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The Anatomic Reconstruction of Acromioclavicular Joint Dislocations Using 2 TightRope Devices

A Biomechanical Study

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Background: For the reconstruction of acromioclavicular (AC) joint separation, several operative procedures have been described; however, the anatomic reconstruction of both coracoclavicular ligaments has rarely been reported.

Purpose: The aim of this biomechanical study is to describe a new procedure for anatomic reconstruction of the AC joint.

Study Design: Controlled laboratory study.

Materials and Methods: Forty fresh-frozen cadaveric shoulders were tested. Cyclic loading and a load-to-failure protocol was performed in vertical (native, n = 10; reconstructed, n = 10) and anterior directions (native, n = 10; reconstructed, n = 10) on 20 AC joints and repeated after anatomic reconstruction. Reconstruction of conoid and trapezoid ligaments was achieved by 2 TightRope devices (Arthrex, Naples, Florida). Dynamic, cyclic, and static loading until failure in vertical (n = 5) and horizontal (n = 5) directions were tested in native as well as reconstructed joints in a standardized setting.

Results: The native coracoclavicular ligaments in static load for vertical force measured 598 N (range, 409-687), elongation 10 mm (range, 6-14), and stiffness 99 N/mm (range, 67-130); static load for anterior force was 338 N (range, 186-561), elongation 4 mm (range, 3-7), and stiffness 140 N/mm (range, 70-210). The mean maximum static load until failure in reconstruction for vertical force was 982 N (range, 584-1330) ($P = .001$), elongation 4 mm (range, 3-6) ($P < .001$), and stiffness 80 N/mm (range, 66.6-105) ($P = .091$); and for anterior static force 627 N (range, 364-973) ($P < .001$), elongation 6.5 mm (range, 4-10) ($P = .023$), and stiffness 78 N/mm (range, 46-120) ($P = .009$). During dynamic testing of the native coracoclavicular ligaments, the mean amount of repetitions (100 repetitions per stage, stage 0-100 N, 100-200 N, 200-300 N, etc, and a frequency of 1.5 Hz) in native vertical direction was 593 repetitions (range, 426-683) and an average of 552 N (range, 452-683) load until failure. In vertical reconstructed testing, there were 742 repetitions (range, 488-893) ($P = .222$) with a load until failure of 768 N (range, 486-900) ($P = .095$). In the anterior direction load, the native ligament failed after an average of 365 repetitions (range, 330-475) and an average load of 360 N (range, 307-411), while reconstructed joints ended in 549 repetitions (range, 498-566) ($P = .008$) with a load until failure of 547 N (range, 490-585) ($P = .008$). In all testing procedures, a preload of 5 N was performed.

Conclusion: The anatomic reconstruction of the AC joint using TightRope is a stable and functional anatomic reconstruction procedure. The reconstruction technique led to favorable in vitro results with equal or even higher forces than native ligaments.

Clinical Relevance: Through anatomic repair, stable function of the AC joint can be achieved in an anatomic manner.

Keywords: shoulder; acromioclavicular joint; biomechanics; anatomic reconstruction; TightRope

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Acromioclavicular (AC) joint dislocations are among the most common injuries of the upper extremity.[13] They often occur in athletic, young patients after blunt force to the shoulder. Rockwood dislocations types IV through VI are recommended to be approached operatively, due to the involvement of the coracoclavicular ligaments that leads to a

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relative clavicular dislocation. Treatment of type III dislocations remains controversial.[21] Several static and dynamic techniques to reconstruct a separated AC joint have been described. Acromioclavicular and coracoclavicular fixation techniques, ligament substitution, clavicle excision, or dynamic stabilization (eg, with a coracoid transfer) describe the different procedures.[7.27.29] Simple pinning or a cerclage can lead to degenerative AC joint disease or implant migration and often results in malreduction.[1,12,14,18,20,26] A Bosworth screw or hook plate is often associated with breakage, bony erosion, and infection, while requiring implant removal during a second procedure.[22] Despite numerous procedures, no standard has been defined, and complications still occur frequently. Therefore, novel reconstruction techniques have been designed to reconstruct the AC joint in an anatomic manner. Stable and functional reconstruction is attempted through reconstruction of the conoid and trapezoid ligaments.[2,5,6,8,15] Nevertheless, biomechanical studies have shown that described anatomic procedures do not restore the strength and stiffness of the native AC joint complex.[5,11,19] Chernchujit et al[4] previously described an arthroscopic technique to anatomically reconstruct a separated AC joint by replacing coracoclavicular ligaments with sutures. Clinical results of the study were promising, although over 20% of patients developed malreduction after the procedure. In this biomechanical study, we present an anatomic reconstruction of AC joint dislocations based on the previously described principle. By using TightRope (Arthrex, Naples, Florida), we hypothesize the ability to regain anatomy and ensure a stable and safe fixation of the AC joint. No autograft or allograft or hardware removal is necessary. The technique can be performed via an arthroscopically assisted procedure and is currently in clinical use.

