

Coracoclavicular Ligament Reconstruction

A Systematic Review and a Biomechanical Study of a Triple Endobutton Technique

Qi Li, MD, PhD, Pei-ling Hsueh, MD, and Yun-feng Chen, MD, PhD

Abstract: Operative intervention is recommended for complete acromioclavicular (AC) joint dislocation to restore AC stability, but the best operative technique is still controversial.

Twelve fresh-frozen male cadaveric shoulders (average age, 62.8 ± 7.8 years) were equally divided into endobutton versus the modified Weaver-Dunn groups. Each potted scapula and clavicle was fixed in a custom made jig to allow translation and load to failure testing using a Zwick BZ2.5/TS1S material testing machine (Zwick/Roell Co, Germany). A systematic review of 21 studies evaluating reconstructive methods for coracoclavicular or AC joints using a cadaveric model was also performed.

From our biomechanical study, after ligament reconstruction, the triple endobutton technique demonstrated superior, anterior, and posterior displacements similar to that of the intact state ($P > 0.05$). In the modified Weaver-Dunn reconstruction group, however, there was significantly greater anterior ($P < 0.001$) and posterior ($P = 0.003$) translation after ligament reconstruction. In addition, there was no significant difference after reconstruction between failure load of the triple endobutton group and that of the intact state (686.88 vs 684.9 N, $P > 0.05$), whereas the failure load after the modified Weaver-Dunn reconstruction was decreased compared with the intact state (171.64 vs 640.86 N, $P < 0.001$).

From our systematic review of 21 studies, which involved comparison of the modified Weaver-Dunn technique with other methods, the majority showed that the modified Weaver-Dunn procedure had significantly ($P < .05$) greater laxity than other methods including the endobutton technique.

The triple endobutton reconstruction proved superior to the modified Weaver-Dunn technique in restoration of AC joint stability and strength. Triple endobutton reconstruction of the coracoclavicular ligament is superior to the modified Weaver-Dunn reconstruction in controlling both superior and anteroposterior displacements with a failure load that approximates the intact ligament.

(*Medicine* 93(28):e193)

Editor: Caroline Chebli.

Received: August 27, 2014; revised: September 25, 2014; accepted: September 28, 2014.

From the Department of Orthopaedics Trauma (QL, PL-H, YF-C), Shanghai Medical Trauma Center, Shanghai Jiao Tong University Affiliated Sixth People's Hospital, Shanghai 200233, China.

Correspondence: Yun-feng Chen, Department of Orthopaedics Trauma, Shanghai Medical Trauma Center, Shanghai Jiao Tong University Affiliated Sixth People's Hospital, 600 Yishan Road, Shanghai 200233, China (e-mail: drchenyf@aliyun.com).

QL and PL-H are joint first authors, who contributed equally to this study. The authors have no funding and conflicts of interest to disclose.

Copyright © 2014 Wolters Kluwer Health | Lippincott Williams & Wilkins. This is an open access article distributed under the Creative Commons Attribution-NonCommercial-NoDerivatives License 4.0, where it is permissible to download, share and reproduce the work in any medium, provided it is properly cited. The work cannot be changed in any way or used commercially.

ISSN: 0025-7974

DOI: 10.1097/MD.0000000000000193

Abbreviations: AC = acromioclavicular, CA = coracoacromial, CC = coracoclavicular, PDS = polydioxansulfate.

INTRODUCTION

Acromioclavicular (AC) joint dislocation accounts for approximately 9% of shoulder girdle injuries.¹ These injuries are classified into type I–VI injuries on the basis of the radiographic findings using the Rockwood criteria.² The Rockwood classification takes into account not only the AC joint, but also the coracoclavicular (CC) ligament (which consists of 2 fasciculi, the trapezoid and conoid ligaments), the deltoid and trapezius muscles, and the direction of dislocation of the clavicle with respect to the acromion.³ Most type I and type II injuries can be successfully treated nonoperatively in the majority of patients.⁴ Although Type IV through type VI injuries are treated operatively because of their severe instability,⁵ treatment for type III injury is still controversial.⁶

Most surgical procedures involving the AC joint primarily involve fixation of the joint and reconstruction of the CC ligament.⁷ AC joint fixation methods involve the use of wires, screws, and hook plates, although these techniques have significant limitations including unsatisfactory maintenance of AC joint reduction, osteolysis, and fracture as well as hardware-related complications.⁸ In addition, many of these procedures necessitate a second procedure for hardware removal.

