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Biomechanical evaluation of native acromioclavicular joint ligaments and two reconstruction techniques in the presence of the sternoclavicular joint: A cadaver study

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Abstract

Background: Where is over 100 reconstruction techniques described for acromioclavicular (AC) joint reconstruction. Although, it is not clear whether the presence of the sternoclavicular (SC) joint influences the biomechanical properties of native AC ligaments and reconstruction techniques. The purpose of the present study was to investigate the biomechanical properties of native AC joint ligaments and two reconstruction techniques in cadavers with the SC joint still present. **Materials and Methods:** We tested eight fresh-frozen cadaver hemithoraces for superior translation (70 N load) and translation increment after 1000 cycles (loading from 20 to 70 N) in a controlled laboratory study. There were three testing groups created: native ligaments, the single coracoclavicular loop (SCL) technique, and the two coracoclavicular loops (TCL) technique. Superior translation was measured after static loading. Translation increment was calculated as the difference between superior translation after cyclic and static loading. **Results:** Native AC ligaments showed significantly lower translation than the SCL ($p = 0.023$) and TCL ($p = 0.046$) groups. The SCL had a significantly lower translation increment than native AC ligaments ($p = 0.028$). There was no significant difference between reconstruction techniques in terms of translation ($p = 0.865$) and translation increment ($p = 0.113$). **Conclusions:** Native AC joint ligaments had better static properties than both reconstruction techniques and worse dynamic biomechanical properties than the SCL technique. The SCL technique appeared to be more secure than the TCL technique. The presence of the SC joint did not have an observable influence on test results.

Keywords

acromioclavicular joint, biomechanical, coracoclavicular space, native ligaments, sternoclavicular joint

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Introduction

From its physical appearance, the acromioclavicular (AC) joint seems to have a simple structure; however, a growing amount of laboratory-based research shows that its biomechanics are not yet fully understood.[1] AC dislocation usually occurs as a result of direct force to the acromion with the arm in an adducted position.[2] AC dislocation injuries are generally classified into six different types according to Rockwood.[3,4] Most authors agree that Rockwood types I and II should be treated conservatively, and types IV–VI should be treated operatively.[5,6] However, treatment of Rockwood type III injury remains controversial; recent literature advocates a conservative approach, with surgical reconstruction only conducted in particular cases.[1,7] Despite the description of numerous techniques, treatment of AC joint dislocation remains controversial.[1,5,8–10]

There have been a number of biomechanical studies conducted on cadaver shoulders.[6–8,11–22] In all previous studies, the scapula and clavicle were positioned anatomically, but the sternoclavicular (SC) joint was removed. The SC joint provides movement around the sagittal axis; during full elevation of the upper limb, the clavicle is raised to an angle of approximately 60°.[23] It is not clear whether the presence of the SC joint influences the biomechanical properties of native AC ligaments and reconstruction techniques.

The purpose of the present study was to investigate the biomechanical properties of native AC ligaments and AC joint reconstruction techniques in cadavers with the SC joint still present. Our hypotheses were that (1) native AC ligaments would have better biomechanical performance than both AC joint reconstruction techniques and (2) the single coracoclavicular loop (SCL) technique would have better biomechanical properties than the two coracoclavicular loops (TCL) technique.

Materials and methods

Specimen preparation

We used eight fresh-frozen cadaveric hemithoraces (complex of the shoulder with the arm, half of the sternum, ribs, and half of the vertebral column). The mean cadaver age was 76 years (range 70–85 years). Each specimen was thawed for 24 h before testing was conducted at room temperature. Before dissection, the scapula was fixed to a custom-made plate by five custom-made screws (6 mm diameter) inserted into the infraspinatus fossa. The plate was rigidly connected to the autopsy table in a specific manner, with the plane of the clavicle oriented perpendicular to the linear actuator. We then dissected all soft tissue surrounding the clavicle and acromion, leaving an intact AC joint, coracoclavicular (CC) ligaments, and SC joint. Two experienced surgeons visually inspected all specimens for observable diseases and cortical bone quality.

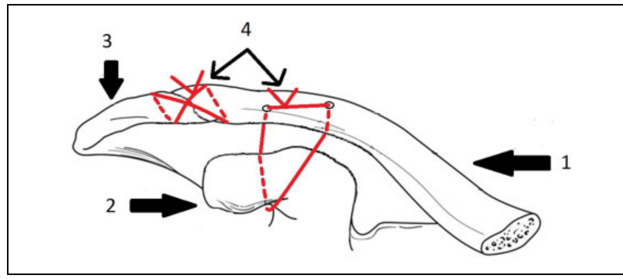

Figure 1. Schematic drawing of the single coracoclavicular loop technique (front view): (1) clavicle, (2) coracoid process, (3) acromion process, and (4) knots.