MATERIAL AND METHODS

Specimen Preparation

Shoulders (N = 40, 22 male, 18 female) were obtained from fresh-frozen human cadavers. All specimens had an average age of 49 years (range, 23-65 years) and were free from systemic disease or previous injury to the AC joint. All donors had died from causes unrelated to the musculoskeletal system. Shoulder specimens were stored at –20°C and allowed to thaw at room temperature for 24 hours before use. The skin, subcutaneous tissues, and muscles were removed, and the AC ligaments and capsule were divided, leaving the coracoclavicular ligament complex intact (Figure 1). The glenohumeral joint was disarticulated. Load procedures were performed along a vertical (cranial, superior) and anterior (horizontal) oriented axis. The 2 major restraints given by the coracoclavicular ligaments to either vertical or anterior translation could be simulated by this setup. For vertical testing, immediately after dissection the body of the scapula was embedded in an open-top steel box, allowing the upper part of the spine, glenoid, and coracoid to protrude (vertical load) (Figures 2 and 3). The specimen was then fixed by synthetic epoxy resin (Ureol FC 52 Polyol, Vantico, Wehr, Germany).

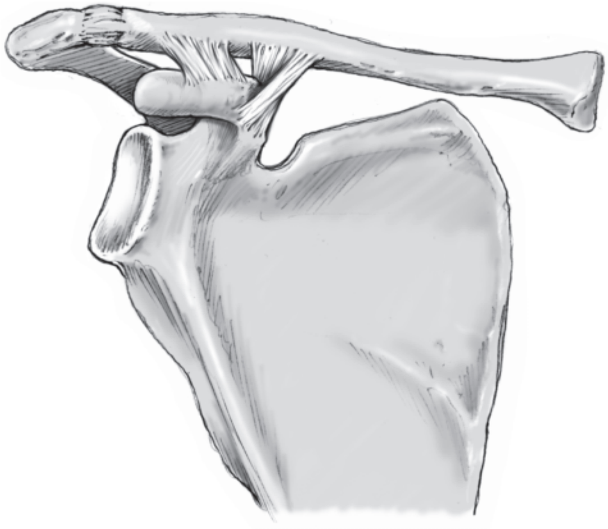

Figure 1. The normal position of the coracoclavicular ligaments.

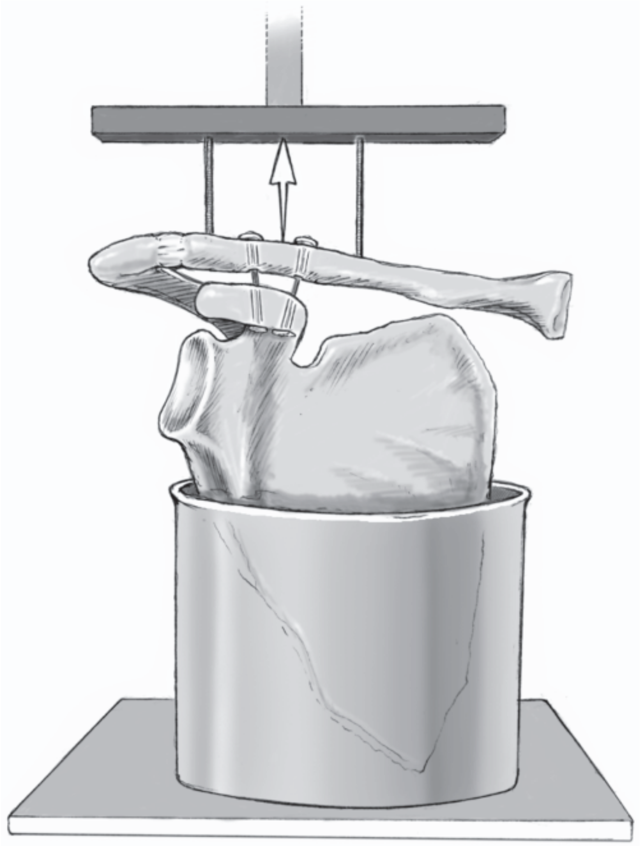

Figure 2. Technical testing setup for vertical forces, with potted scapula and fixated calvicle.

