# Acromioclavicular joint reconstruction: a comparative biomechanical study of three techniques

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**Background:** Acute acromioclavicular joint dislocations indicated for surgery can be treated with several stabilization techniques. This in vitro study evaluated the acromioclavicular joint stability after 3 types of validated repair techniques compared with the native situation.

**Materials and methods:** Nine pairs (right-left) of intact cadaveric shoulder specimens were assigned to 3 study groups with randomly distributed samples according to the coracoclavicular distance. The groups were instrumented with acromioclavicular and coracoclavicular cerclages (CE), a Twin Tail TightRope (TR), or a locking compression superior and anterior clavicle plate (CP). Native and instrumented specimens were tested quasi-static nondestructively (superior: 70 N; anteroposterior: ±35 N, 10 mm/min) and cyclically until failure (superior, valley load: 20 N; initial peak load: 70 N; increment: 0.02 N/cycle).

**Results:** The TR study group showed the highest (in N/mm) superoinferior (73.77 ± 14.04) and anteroposterior (29.58 ± 1.52) stiffness, followed by CE (superoinferior: 59.73 ± 10.33; anteroposterior: 24.31 ± 4.14) and CP (superoinferior: 24.08 ± 5.29). Instrumentation generally led to increased superoinferior and anteroposterior stiffness in each study group but to a significant superoinferior stiffness reduction for CP ($P = .029$). Significantly lower coracoclavicular displacement at valley load after 1 and 500 cycles was observed for TR ($P = .018$) and CE ($P = .041$) compared with CP. Cycles to failure were significantly higher in CE (7298 ± 1244 cycles, $P = .011$) and TR (4434 ± 727 cycles, $P = .031$) compared with CP (1683 ± 509 cycles).

**Conclusions:** The CE and TR techniques led to similar biomechanical performances. The CE repair might mimic the native acromioclavicular joint stiffness better than the other 2 setups, leading to more physiological stabilization.

**Level of evidence:** Basic science study, Biomechanical study.

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**Keywords:** Shoulder biomechanics; acromioclavicular joint stabilization; coracoclavicular ligaments; cerclage reconstruction; TightRope system; clavicular hook plate

The ideal system for acute stabilization of the coracoclavicular ligament complex should restore its anatomy. Several surgical techniques have been recommended for treatment of acute acromioclavicular dislocations. These

include temporary static stabilization of the acromioclavicular joint with pins or hook plates,[5,8,11,16,25] fixation using coracoclavicular screws,[1,26,28] stabilization with muscle or ligament transfer,[17,27,30] retention of the joint using a coracoclavicular loop cerclage,[7,9] and direct repair of the coracoclavicular ligaments.[12] For each of these techniques, specific benefits and disadvantages or complications have been reported. The use of temporary pins is no longer recommended because of the reported risk of metalwork migration into the adjacent intrathoracic cavity, with possible lesions of vital structures.[24]

The aim of this in vitro biomechanical study was to characterize acromioclavicular joint stability after acute repair with acromioclavicular and coracoclavicular cerclages (CE), the Twin Tail TightRope (TR) system (Arthrex GmbH, Munich, Germany), or the LCP superior anterior clavicle plate (CP; Synthes GmbH, Solothurn, Switzerland), and to compare the results with the native situation. Our hypothesis was that the CE technique would provide stiffness in superior direction, equivalent to that of the TR and the CP, but would allow higher anteroposterior stiffness.

## Materials and methods

The study included 9 pairs (right-left) of fresh frozen ($-20°$C) shoulder specimens from deceased donors (6 women, 3 men) with native clavicle and scapula. The mean age was 89 years (range, 76-100 years).

The coracoclavicular distance was assessed radiologically with a routine Zanca view[33] in the native state. Then the specimens were divided into 3 categories, including 6 specimens each, according to their native coracoclavicular distance (small: $3.83 \pm 0.52$ mm, middle: $5.25 \pm 0.69$ mm, large: $6.92 \pm 0.74$ mm). Subsequently they were randomly assigned into 3 study groups (n = 6) with 2 specimens from each category.