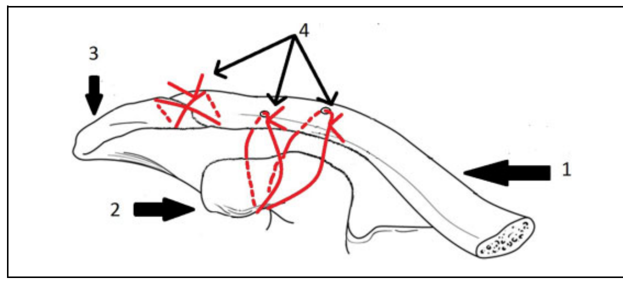

Figure 2. Schematic drawing of the two coracoclavicular loops technique (front view): (1) clavicle, (2) coracoid process, (3) acromion process, and (4) knots.

Surgical techniques

Native ligaments group. Native AC ligaments.

SCL group. Two 2.5 mm drill holes were made; the first was 4.5 cm from the distal end of the clavicle in its anterior half, and the second was 2.5 cm distal from the first drill hole in an oblique direction in the posterior half of the clavicle. The position of the drill holes imitated the normal attachment points of the CC ligaments.[6] Double no. 2 polyester suture (Atramat, International Farmaceutica, Mexico City, Mexico) was passed under the coracoid process through the drill holes in the clavicle. A knot was made on the superior surface of the clavicle. Next, a 2-mm diameter hole was drilled horizontally from ventral to dorsal in the acromion and the sternal end of the clavicle. To secure the AC joint, no. 2 polyester suture was passed through these holes, and an additional figure of eight-shaped configuration suture was made (Figure 1).

TCL group. The same drill holes were used for the SCL technique. This technique was performed similarly to previously described polydioxanone suture (PDS) reconstruction with additional AC cerclage[10]; we modified this technique using polyester suture instead of PDS. The CC ligaments were repaired using two no. 2 polyester cords. Each of the cords was guided around the base of the coracoid and then passed through one of the drill holes in the clavicle. A figure of eight-shaped AC suture was then made as described previously (Figure 2). All sutures were tied by the same experienced surgeon.

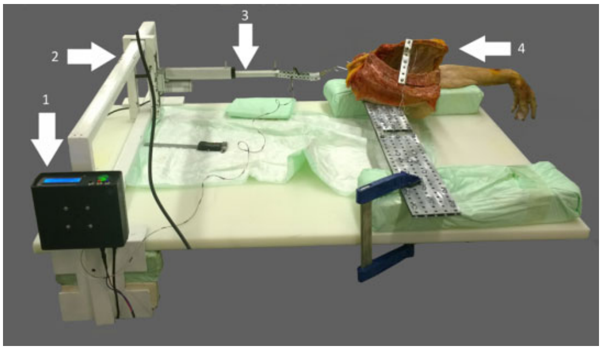

Figure 3. Biomechanical testing setup: (1) processor, (2) frame, (3) linear actuator, and (4) specimen.

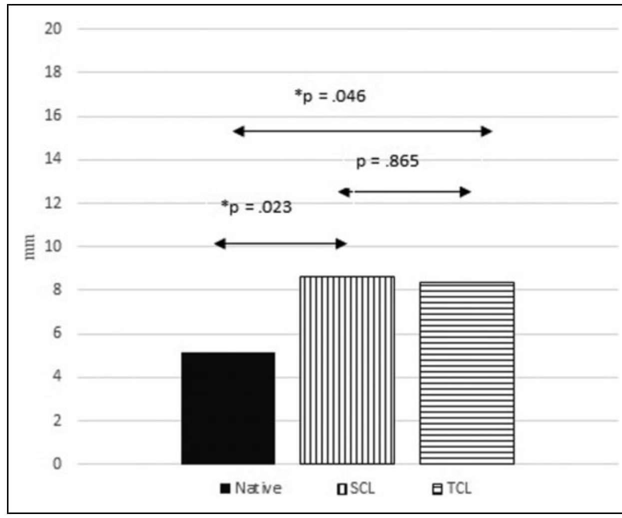

Figure 4. Translation in the superior direction. *A statistically significant difference. SCL: single coracoclavicular loop; TCL: two coracoclavicular loops.