For anterior oriented load procedures, the specimen was positioned flat on the testing device. The body of the scapula was fixed using a steel bar, screws, and 2 metal

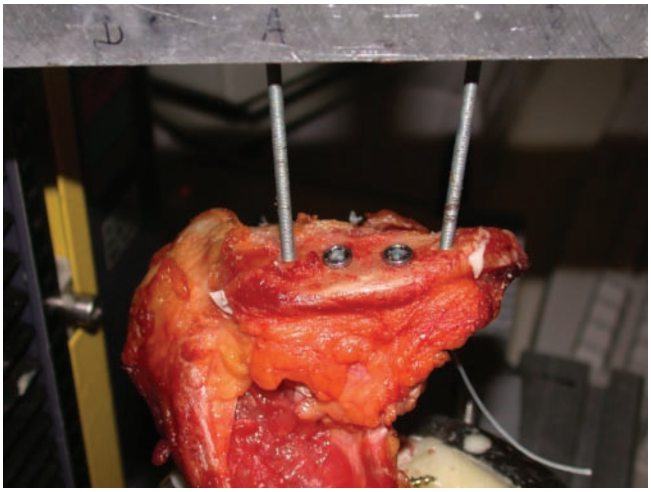

Figure 3. Testing setup with potted scapula, metal clavicle fixation, and 2 TightRope devices.

clamps to fix the glenoidal and superior scapula part (Figure 4). By either setup, standard force could be applied along strict directions. Care was taken to embed each specimen in the correct anatomic position, with the long axis of the clavicle and the scapular plane oriented at approximately 90° to one another. During preparation and testing, specimens were kept appropriately hydrated with physiologic saline at room temperature. For native and reconstructed testing, the fixed specimen was connected to a metal fixation of the electromechanical testing device (Zwicki, Zwick-Roell, Ulm, Germany). The 2 drill holes for the metal fixation were drilled free through the clavicle (either vertical or anterior oriented). This setup provided standard rigid fixation of the clavicle and scapula to the testing machine and allowed the coracoclavicular ligaments and augmentations to be oriented parallel and in line with the pulling force of the testing device. Initial use of trial constructs ensured that no slippage occurred between the clavicle-fixture or scapula-fixture interfaces. The native shoulders were tested after this fixation procedure. For reconstructed testing, the coracoclavicular ligaments were removed and reconstructed as described later.

Tunnel Placement and Surgical Reconstruction

In a cadaver study, Rios et al[24] found that the coracoclavicular ligaments arise at a constant region, which is proportional to the size of the clavicle. The conoid tuberosity is positioned in the posterior third of the clavicle, whereas the trapezoid tuberosity is positioned in the middle third of the clavicle in the sagittal plane. According to this study, we measured the total clavicle length in addition to the standard anatomic landmarks (coracoid, clavicle, acromion, AC joint, posterior and anterolateral portals). Two independent points, representing 17% (trapezoid insertion, approximately 2.5 cm) and 30% (conoid insertion, approximately 4.5 cm) of the total clavicle length were measured medial from the lateral clavicular edge and marked for optimal clavicular tunnel placement on top of the clavicle with an awl. An aiming device for drilling (Constant Guide for AC TightRope, Arthrex) was used and its tip positioned at the undersurface of the coracoid process close to its base. The device's manual adjustable counterpart comes in place on top of the clavicular body with an angle variable from 70° to 90°. For the conoidal tunnel placement, we acted as described by Harris et al[10]; the conoid coracoid width is 10.6 mm (medio-lateral) with an insertion thickness of 4.4 mm, and the trapezoid coracoid width is 14 mm (anterior-posterior) with an insertion thickness of 4.8 mm (medio-lateral). The conoid ligament originates, proceeds, and inserts posteromedial to the trapezoid. According to these data, optimal tunnel placement of the conoid coracoidal tunnel should be at the posterior aspect of the coracoidal base, 5 mm lateral to the medial border. The trapezoid coracoidal tunnel should be 10 mm anterior to the conoidal tunnel and 5 mm medial to the lateral border of the coracoid, leaving a bony bridge between tunnels of at least 10 mm. After the optimal position of the guide was secured, two 3.5-mm–wide bony tunnels were drilled through the clavicle and the coracoid process. Two meniscal needles were pushed through the holes. On top of the clavicle the needles were aimed each by