Specimens were thawed at room temperature for 24 hours before instrumentation and biomechanical testing and freed from soft tissue by dissection. They were confirmed to be free of previous fractures or injuries of the coracoclavicular or acromioclavicular ligaments. The acromioclavicular joint, coracoclavicular ligaments, and bony architecture of the scapula and lateral clavicle were left intact. The deltotrapezius fascias were removed. The inferior part of the scapula and the medial end of the clavicle were separately embedded in polymethylmethacrylate (SCS Beracryl D28, Swiss Composite, Jegenstorf, Switzerland, Fig. 1) and attached to a testing machine (MTS Bionix 858, MTS Systems Corp, Eden Prairie, MN, USA).

A load cell with maximum force of 4 kN was used. A custom-made clamping device with 2 rotational degrees of freedom was used to allow an exact positioning of the specimens in alignment with the superior or anteroposterior direction. The native specimens were tested with nondestructive quasi-static tensile tests, performed in a superior direction with a minimum and maximum tensile force of 10 N and 70 N, respectively, as well as anteroposteriorly with maximum tensile forces of $\pm 35$ N, using a crosshead speed of 10 mm/min for the ramps. Each quasi-static test was repeated 5 times to include settling effects. After the



**Figure 1** A native specimen is shown with the inferior part of the scapula and the medial end of the clavicle embedded in polymethylmethacrylate.

quasi-static tests, the study groups were instrumented with coracoclavicular and acromioclavicular cerclages (CE) in Ethibond No. 6 sutures (Ethicon, Hamburg, Germany) according to previously described techniques,[13] a Twin Tail TightRope system with a double coracoclavicular cerclage (TR) in FiberWire No. 5 (Arthex, Naples, FL, USA) or a LCP superior anterior clavicle plate (CP) completely cutting the coracoclavicular and acromioclavicular ligaments in all study groups (Fig. 2).

The CE system stabilizes the coracoclavicular and acromioclavicular complexes. The TR construct repairs the coracoclavicular complex and the CP system stabilizes the acromioclavicular joint. The latter does not provide anteroposterior stability and was tested to compare its vertical stability with the other 2 repair techniques. All specimens were instrumented by an experienced surgeon (A.L.). Routine Zanca views[33] were taken postoperatively to assure a correct anatomic reconstruction.

The instrumented specimens were initially tested with nondestructive quasi-static tensile tests in the same way as the native ones (Fig. 3). The CP instrumented specimens were loaded quasi-statically only in the superior direction because the plate is not designed to provide anteroposterior stability. After the quasi-static tests, destructive cyclic tensile tests with sinusoidal loading until failure, defined as an increase in coracoclavicular distance by 5 mm at the valley load, were performed at a rate of 2 Hz in the superior direction with continuously increasing peak load, starting at 70 N with a fixed force increment of 0.02 N/cycle, while keeping a constant valley load of 20 N. The principle of cyclic testing with monotonically increasing peak load levels has been found useful in previous studies.[32]

## Data acquisition and analysis

For all the tests, machine data (axial loads and axial displacements) were recorded from the system's transducers at a frequency of 128 Hz.