Biomechanical testing

A custom-built testing device was used (Figure 3). This device had three main parts: (1) the frame with the linear actuator attached to it (the frame was rigidly connected to the autopsy table, and the linear actuator was connected to the acromial end of the clavicle by a 2-mm diameter cable); (2) the plate for fixing the scapula to the autopsy table; and (3) the processor for linear actuator control and data acquirement from the force sensor (at a rate of 9.6 kHz). The force sensor was set in between the linear actuator and the clavicle. Digital calipers (Vagner SDH, Slovenia) with an accuracy of 0.01 mm were used to measure the distance between two points on the linear actuator: one point on the moving part and the other on the stable part. The change in the distance between these points was considered as elongation of the structures between the clavicle and the scapula.

Each specimen underwent three tests: one in its native state and one for each of the two different reconstruction techniques. After native state test, AC and CC ligaments were dissected. All specimens were preconditioned from 0 to 70 N for one cycle in a superior direction to eliminate creep phenomenon. The testing protocol included static and cyclic loading. In the static part, there were two measurements: the first was taken at a load of 10 N and the second at 70 N. To achieve equal tension of the structures, each load was applied for 5 s before measurement. The difference between the first and the second measurements was defined as translation in the superior direction. Immediately after the static testing, cyclic loading was started for 1000 cycles from 20 to 70 N at a rate of 1 Hz. The third measurement was made after the last cycle, at the peak of 70 N and 5 s hold. The difference between the second and the third measurements was defined as the translation increment.

Statistical analysis

All variables are presented as mean ± standard deviation. A power analysis revealed that we needed a minimum of five tests per group. This was calculated using translation from the primary tests of the native ligaments group and the SCL group. The difference to detect was set at 0.24 ± 0.13 mm with an α value of 0.05 and a power of 0.80 ($1 - \beta$). To reduce the risk of types I and II failure, we set a sample size of eight. The Kolmogorov–Smirnov test was used to assess the normal distribution for translation and translation increment. Two-way analysis of variance (ANOVA) was used to assess differences between the three groups. SPSS v22.0 software was used for statistical analysis. MS excel software was used for additional calculations.

Results

Native ligaments group

Native ligaments had a translation of 5.13 ± 1.17 mm and a translation increment of 0.74 ± 0.23 mm (Figure 4).

SCL group

The SCL technique had a translation of 8.62 ± 3.04 mm and a translation increment of 0.42 ± 0.20 mm.

TCL group

The TCL failed during static loading in one specimen. The pattern of failure was a tear of one of the CC slings, followed by a tear of the other (it was not recorded which of the CC slings failed first) and complete cutoff of the figure of eight-shaped AC suture from the acromial end of the clavicle. The final sample size in the TCL group was therefore seven. TCL reconstruction had a translation of 8.33 ± 3.30 mm and a translation increment of 1.19 ± 1.07 mm.

Translation was significantly lower in the native ligaments group than in the SCL ($p = 0.023$) and the TCL ($p = 0.046$) groups. Translation increment was significantly higher than in the SCL group than the native

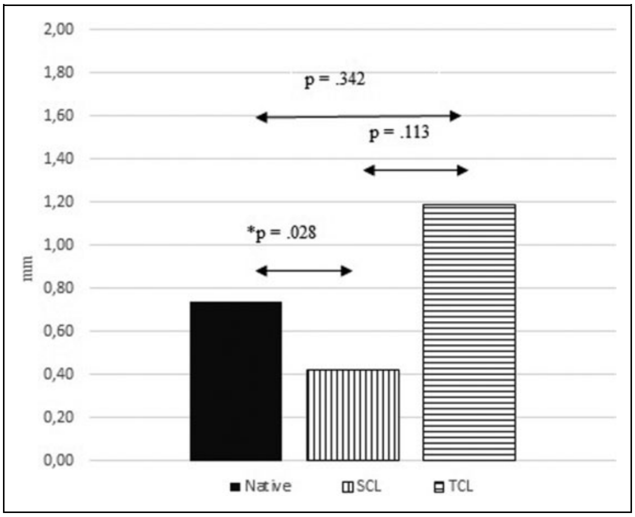

Figure 5. Translation increment. *A statistically significant difference. SCL: single coracoclavicular loop, TCL: two coracoclavicular loops.

Table 1. Review of the literature.

Study	Number of specimens	Displacement under 70 N (mm)
Mazzocca et al.[6]	14	6.14 ± 3.70
	14	5.63 ± 2.14
	14	4.38 ± 2.45
Beitzel et al.[13]	18	4.28 ± 1.81
Beitzel et al.[8]	12	3.8 ± 1.48
Beitzel et al.[12]	18	From 2 to 8
Present study	8	5.13 ± 1.17

ligaments group ($p = 0.028$), and there was no significant difference between the native ligaments group and the TCL group ($p = 0.342$; Figure 5). There was no significant difference between the SCL and the TCL group in terms of translation ($p = 0.865$) and translation increment ($p = 0.113$).

