findings to the in vivo conditions of the shoulder complex. This is particularly true in the AC joint, with its specific 3D forces and complex contributions to multiple shoulder motions. Accurate replication of these forces in a cadaveric study may be difficult. To evaluate changes in biomechanical behavior under translational and rotational stress, we used a methodology based on the previous descriptions [3, 9]. The major strength of this biomechanical setup was that all tested motions could be performed without changing the position of the specimens. Each specimen was placed and centered in the materials testing machine, so that all changes measured through the test could be compared to the native state. We thought that this would be necessary to detect the changes that would arise with each consecutive modification to the specimens. (2) Specimens tested were from donors with a mean age of 58 ± 13 years, whereas patients with AC dislocation are usually younger. (3) Biomechanical testing with cadaveric specimens does not give information on healing biology, and the tested biomechanical setup cannot reproduce the clinical situation. The clinical relevance of this study is to add the knowledge that each segment of the ACLC's superior has different contributions for posterior translational and rotational stability of AC joint and surgical techniques restoring the entire superior ACLC are recommended to address both posterior translational and rotational stability.

Conclusions

Region A + B (0° – 120°) contributed more to posterior translational stability than Region B + C (60° – 180°) or Region A + C (0° – $60^\circ/120^\circ$ – 180°). In contrast, Region A + C contributed more to posterior rotational stability than Region A + B or Region B + C. Based on these findings, surgical techniques restoring the entire superior ACLC are recommended to address both posterior translational and rotational stability of the AC joint.

Author contributions Authors DM, JDJ, EO, and BS participated in obtaining the data. Authors ADM and MPC were responsible for the analysis of data. Authors FD, FBI, and KB made substantial contribution in designing the methodology and providing oversight to the conduct of the study. All authors (DM, JDJ, EO, BS, ADM, MPC, FD, FBI, and KB) made significant contributions to the development and revision of the manuscript. In addition, all authors have given final approval for the submitted manuscript.

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on study design, data collection, or interpretation of the results or the final manuscript.

Compliance with ethical standards

Conflict of interest The authors DM, FD, JDJ, EO, FBI, BS declare no conflict of interest. MPC received personal fee from the Arthroscopy Association of North America. KB is a consultant for Arthrex GmbH, Germany. ADM received grants to his institution from Arthrex Inc. Naples, FL, USA. He is a consultant for Arthrex Inc. Naples FL, USA and Ortho x, Inc., Lewisville, TX, USA.

Ethical approval The above study was conducted using only de-identified cadaveric specimens and is therefore not considered human subjects research. Our institutional review board (IRB) provides a Human Research Determination Form to help investigators determine whether IRB review is needed. While we have confirmed with our IRB that projects conducted in our biomechanics laboratory that utilize de-identified specimens does not constitute human subjects research and therefore no review required.

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