On the basis of the machine data from the quasi-static tests, stiffness of the native as well as instrumented specimens was evaluated superoinferiorly and anteroposteriorly (excluding the instrumented CP specimens for the latter) using MATLAB 2010a
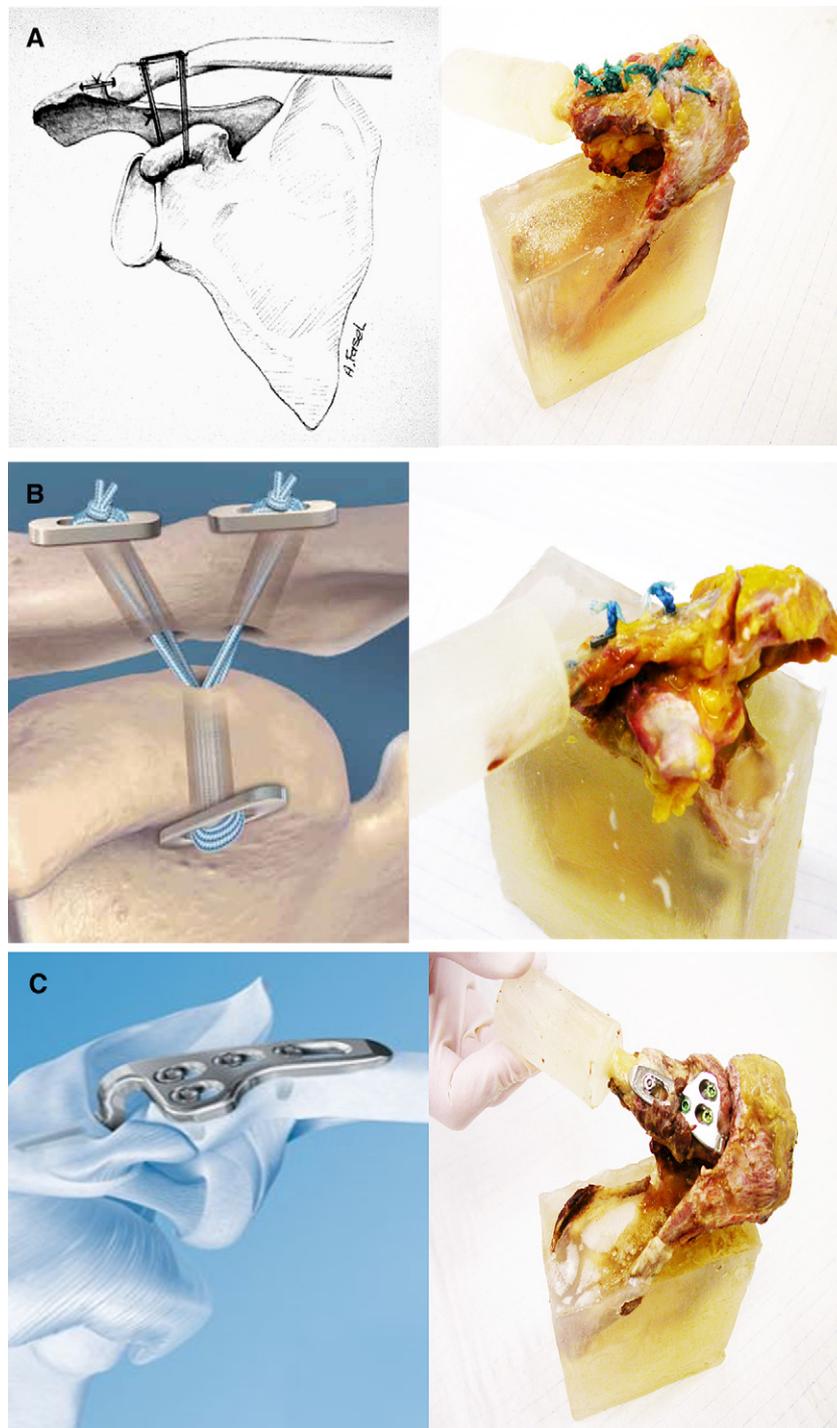
**Figure 2**   Diagrams and pictures of the 3 techniques for acromioclavicular joint reconstruction: (**A**) coracoclavicular and acromioclavicular cerclage, (**B**) Twin Tail TightRope system, and (**C**) LCP superior anterior clavicle plate.

software (MathWorks, Natick, MA, USA). In addition, the neutral zone of the anteroposterior load displacement hysteresis curve, representing its width at a level of 0 N, was evaluated in anteroposterior direction for all native specimens and the TR and CE reconstructions. In the native and instrumented condition, the range of motion in the superior direction, representing the initial superior displacement of the clavicle at a load of 20 N during the superior quasi-static test, was evaluated from the load

displacement curve as well. Further, the coracoclavicular displacement at valley load after 1 and 500 cycles, as well as cycles to failure, were calculated from the machine data of the destructive cyclic tests.