Discussion

To the best of our knowledge, this is the first report on biomechanical testing of the AC joint and its reconstruction techniques in the presence of the SC joint. The most important finding was that the presence of the SC joint did not have a measurable influence on testing data. Native AC ligaments had better static properties than both reconstruction techniques and worse dynamic biomechanical properties than the SCL technique. The SCL technique appeared to be more secure than the TCL technique.

In the literature, the average superior translation of native AC ligaments under 70 N loading varies from 2 to 8 mm, which is consistent with the 5.13 ± 1.17 mm found in the present study (Table 1). However, in both reconstruction groups, we observed a slight cutoff in the transverse tunnel of the figure of eight-shaped suture in the acromial end of the clavicle. This resulted in increased translation, and we did not have a method to measure its influence on the final data. We propose two possible reasons for this cutoff: (1) the acromial end of the clavicle mainly consists of trabecular bone, and no. 2 polyester suture might not have had enough surface contact with the bone. This size suture should be considered insufficient for use in the acromial end of the clavicle. (2) The SC joint provides motion in the sagittal axis; therefore, the acromial end has higher superior translation than the more proximal parts of the clavicle under loading. This might result in additional stresses on the AC site, which may help to explain the cutoff and the significantly higher translation that the reconstruction techniques had compared with native AC ligaments. It is also possible that the SC joint has an influence on the biomechanical behavior of native AC ligaments and AC reconstruction techniques, but our testing setup failed to detect this. It should be taken into account that specimens in this study had a mean age of 76 years and eight-shaped suture might be more beneficial in young persons with better quality of trabecular bone to maintain horizontal stability.

The purpose of the present study was to investigate the biomechanical performance of native AC ligaments and AC joint reconstruction techniques. The results are partially in agreement with our first hypothesis; native AC ligaments had better static biomechanical properties, but they showed inferior cyclic results compared with the SCL group, and there was no difference compared with TCL group. The second hypothesis is rejected, as there was no significant difference between SCL and TCL reconstruction in terms of translation and translation increment. Although SCL tended to have higher estimates than TCL in cyclic loading, this difference was not statistically significant. However, TCL had higher variance around the mean in translation and translation increment than SCL, and TCL reconstruction failed during static loading in one specimen. This might be because both CC loops were knotted separately, and it was impossible to pre-tension them equally; one of the loops was more tensioned than the other, and thus sustained higher stresses under loading. Because of these abovementioned circumstances, SCL appeared to be more secure than TCL.

We chose 70 N as the maximum magnitude loading in this study because of the assumption that the scapula (coracoid process and acromion) and clavicle are rigid bodies with ligamentous structures between them, and this 70 N loading simulates arm weight.[2,8,12,13,24] The prescribed cyclic testing protocol covers at least 10% physiological load situation in the early postoperative rehabilitation period.[2,24] In the literature, under the same cyclic loading protocol, synthetic materials are reported to have superior cyclic biomechanical properties compared with biological material.[22] Our results confirm these previous findings; the native AC ligaments had a significantly higher translation increment than the SCL reconstruction technique.

One of the limitations of the present study is that each specimen was used for three tests. This iterative loading might have influenced the ligaments of the SC joint and caused additional translation increment in the group that was tested last. The second limitation is that we did not measure bone mineral density; however, two experienced surgeons visually inspected all specimens for observable diseases and cortical bone quality.