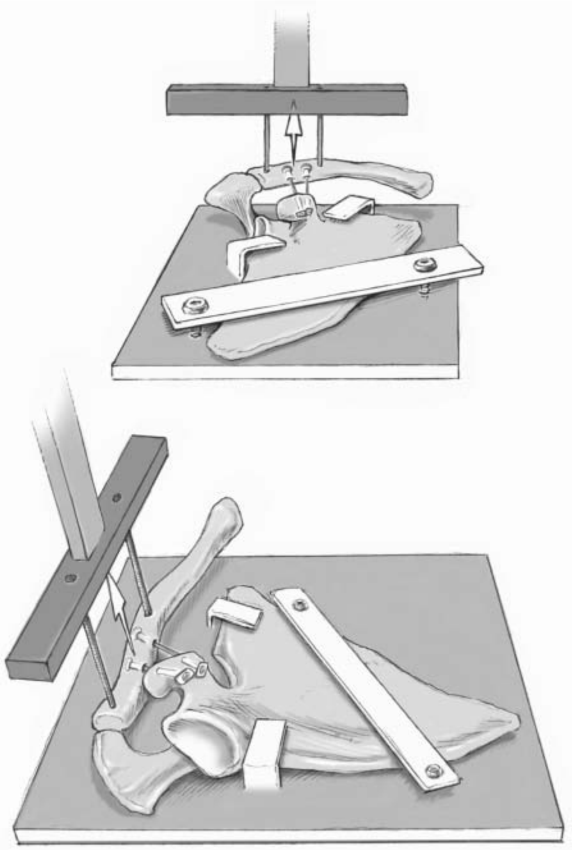

Figure 4. Schematic testing setup for anterior forces. The scapula is placed flat, fixed with 1 steel bar and 2 metal clamps (glenoid, superior scapula).

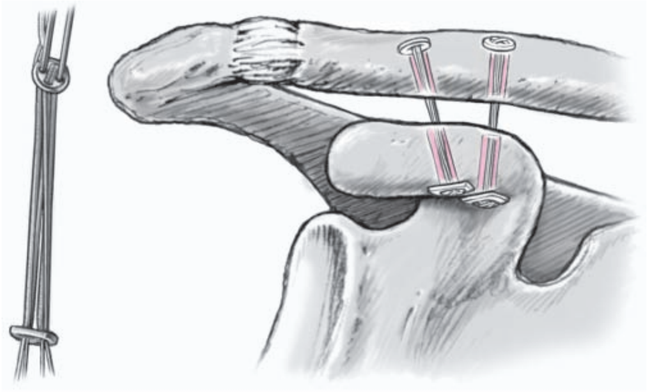

Figure 5. The anatomic coracoclavicular reconstruction using 2 TightRope devices.

one TightRope. The TightRope device consists of 1 round clavicular titanium button and 1 long coracoidal titanium button connected by one No. 5 nonabsorbable suture (FiberWire, Arthrex) organized as a pulley. The device was then pulled through the channels. After the caudal button could be visualized at the coracoidal undersurface, the buttons were flipped and positioned transverse to the long axis of the coracoid and tightened with aid of the pulley (Figure 5). The clavicular buttons were placed on top of the cortical clavicular bone, and the device was secured by a minimum of 5 alternating knots.

Mechanical Testing

Two different protocols were run for each of the 2 directions. For superior and anterior translation, unidirectional static and dynamic load was applied until failure. The ultimate tensile strength, stiffness, and elongation at failure were digitally collected. For static measurement, the applied force was continuously raised until failure and the controller was programmed to produce a displacement rate of 25 mm/min and an initial preload of 5 N as described by Harris et al.[9] The native ligament complexes were kept moist with saline solution and tested at room temperature. Static loading until load-to-failure protocol was performed in vertical (n = 10) and anterior (n = 10) directions. The same protocol was run for the same reconstructed shoulders (vertical n = 10, anterior n = 10).