Several procedures for reconstruction of CC ligament have been described. The Modified Weaver-Dunn procedure is the most widely used CC reconstruction method.⁹ After resecting the distal clavicle, it involves transfer of the coracoacromial (CA) ligament (which was detached from the under surface of the acromion) together with a small piece of bone, the distal clavicle using cerclage wires. However, postsurgical complications include persistent pain, weakness, and clavicular osteolysis.¹⁰

Anatomic and biomechanical studies have addressed the contributions of both CC and AC ligaments to AC joint stability.^{11,12} Consequently, different stabilizing procedures have been developed, which focus on reconstruction of the CC ligament, including single-bundle, double-bundle, as well as a sling-fashion reconstructions using autograft, allograft, or synthetic materials.^{13–18} Reconstruction of the trapezoid and conoid ligaments in independent procedures was found to be biomechanically superior. Clinical articles also report promising outcomes from such reconstruction techniques.^{16,19,20}

Recently, the triple endobutton technique has been used in reconstruction of complete AC joint dislocations.^{21,22} This technique allows restoration of the CC ligament to be in a position as anatomical as possible with the strength of the fixation superior to its original strength. We present our experience with reconstruction of CC ligaments using the triple endobutton technique (Acuflex; Smith & Nephew, Andover,

MA), including its biomechanical performance in comparison with the modified Weaver-Dunn technique using a cadaveric model. We hypothesized that the triple endobutton reconstruction would prove superior to the modified Weaver-Dunn technique in restoration of AC joint stability and strength.

MATERIALS AND METHODS

Biomechanical Study

The study received approval from the ethics committee of the Shanghai Jiao Tong University Affiliated Sixth People's Hospital. The cadavers were purchased from the Department of Anatomy, Fudan University Medical College, which abides by the rules of ethics. Twelve fresh-frozen cadaveric shoulders, consisting of right and left shoulders from each of 6 male cadavers, were equally divided into 2 groups (endobutton and the modified Weaver-Dunn groups). The average age of the specimens was 62.8 ± 7.8 years. Prior to be used for testing, the specimens were frozen and stored at -20°C and thawed overnight at room temperature on the day before testing. Each shoulder was disarticulated at the glenohumeral joint. The skin, subcutaneous tissues, and musculature were removed, whereas the AC ligaments, AC capsule, CA ligament, and CC ligaments were preserved. Specimens showing any gross damage to clavicle, scapula, or ligaments were not used. Throughout the study, the specimens were kept moist with normal saline.

The scapula was potted with polymethylmethacrylate in a custom aluminum alloy block from the inferior angle to the edge of glenoid (Figure 1A). The scapula was rotated in the block to make sure that superior translation of the clavicle was parallel to the long axis of CC ligament, and the anteroposterior translation was parallel to the sagittal plane. Fixation of the scapula was supplemented with 2 screws placed transversely through drill holes in the fixture into the potted scapula.

Custom-made fixtures were designed for fixation of the potted scapula and clavicle to the Zwick BZ2.5/TS1S material testing machine (Zwick/Roell Co). For the anterior and posterior translation tests, the scapula was rotated to a supine position so that the anterior direction was in line with actuation. The scapula block was bolted to the machine base with a set of custom-made plates and screws. The test setup allowed the scapula to move freely on the machine base, thus, the relative position of scapula and clavicle was adjustable. The clavicle and scapula were rigidly fixed to the testing machine and approximated anatomical positions. The anatomical position was defined by aligning the bony articulation of the distal end of the clavicle and the acromion process with equal tensioning throughout the soft tissue structures. The machine's starting point and the clavicle's position relative to the scapula were recorded.

For the superior translation test, the scapula was rotated such that when the specimen was fixed to the test machine, the long axis of CC ligament was in line with the actuator. The scapula and clavicle were also adjusted to be in approximate anatomical positions.

All specimens were conditioned for 10 cycles to 20 N for anterior–posterior and superior testing to eliminate creep phenomenon. The specimens were then loaded to 70 N in anterior, posterior, and superior directions (Figure 1B). Clavicular displacement relative to the scapula was recorded by the digital image correlation (DIC) technique. The accuracy of the DIC technique for displacement measurement was <0.1 mm.²³ After the translation test was finished, a tension band was placed lateral to the CC ligaments, and a load-to-failure test followed at