Statistical analysis was performed using SPSS 19.0 software (SPSS Inc, Chicago, IL, USA). Normal distribution within each study group was tested with Shapiro-Wilk test. For detection of significant differences between the study groups regarding
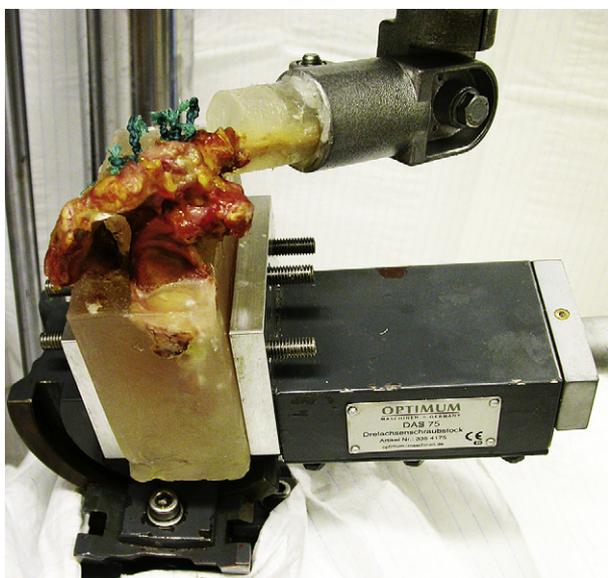
**Figure 3** Specimen instrumented with coracoclavicular and acromioclavicular cerclage and mounted on the test machine for quasi-static and cyclic testing in superoinferior direction.

stiffness, neutral zone, range of motion (in superior direction), and cycles to failure, analysis of variance (ANOVA) with Bonferroni post hoc multiple comparisons was used. A comparison of the coracoclavicular joint distance at valley load after 1 and 500 cycles between the study groups was performed using the general linear model repeated measures test with Bonferroni post hoc multiple comparisons. Correlation between the range of motion in superior direction and cycles to failure was detected by Pearson correlation test.

## Results

The 3 study groups, consisting of two randomly selected specimens from each category, were with normal distribution and showed no significant difference with regard to coracoclavicular distance or to age. In the native state, the neutral zone in anteroposterior direction was not significantly different between the 3 groups (Table I). After instrumentation, the TR repair in anteroposterior direction showed a slightly but not significantly higher mean 3.47 mm (range, 2.02-6.69 mm) compared with the CE reconstruction of 3.26 mm (range, 1.28-7.19 mm). For both techniques, the neutral zone decreased slightly, but not significantly, compared with the native situation.

Although the range of motion in the superior direction was similar in the native state for all study groups, it was significantly higher for CP (0.84 [range, 0.45-1.27] mm) compared with TR (0.39 [range, 0.13-0.95] mm, $P = .037$) but not with CE (0.45 [range, 0.23-0.88] mm) in the instrumented state (Fig. 4). The CE and TR reconstructions showed a similar range of motion after reconstruction. In the CE and CP study groups, no significant change was observed after instrumentation, whereas the TR

reconstruction showed a significantly decreased range of motion ($P = .028$, Fig. 4).

Anteroposterior stiffness was not significantly different among the study groups in the native and instrumented state, but the CE reconstruction showed lower mean stiffness (24.31 [range, 14.70-40.88] N/mm) compared with TR (29.58 [range, 25.65-35.38] N/mm, Table I). For both techniques, anteroposterior stiffness increased slightly, but not significantly, compared with the native situation. In the superoinferior direction, the native stiffness was similar for all study groups, but significantly higher stiffness was observed for the TR (73.77 [range, 37.36-126.42] N/mm; $P = .013$) but not the CE (59.74 [range, 33.69-97.93] N/mm) after reconstruction compared with CP (24.09 [range, 14.27-46.55] N/mm, Fig. 5). A significant reduction ($P = .029$) in superoinferior stiffness after instrumentation was only observed for the CP reconstruction (Fig. 5).