For dynamic measurement, load was applied in a cyclic manner at 1.5 Hz between 0 and 100 N, 100 and 200 N, 200 and 300 N, etc. For each force, 100 repetitions were performed. Every measurement started at dynamic loads between 0 and 100 N at 1.5 Hz and was raised by 100 N thereafter until failure and an initial preload of 5 N was performed (native: vertical n = 5 and anterior n = 5; reconstructed: vertical n = 5 and anterior n = 5). Data were recorded with dedicated software (Textexpert 8.1, Zwick-Roell) and compiled using a desktop computer and Excel software (Microsoft Corp, Redmond, Washington). Stiffness was calculated from the slope of the linear portion of the load-displacement curve. Modes of failure were analyzed by the computer sensor and direct observation. Load-displacement values were analyzed for each test to determine structural properties, namely, peak load (in N), stiffness (in N/mm), and elongation at peak load (in mm).

Statistical Analysis

To compare the difference in location between native and reconstructed AC joints, a robust nonparametric estimator with its confidence interval was calculated using Wilcoxon score statistics. The null hypothesis of "no shift in location between native and reconstructed AC joints" was compared using the Wilcoxon rank test. Calculations were performed using the statistical software R (R Foundation for Statistical Computing, Vienna, Austria).[23]

RESULTS

Static Protocol

Maximum load-to-failure values for each group, load direction, type of applied force, and reason for failure are presented in Table 1. For native vertical static pull-out of coracoclavicular ligaments (n = 10), mean average load until failure was 598 N (range, 409-687), elongation 10 mm (range, 6-14), and stiffness 99 N/mm (range, 67-130). Midsubstance tear accounted for 70% of failures, while 30% were related to coracoidal ligament insertion pull-out. Mean vertical static load until failure for vertical reconstruction (n = 10) was 982 N (range, 584-1330) (P = .001), elongation 4 mm (range, 3-6) (P < .001), and stiffness 80 N/mm (range, 67-105) (P = .091). Suture rupture accounted for 60% of failures, while the remaining failures were related to coracoidal (n = 1 conoidal) or clavicular (n = 2; 1 medial and 1 lateral) pull-through and a coracoidal fracture (n = 1 base fracture).

Mean average static load until failure for anterior pull-out of native coracoclavicular (n = 10) ligaments was 338 N (range, 186-561). Measured elongation in native ligaments was 4 mm (range, 3-7) and stiffness 140 N/mm (range, 70-210). All failures were related to midsubstance tears of the coracoclavicular ligaments. Mean anterior static load (n = 10) until failure for reconstruction was 627 N (range, 364-973) *(P < .001),* elongation 6.5 mm (range, 4-10) (P = .023), and stiffness 78 N/mm (46-120) (P = .009). Seven failures were related to suture rupture and 3 to plate pull-through at the base of the coracoid (1 conoidal, 2 trapezoidal) (Table 1).

Dynamic Protocol

In native vertical dynamic testing, there was an average of 593 repetitions (range, 426-683) and an average strength of 552-N (range, 452-683) load until failure. All failures were related to ligament rupture. In vertical reconstructed testing, there were 742 repetitions (range, 488-893) (P = .222*)* with a load until failure of 768 N (range, 486-900) (P = .095*).* Four failures were caused by bone failure (n = 4 coracoid base fractures) and 1 coracoid pull-through (drill hole trapezoideum).