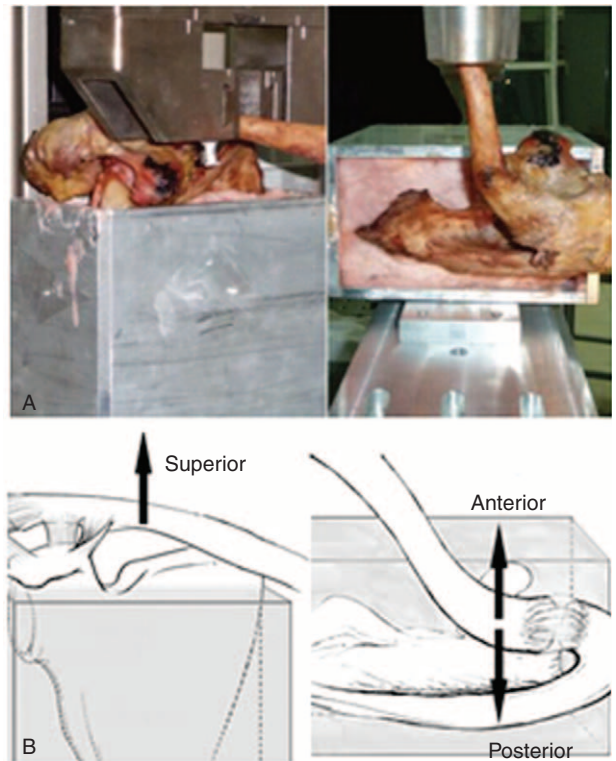


FIGURE 1. Biomechanical test setup. (A) Test setup with scapula potted in a custom-made box and clavicle secured to the actuator, showing the specimen position for both superior and anteroposterior translation testing. (B) Illustration showing superior, anterior, and posterior loading of clavicle with respect to the scapula.

25 mm/min in the superior direction to simulate AC joint dislocation.

After failure, the machine was returned to the starting point. Random reconstructions were performed with either the triple endobutton technique or the modified Weaver-Dunn procedure. Specimens exhibiting bony failure were not used for reconstruction. When the specimen was reconstructed, the same test protocol for the intact specimens was repeated, and the displacement values, as well as the ultimate tensile load, were recorded.

Surgical Reconstructions: The Modified Weaver-Dunn Procedure

The modified Weaver-Dunn procedure is shown schematically in Figure 2. As there was no clear consensus regarding the best type of augmentation suture material to use for the modified Weaver-Dunn procedure, No. 2 Ethibond (Shanghai, China) was chosen.

The CA ligament was transected sharply from its acromial attachment. A locking stitch was then weaved into the distal end of the CA ligament with No. 2 Ethibond suture. After 10 mm of distal clavicle was resected, the suture ends were passed through drill holes in the superior aspect of the distal clavicle through the medullary canal. The clavicle was then reduced into an anatomic position, and the sutures were tied.

Two additional 1.5 mm drill holes, placed 15 mm and 25 mm from the distal end, were created to secure an additional

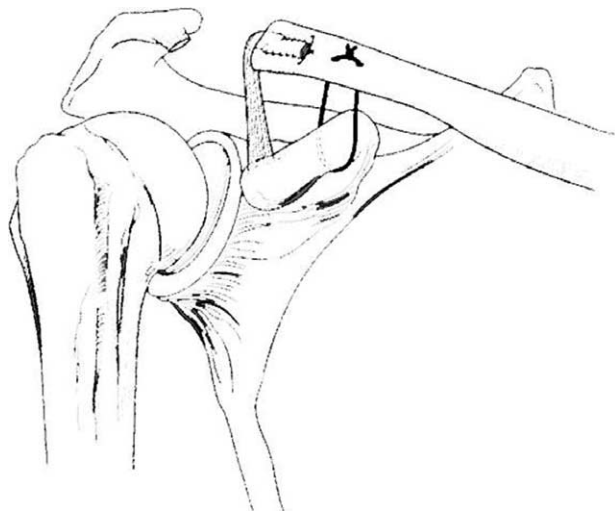


FIGURE 2. The modified Weaver-Dunn procedure. The distal clavicle is resected, and the CA ligament is transferred through the intramedullary canal of the distal clavicle and secured with a No. 2 Ethibond nonabsorbable suture. CA = coracoclavicular.

augmentation suture. This No. 2 Ethibond suture was looped underneath the coracoid and brought up through the 2 drill holes into the distal clavicle and tied.