The superior coracoclavicular displacement at valley load during cyclic loading was significantly higher for the CP reconstruction (1.59 [range, 0.97-1.89] mm) compared with TR (0.82 [range, 0.51-1.33] mm, $P = .028$) but not CE (0.96 [range, 0.41-1.81] mm, $P = .080$) after 1 load cycle (Table II). Although the mean displacement after 500 cycles increased more than 50% for the CP (3.36 [range, 1.12-5.78] mm), the increase observed for TR (1.16 [range, 0.63-1.77] mm) and CE (1.40 [range, 0.54-2.74 mm]) after 500 load cycles was less than 50% compared with the baseline.

The repeated measures analysis of the coracoclavicular displacement after 1 and 500 cycles revealed significant differences between the TR and CP ($P = .018$) as well as between the CE and CP reconstruction ($P = .041$). The CE and TR reconstruction resisted significantly longer until failure, reaching the failure criterion of 5 mm (CE: 7298 [range, 3476-11090] cycles; TR: 4434 [range, 2928-7606] cycles), compared with CP (1683 [range, 548-3174] cycles; $P = .011$ and $P = .031$, respectively), whereas no significantly different cycles to failure were observed between the CE and TR reconstruction techniques ($P = .177$; Fig. 6).

Further, the CE and TR reconstruction had significantly higher peak load until reaching the failure criterion of 5 mm (CE: 228.79 [range, 146.36-292.90] N); TR: 172.96 [range, 128.90-222.20] N) compared with CP (106.79 [range 81.16-135.04] N; $P = .006$ and $P = .014$, respectively), although no significantly different peak loads to failure were detected between the CE and TR reconstruction techniques ($P = .118$).

There was no correlation between the range of motion in the superior direction and the cycles to failure for any of the repair techniques ($P > .196$ in all correlation tests). The main failure pattern for the CP reconstruction was a fracture of the clavicle initiated at the most medial screw hole, whereas the TR commonly (5 of 6 cases) showed a complete cutout of the coracoid button. For the CE reconstruction, the rope was relaxing during cyclic loading in 5 of 6 cases, and only in 1 of 6 cases was the coracoid process completely cutout. For the CE and TR reconstructions, the rope remained

**Table I** Means values (ranges) for the neutral zone, range of motion (superiorly) and stiffness (anteroposteriorly and superoinferiorly) calculated from the quasi-static tests in the intact and instrumented condition

| Variable | Neutral zone (mm) | ROM (SI) (mm) | Stiffness (AP) (N/mm) | Stiffness (SI) (N/mm) |
|---|---|---|---|---|
| Intact | | | | |
| TR | 5.45 (0.61-9.43) | 0.77 (0.60-0.89) | 27.96 (8.34-50.51) | 38.85 (31.48-44.70) |
| CE | 5.03 (1.65-9.84) | 0.76 (0.37-1.27) | 14.99 (6.30-29.87) | 45.51 (23.97-71.14) |
| CP | 6.01 (0.47-10.67) | 0.68 (0.39-1.49) | 21.90 (7.04-35.48) | 49.41 (28.60-65.59) |
| Instrumented | | | | |
| TR | 3.47 (2.02-6.69) | 0.39 (0.13-0.95) | 29.58 (25.65-35.38) | 73.77 (37.36-126.42) |
| CE | 3.26 (1.28-7.19) | 0.45 (0.23-0.88) | 24.31 (14.70-40.88) | 59.74 (33.69-97.93) |
| CP | - | 0.84 (0.45-1.27) | - | 24.09 (14.27-46.55) |