In the anterior direction, native ligament failed after an average of 365 repetitions (range, 330-475) and an average load of 360 N (range, 307-411). All failures were related to ligament rupture. Reconstructed testing ended

TABLE 1
Results From Static Testing: Median (Range) of the Measurements for Native and Reconstructed Is Reported Together With the Estimated Difference and Its 95% Confidence Intervals (CI)[a]

	N	Strength (N)	Elongation to Failure (mm)	Stiffness (N/mm)	Reasons for Failure
Vertical					
Native	10	598 (409-687)	10 (6-14)	99 (67-130)	10 ligament rupture
Reconstructed	10	982 (584-1330)	4 (3-6)	80 (67-105)	6 suture rupture 2 clavicular pull-through 1 coracoid pull-through 1 coracoid fracture
Difference estimate (95% CI)		–290 (–457; –145)	5.6 (3; 8)	13 (–2; 33)	
P value		.001	< .001	.091	
Anterior					
Native	10	338 (186-561)	4 (3-7)	140 (70-210)	10 ligament rupture
Reconstructed	10	627 (364-973)	6.5 (4-10)	78 (46-120)	7 suture rupture 3 coracoid pull-through
Difference estimate (95% CI)		–299 (–421; –153)	–2 (–4; 0)	60 (13; 110)	
P value		< .001	.023	.009	

[a] Both *P* values indicate that the null hypothesis of no difference is rejected at the .05 level of significance.

TABLE 2
Results From Dynamic Testing: Median (Range) of the Measurements for Native and Reconstructed Is Reported Together With the Estimated Difference and Its 95% Confidence Intervals (CI)[a]

	N	Strength (N) at Failure	Repetitions to Failure	Reasons for Failure
Vertical				
Native	5	552 (452-683)	593 (426-683)	5 ligament rupture
Reconstructed	5	768 (486-900)	742 (488-893)	1 coracoid pull-through 4 coracoid fracture
Difference estimate (95% CI)		–209 (–349; 66)	–140 (–322; 105)	
P value		.095	.222	
Anterior				
Native	5	360 (307-411)	365 (330-475)	5 ligament rupture
Reconstructed	5	547 (490-585)	549 (498-566)	1 coracoid pull-through 1 clavicle fracture 3 coracoid fracture
Difference estimate (95% CI)		–183 (–250; -130)	–168 (–226; –68)	
P value		.008	.008	

[a] Both *P* values indicate that the null hypothesis of no difference is rejected at the .05 level of significance.

in 549 repetitions (range, 498-566) (*P* = .008) with a load to failure of 547 N (range, 490-585) (*P* = .008). Failures were related to 3 full coracoid fractures at the base, 1 clavicle fracture (lateral drill hole), and 1 coracoid pull-through (drill hole conoideum) (Table 2).

Difference in Gender

In all testing procedures we could not find a statistical difference between male and female specimens, as shown in Tables 3 and 4.

TABLE 3
Static Testing: Median (Range) of the Measurements for Female and Male Are Reported Together With the Estimated Difference and Its 95% Confidence Interval (CI)[a]

	N	Strength (N)	Elongation to Failure (mm)	Stiffness (N/mm)	Reasons for Failure
Vertical					
Female	10	703 (450-1057)	6 (3-12)	98 (67-130)	5 ligament rupture 3 suture rupture 1 clavicular pull-through 1 coracoid pull-through
Male	10	655 (409-1330)	7 (3-14)	73 (67-120)	5 ligament rupture 3 suture rupture 1 clavicular pull-through 1 coracoid fracture
Difference estimate (95% CI)		41 (–173; 225)	–1 (–5; 2)	13 (–7; 33)	
P value		.684	.542	.192	
Anterior					
Female	8	566 (186-638)	4.5 (3-9)	100 (46-180)	4 ligament rupture 3 suture rupture 1 coracoid pull-through
Male	12	500 (227-973)	6 (3-10)	100 (50-210)	6 ligament rupture 4 suture rupture 2 coracoid pull through
Difference estimate (95% CI)		–36 (–268; 192)	–1 (–3; 1)	–4 (–54; 50)	
P value		.792	.346	.697	

[a] Both *P* values indicate that the null hypothesis of no difference is rejected at the .05 level of significance.

TABLE 4
Dynamic Testing: Median (Range) of the Measurements for Female and Male Are Reported Together With the Estimated Difference and Its 95% Confidence Interval (CI)[a]

	N	Strength (N) at Failure	Repetitions to Failure	Reasons for Failure
Vertical				
Female	4	668 (452-900)	636 (489-893)	2 ligament rupture 1 coracoid pull-through 1 coracoid fracture
Male	6	618 (486-801)	638 (426-748)	3 ligament rupture 3 coracoid fracture
Difference estimate (95% CI)		46 (–231; 348)	42 (–94; 300)	
P value		1.000	.762	
Anterior				
Female	5	360 (307-411)	475 (330-566)	3 ligament rupture 1 coracoid pull-through 1 coracoid fracture
Male	5	490 (334-557)	498 (365-549)	2 ligament rupture 1 clavicle fracture 2 coracoid fracture
Difference estimate (95% CI)		–13 (–197; 182)	–23 (–213;123)	
P value		0.841	1.000	

[a] Both *P* values indicate that the null hypothesis of no difference is rejected at the .05 level of significance.