Declaration of conflicting interests

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References

1. Beitzel K, Cote MP, Apostolakos J, et al. Current concepts in the treatment of acromioclavicular joint dislocations. *Arthroscopy* 2013; 29: 387–397.
2. Lee SJ, Keefer EP, McHugh MP, et al. Cyclical loading of coracoclavicular ligament reconstructions: a comparative biomechanical study. *Am J Sports Med* 2008; 36: 1990–1997.
3. Baldwin K, Namdari S, Andersen JR, et al. Luggage tag technique of anatomic fixation of displaced acromioclavicular joint separations. *Clin Orthop Relat Res* 2010; 468: 259–265.
4. Martetschläger F, Horan MP, Warth RJ, et al. Complications after anatomic fixation and reconstruction of the coracoclavicular ligaments. *Am J Sports Med* 2013; 41: 2896–2903.
5. LaPrade RF, Wickum DJ, Griffith CJ, et al. Kinematic evaluation of the modified Weaver–Dunn acromioclavicular joint reconstruction. *Am J Sports Med* 2008; 36: 2216–2221.
6. Mazzocca AD, Santangelo SA, Johnson ST, et al. A biomechanical evaluation of an anatomical coracoclavicular ligament reconstruction. *Am J Sports Med* 2006; 34: 236–246.
7. Rasmont Q, Delloye C, Bigare E, et al. Is conservative treatment still defensible in grade III acromioclavicular dislocation? Are there predictive factors of poor outcome. *Acta Orthop Belg* 2015; 81: 107–114.
8. Beitzel K, Sablan N, Chowaniec DM, et al. Sequential resection of the distal clavicle and its effects on horizontal acromioclavicular joint translation. *Am J Sports Med* 2012; 40: 681–685.
9. Lädermann A, Gueorguiev B, Stimec B, et al. Acromioclavicular joint reconstruction: a comparative biomechanical study of three techniques. *J Shoulder Elbow Surg* 2013; 22: 171–178.
10. Martetschläger F, Buchholz A, Sandmann G, et al. Acromioclavicular and coracoclavicular PDS augmentation for complete AC joint dislocation showed insufficient properties in a cadaver model. *Knee Surg Sports Traumatol Arthrosc* 2013; 21: 438–444.
11. Abrams GD, McGarry MH, Jain NS, et al. Biomechanical evaluation of a coracoclavicular and acromioclavicular ligament reconstruction technique utilizing a single continuous intramedullary free tendon graft. *J Shoulder Elbow Surg* 2013; 22: 979–985.
12. Beitzel K, Obopilwe E, Chowaniec DM, et al. Biomechanical comparison of arthroscopic repairs for acromioclavicular joint instability: suture button systems without biological augmentation. *Am J Sports Med* 2011; 39: 2218–2225.
13. Beitzel K, Obopilwe E, Chowaniec DM, et al. Biomechanical properties of repairs for dislocated AC joints using suture button systems with integrated tendon augmentation. *Knee Surg Sports Traumatol Arthrosc* 2012; 20: 1931–1938.
14. Millett PJ, Braun S, Gobezie R, et al. Acromioclavicular joint reconstruction with coracoacromial ligament transfer using the docking technique. *BMC Musculoskelet Disord* 2009; 14: 10–16.
15. Sandmann GH, Martetschläger F, Mey L, et al. Reconstruction of displaced acromioclavicular joint dislocations using a triple suture-cerclage: description of a safe and efficient surgical technique. *Patient Saf Surg* 2012; 25: 6–25.
16. Shu B, Johnston T, Lindsey DP, et al. Biomechanical evaluation of a novel reverse coracoacromial ligament reconstruction for acromioclavicular joint separation. *Am J Sports Med* 2012; 40: 440–446.
17. Staron JS, Esquivel AO, Pandhi NG, et al. Biomechanical evaluation of anatomical double-bundle coracoclavicular ligament reconstruction secured with knot fixation versus screw fixation. *Orthopedics* 2013; 36: 1047–1052.
18. Tashjian RZ, Southam JD, Clevenger T, et al. Biomechanical evaluation of graft fixation techniques for acromioclavicular joint reconstructions using coracoclavicular tendon grafts. *J Shoulder Elbow Surg* 2012; 21: 1573–1579.
19. Thomas K, Litsky A, Jones G, et al. Biomechanical comparison of coracoclavicular reconstructive techniques. *Am J Sports Med* 2011; 39: 804–810.
20. Walz L, Salzmann GM, Fabbro T, et al. The anatomic reconstruction of acromioclavicular joint dislocations using 2 TightRope devices: a biomechanical study. *Am J Sports Med* 2008; 36: 2398–2406.
21. Wei HF, Chen YF, Zeng BF, et al. Triple endobuttton technique for the treatment of acute complete acromioclavicular joint dislocations: preliminary results. *Int Orthop* 2011; 35: 555–559.
22. Wellmann M, Kempka JP, Schanz S, et al. Coracoclavicular ligament reconstruction: biomechanical comparison of tendon graft repairs to a synthetic double bundle augmentation. *Knee Surg Sports Traumatol Arthrosc* 2009; 17: 521–528.
23. Moore KL, Dalley AF, and Agur AMR. *Clinically oriented anatomy*, 6th ed. Baltimore: W. Wilkins, 2010, pp. 794–796.
24. Lee SJ, Nicholas SJ, Akizuki KH, et al. Reconstruction of the coracoclavicular ligaments with tendon grafts: a comparative biomechanical study. *Am J Sports Med* 2003; 31: 648–655.