*AP,* anteroposterior; *CE,* coracoclavicular and acromioclavicular cerclages; *CP,* LCP superior anterior clavicle plate; *ROM,* range of motion; *SI,* superoinferior; *TR,* double coracoclavicular cerclage (Twin Tail TightRope).
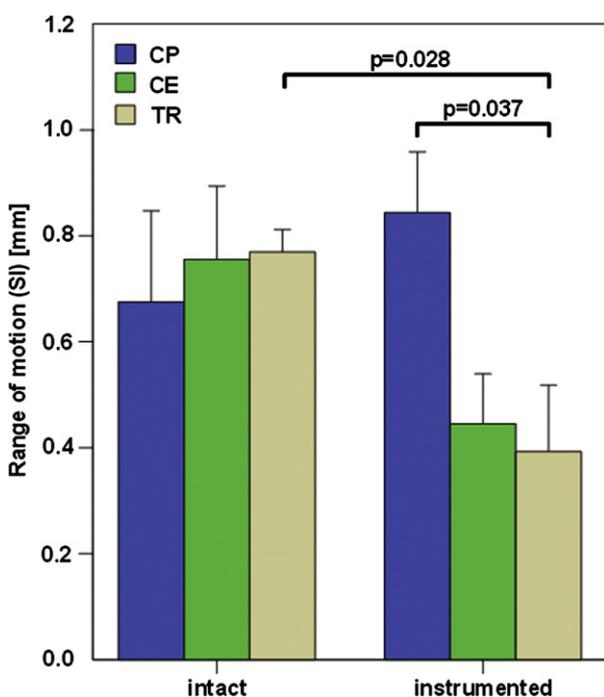


**Figure 4** Mean values with standard error of mean (*range bars*) for superoinferior (*SI*) range of motion calculated from the quasi-static tests, together with the significant differences among the study groups in the intact and instrumented condition. *CE,* Coracoclavicular and acromioclavicular cerclage; *CP,* LCP superior anterior clavicle plate; *TR,* Twin Tail TightRope system.



**Figure 5** Mean values with standard error of mean (*range bars*) for superoinferior (*SI*) stiffness calculated from the quasi-static tests, together with the significant differences among the study groups in intact and instrumented conditions. *CE,* Coracoclavicular and acromioclavicular cerclage; *CP,* LCP superior anterior clavicle plate; *TR,* Twin Tail TightRope system.

intact whereas the plate showed a slight bending pattern in some cases with the CP repair technique.

## Discussion

A basic principle in the treatment of acute acromioclavicular joint dislocations is to restore joint congruity and mechanical stability as accurately as possible to prov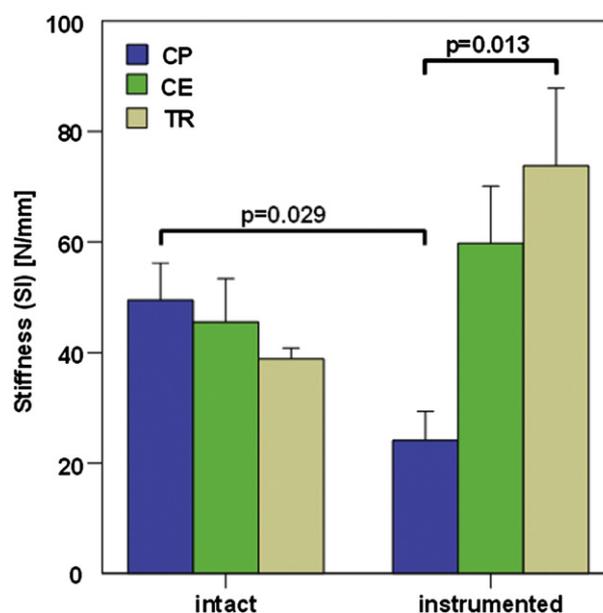ide physiologic conditions for the development of rigid scar tissue healing. Effectively, the ability to achieve a functional reconstruction of the joint anatomy with surgery might lessen the incidence of secondary late joint osteoarthritis and avoid persistent discomfort.[3] To reach this objective, numerous surgical procedures have been proposed, with no specific indications for their respective use. The aim of this cadaveric study was to analyze the effectiveness of restoring native conditions with 3 commonly used techniques of acromioclavicular stabilization through the measurement of anteroposterior and superior displacement.