DISCUSSION

In athletic patients, injuries of the AC joint are causing a lot of problems.[12,13] The best operative technique for the treatment is a controversial issue; more than 80 techniques have been described until now to address this problem.

The surgical technique typically includes either the repair of the coracoclavicular ligaments and augmentation with absorbable or nonabsorbable sutures, screws, pins, hook plates, or other types of internal fixation.[14,16-18,20,25] One of them is the coracoacromial ligament transfer with either suture, tape, or other hardware.[24] The premise of this technique is that the coracoclavicular ligaments will heal and biomechanically withstand forces equivalent to tensile strength. However, biomechanical properties of the transfer and strength have come into question. Clinical data are reporting subluxation or even dislocation occurring in the chronic setting as high as 30%.[28] This made many surgeons think about other possibilities to restore the coracoclavicular ligaments such as slings, autogenous tendons, allograft tissues, or anchor systems. All these possibilities are described as a modification of the Weaver-Dunn procedure.[7,26-29] It seems to allow complete healing with improved stability and good clinical results in all studies. Bearing this in mind, anatomic reconstruction, restoring the AC structure as well as the coracoclavicular ligaments, would be optimal to provide physiologic stability.[5,8,9,11,15] According to Breslow et al,[3] the AC capsule and ligaments mainly contribute to horizontal stability, whereas the coracoclavicular ligaments limit vertical translation. They are considered the prime suspensor ligaments of the AC joint.[9] The coracoclavicular complex consists of the conoid and the trapezoid ligament, which have been reported to be approximately 10 mm each in total length and span a space of 10 to 15 mm between the clavicle and the coracoid.[22] Furthermore, the AC capsule and ligaments present the major restraint against superior and posterior translation as reported by Breslow et al.[3] Each ligament has a different role in providing AC joint stability in response to various loading conditions.[5,10] Therefore, it has lately been recommended, from a biomechanical point of view, to treat acute AC separations of Rockwood types IV through VI (some type III) by addressing the coracoclavicular ligaments separately in an anatomic manner during surgery.[9,11,24] The importance of anatomic graft positioning in ligament reconstruction has been known since 1938[25] and has been clearly demonstrated in anterior cruciate ligament reconstruction.[26] Jerosch et al[12] evaluated 8 different AC reconstruction techniques in 10 cadaveric shoulders and found the best results in the bone anchor system for distal clavicle fixation in the base of the coracoid. They recommended this technique for anatomic AC reconstruction. Most other techniques, especially the coracoid sling procedure, led to a significant anterior displacement of the clavicle in relation to the scapula.[12] Jari et al[11] evaluated the biomechanical function between a suture-type coracoclavicular sling procedure with a coracoacromial ligament transfer construct and a Rockwood screw. This study was unique in the assessment of not only superior translation but also anterior and posterior translation after surgical procedures.[11] Breslow et al[3] explored the benefits of using suture versus suture anchors for AC joint separation. Their study showed similar stability between the 2 methods of coracoclavicular fixation. Nevertheless, suture anchors have some further advantages. For example, access to the top of the base of the coracoid is easier.[3] Because of this, Chernchujit et al[4] developed an arthroscopic method with drill guides to place 2 anchors in addition to the native coracoclavicular ligament course. FiberWire No. 5 was chosen for their study. Biomechanical testing was performed in 6 cadaveric shoulders to compare tensile strength. The ultimate tensile strength of this anchor system resulted in a value of 767 ± 109 N, which was more than the tensile strength of the native coracoclavicular ligaments (578 ± 111 N).[4] However, each of the presented methods have disadvantages: They are either not completely anatomic, require graft material, or are dependent on open surgery.[4,13-15] Procedures for coracoclavicular replacement using autograft or allograft material are promising, but described techniques are not completely anatomic.[15,18] Also the biologic revascularization of the graft is assumed but has not been explored in the AC joint. Furthermore, the use of an allograft is not a widespread routine during elective surgery in many countries and localities throughout the world (eg, Japan and parts of Europe).