Hoffmeyer[13] presented a surgical technique consisting of open acromioclavicular and coracoclavicular stabilization with nonabsorbable sutures. Advantages of this

**Table II**   Mean values (ranges) of the coracoclavicular displacement at valley load after 1 and 500 cycles and cycles to failure calculated from the destructive cyclic tests in instrumented condition

| Variable | Coracoclavicular displacement | | Cycles to failure (mm) |
|---|---|---|---|
| | Cycle 1 (mm) | Cycle 500 (mm) | |
| Instrumented | | | |
| TR | 0.82 (0.51-1.33) | 1.16 (0.63-1.77) | 2928-7606 |
| CE | 0.96 (0.41-1.81) | 1.40 (0.54-2.74) | 3476-11090 |
| CP | 1.59 (0.97-1.89) | 3.36 (1.12-5.78) | 548-3174 |

*CE,* coracoclavicular and acromioclavicular cerclages; *CP,* LCP superior anterior clavicle plate; *TR,* double coracoclavicular cerclage (Twin Tail TightRope).
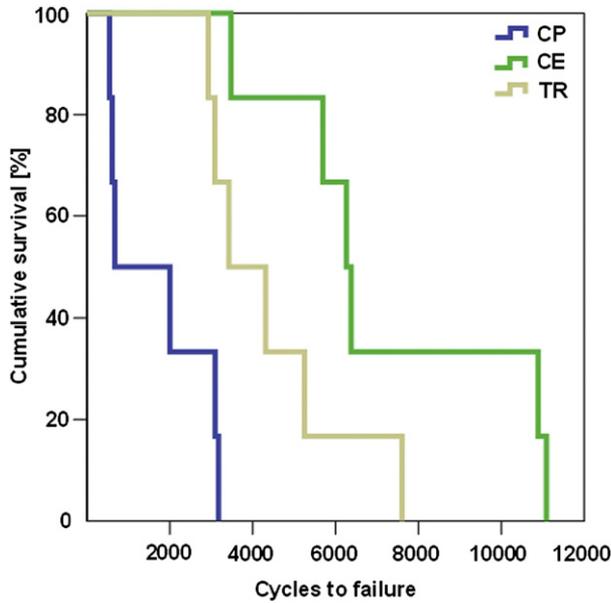


**Figure 6**   Cycles to failure defined as an increase in coracoclavicular distance by 5 mm at valley load. The coracoclavicular and acromioclavicular cerclage (*CE*) and Twin Tail TightRope (*TR*) reconstruction resisted significantly longer until failure compared with the LCP superior anterior clavicle plate (*CP*). No significantly different cycles to failure were observed between the CE and TR reconstruction techniques.

The techniques of CE and the TR system have another common advantage. Because they can be performed under arthroscopy, the multitude of associated conditions to acromioclavicular joint dislocation[22] can be adequately addressed at the same time, without the morbidity of an open approach.

A third validated method of acromioclavicular reconstruction is the CP system. Reasons for the popularity of this device include the relative ease of implant insertion and the possibility of early active mobilization despite the implant still being in place.[10] However, the plate does not provide anteroposterior stability and has to be removed 8 to 12 weeks after initial placement. Specific complications to this technique, such as cutting upward of the hook through the acromion, have been described.[10]

Our study showed the CE and TR groups performed the best after instrumentation. The CE system mimicked optimally the native motion and stiffness in both planes (superoinferiorly and anteroposteriorly) compared with the TR and CP systems, thus confirming our hypothesis. Moreover, the CE reconstruction resisted longer until failure, even if the difference was not statistically significant compared with the TR system. During cyclic loading, the rope of the CE was progressively relaxing, which may explain the loss of reduction that occurred in some patients after acromioclavicular joint stabilization with this technique.[15] If the surgical treatment of acromioclavicular joint dislocations is aimed at achieving of an anatomic, physiologic, and solid reconstruction,[4] the CE system might mimic the native acromioclavicular joint better than the other 2 repair techniques.

The motion in superior direction was significantly decreased with the TR reconstruction compared with the native situation. Furthermore, the TR system provided the highest superoinferior stiffness compared with the 2 other groups. Nonetheless, we must point out that the nonphysiologic, increased stiffness might be responsible for frequent cutout of the coracoid button. It could also over-constrain the acromioclavicular joint and cause long-term problems. However, the lower motion in the superior direction and the increased stiffness seemed to prevent in this study the progressive relaxation noticed with the CE system.

technique are exclusion of complications linked to implants and graft source morbidity and low costs. Moreover, the stabilization described by adding an acromioclavicular cerclage seems to allow a good control of anteroposterior stability, avoiding persistent malreduction with anterior subluxation that can lead to erosion of the coracoid and clavicle and persistent pain.[2,14,19]

Another potential augmentation method for acute acromioclavicular reconstruction is the TR system.[23,29] A study using an earlier version of the TR system reported good results after reconstruction of the coracoclavicular joint in 15 patients.[23] Walz et al,[29] using an anatomic reconstruction of the coracoclavicular ligaments with 2 TRs fixed with 2 individual tunnels in the coracoid, found a failure force equal to or superior then that of the native ligaments.[29]

Interestingly, the TR allowed also consequent anteroposterior stiffness. This is probably related to the twin-tail construction that fixes the S-shaped clavicle at 2 points. This system provided better initial stability but failed earlier than the CE reconstruction due to an increased stiffness compared with the native situation, and due to the fixation on the coracoid process. Effectively, the main pattern of failure of the TR was a complete cutout of the coracoid button, a complication that has been described in the literature.[31] This was expected, because the weak point of the system is the consequent hole placed in the coracoid. As for CE, the rope remained intact after TR reconstruction.

The CP does not offer biomechanical advantages compared with the 2 other systems. Its superoinferior stiffness was significantly reduced after instrumentation. The coracoclavicular displacement during cyclic loading was also higher for the CP reconstruction. The main failure pattern for the plate was a fracture of the clavicle initiated at the most medial screw hole. This has already been described in the literature.[18] Furthermore, the plate showed a slight bending pattern.

## Strengths and limitations

A strength of this study is that we had, compared with the present literature, a consequent sample size with 9 pairs of shoulders. This allowed us to divide the specimens into 3 categories according to their native coracoclavicular joint distance and to randomize the assigned shoulders. We thus obtained 3 comparable groups whose native specimens were with similar neutral zone as well as motion and stiffness in anteroposterior and superoinferior directions.

The present study has some limitations, however. First, this biomechanical study on cadaveric material cannot account for the progressive healing of the ligaments. We believed the significant differences noted between the 3 systems we tested in this study might be less important in vivo. The clinical results of this kind of acromioclavicular reconstructions have already been published and are all encouraging.[11,15,23]

Second, the osteoporotic bone of these aged specimens can favor the pattern of failure of the systems. However, the modes of failure that we registered have been reported in young patients as well.[20,21] Furthermore, the CP failed earlier than the bone. We thus do not believe that this was a significant factor in this study.

Third, measurement of anteroposterior and superior displacement was chosen in this study to describe acromioclavicular joint congruity. Even if this method has already been validated,[6] the acromioclavicular joint is subject to variable loads and dynamic forces in the clinical setting, leading to multiplanar displacements and rotations. Thus, the displacement pattern may not have ideally been replicated in this in vitro study. Multiplanar movements could be evaluated in future studies.

## Conclusion

The CE and the TR repair techniques had similar biomechanical performance. The CE reconstruction might mimic the native acromioclavicular joint motion and stiffness better than the other 2 setups, leading to more physiologic reconstruction. The TR system provided the highest stability but failed earlier than the CE reconstruction due to its increased stiffness compared with the native situation. The CP system does not offer biomechanical advantage compared with the 2 other techniques for treatment of acromioclavicular joint dislocation.

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