Taking into account all testing procedures, it was possible to develop a reconstruction technique that led to a stable joint that resists forces in different angles. One of the questions that might arise is whether the TightRope system will supply long-term stability. Unlike allografts or autografts, which use tissue to reconstruct the ligaments, techniques such as the TightRope essentially are placing a prosthetic device in place of the ligaments. So is there evidence that soft tissue forms around the devices? Even though there are no long-term results, we can report 2 cases of our clinical study (unpublished data) with biologic reaction after 6 weeks (a case with local wound infection) and after 3 months (removal of the plate) in which we saw tissue complexes around both TightRope devices in second-look arthroscopy. Even in postoperative radiographs, we saw calcification along the TightRope. Bearing this in mind, we suppose there will be long-term stability by scarring the remaining stumps together with soft tissue complexes. Further studies will have to prove this theory.

Compared with other studies, it was possible to show even more strength in the reconstructed group.[8,10,15] The strength of both quadrupled FiberWire in the TightRope devices used for the reconstruction method could be one possible explanation. Another one could be the different protocol for the displacement rate. Mazzocca et al[15] described 3 procedures (including Weaver-Dunn) with a load to failure between 354.3 and 463.16 N and a displacement rate of 120 mm/min. Grutter and Petersen[8] presented a study with a load-to-failure protocol for native 815 N, modified Weaver-Dunn 483 N, anatomic AC reconstruction with plantaris longus tendon 326 N, and with flexor carpi radialis graft 774 N with a displacement of 10 N/s. With the same displacement rate we used, Harris et al[10] showed forces between 145 and 423 N for coracoidal ligament transfer, coracoclavicular sling, suture anchor, and unicortical coracoclavicular screw; only the bicortical coracoclavicular screw showed a tensile strength of 927 N.

Evaluating all different studies independently from the displacement rate, it seems that all reconstruction techniques withstand much lower forces than the native ligament complex. Only the bicortical coracoclavicular screw showed more strength than our reconstruction method, but use of a screw is—not only in our opinion[4]—not a state-of-the-art method nowadays.

We hold the opinion that this is a very stable and flexible reconstruction method. If this is a good method for clinical use, it should be evaluated in clinical studies. Another issue that should be focused on is stiffness. The reconstructed complex (vertical 80 N/mm, anterior 78 N/mm) showed less stiffness than the native ligament complex (vertical 99 N/mm, anterior 140 N/mm). Remembering that decreased stiffness can be a mode of failure for reconstructions (eg, anterior cruciate ligament reconstruction), this could be a clinically relevant parameter. An explanation for the extended stiffness of the reconstructed complex may be the quadrupled FiberWire. This might be a further issue on which future clinical studies should focus.

Our study seems to be the only one that measured forces in vertical and horizontal directions. In all static testing protocols, there were more suture failures. Bone failures appeared in all testing protocols. In vertical static direction, the coracoid fracture occurred due to misplacement of the coracoidal tunnel and, as a result, the 2 TightRope plates pulled through the bone bridge. For the 3 pull-throughs, the cortical bone could not withstand the forces. In the anterior direction, 3 coracoidal pull-throughs occurred. In the dynamic testing protocols for native ligaments, we observed ligament ruptures only. In the vertical direction, 4 coracoid fractures and 1 coracoid pull-through took place. In the anterior direction, 3 coracoid fractures, 1 coracoid pull-through, and 1 clavicular fracture occurred while testing.

Due to all the protocols, it was possible to show in this study a reconstruction method able to restore the normal mechanical function of the intact coracoclavicular ligament complex. From the data in this study, we concluded that we found a reconstruction method for AC joint dislocations that showed a stable and functional anatomic reconstruction method. We recommend this technique for acute AC joint injuries (maximum 3 weeks after injury) only. For chronic cases, we prefer a combination of TightRope and augmentation with a gracilis graft, pulled in a figure-of-8 around the coracoid and twice through the clavicle.

We hypothesize that through anatomic repair, a full and stable function of the AC joint can be achieved while a controlled clinical application is feasible by using described techniques.

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