Surgical Reconstructions: Triple Endobutton Technique

The triple endobutton technique is shown schematically in Figure 3. A guide wire was drilled into the superior surface of

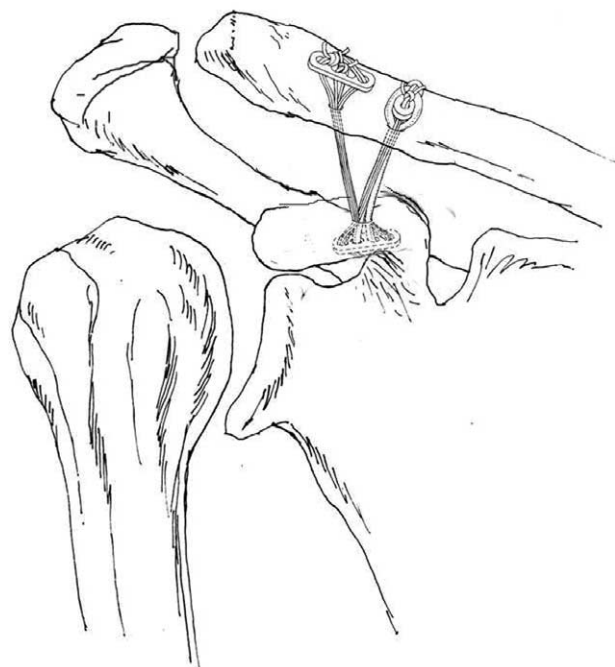


FIGURE 3. Anatomical reconstruction of CC ligament with triple endobutton technique. CC = coracoclavicular.

the clavicle approximately 40 mm medial to the AC joint. The tip of the guide wire was centered between the medial and lateral edges of the coracoid, and drilling was continued to the base of the coracoid. A 4.0 mm drill was then used to ream over the guide wire, and another drill hole was made 20 mm from the distal end of the clavicle. To anatomically reconstruct the CC ligament, the medial drill was positioned at the posterior one-third of the superior surface of the clavicle and the lateral drill was positioned at the anterior one-third. After the depth from the medial drill hole to the base of the coracoid process was determined, an endobutton of appropriate size for the closed loop was chosen and 5 strands of No. 2 Ethibond suture were placed through the first and fourth holes of the endobutton. Using a 3.2 mm smooth cylindrical plunger, the endobutton and the closed loop, together with their related sutures, were pushed into the top of the clavicle through the medial drill hole and then were pushed further into the coracoid drill hole until they passed through the underside of the coracoid. The loop was pulled up, locking the endobutton onto the underside of the coracoid. Three of the 5 strands (6 tails) of Ethibond sutures were pulled out of the interval between the coracoid and the clavicle. This left the 2 remaining strands (4 tails) extending from the coracoid endobutton and exiting from the top of the clavicle. When tension was placed on the loop, the very tip of the closed loop was seen protruding from the top of the clavicular hole. A free endobutton was slid into the protruding loop. The suture tails exiting through the top of the clavicle were passed through the endobutton holes (preferably the second and third holes) and tied on top of the endobutton. The other suture tails were brought out of the CC space and passed through the lateral drill holes. Then, the suture tails were passed through the holes of the free endobutton and tied.

Statistical Analysis

Data were presented as mean ± standard deviation. The paired *t* test was used to compare displacement and failure load between the intact and reconstructed specimens and within the 2 groups. The translation test and load-to-failure test of intact state between the endobutton and the modified Weaver-Dunn groups were tested with the *t* test of the 2 independent samples. When the translation of intact state between groups was comparable, *t* test of the 2 independent samples was performed to determine if there was a significant difference of translation between groups after reconstruction. When the difference in translation of intact state between groups was statistically significant, the analysis of covariance model with 1 covariate for adjustment (translation of intact state) was performed to determine if there was a significant difference of translation between groups after reconstruction. A 2-tailed *P* value < 0.05 was considered statistically significant. Statistical analyses were performed using SPSS 15.0 (SPSS Inc, Chicago, IL).

Systematic Review

Search Strategy

Using keywords such as (coracoclavicular OR acromioclavicular) AND (reconstruction OR repair), we searched Medline, the Cochrane Library, and EMBASE, up to January 31, 2014. Reference lists of relevant studies were hand-searched by 2 independent reviewers, who identified the studies by the search strategy. When there was a question about eligibility, a third reviewer was consulted, and consensus was reached by all 3 reviewers.

A study was included if it covered any reconstructive method of the CC ligament or AC joint and was an in vitro study (eg, biomechanical study) using a cadaveric model. Letters, comments, editorials, case reports, non-English publications, and any study involving nonhuman subjects were excluded.

Data Extraction

The following information was extracted from studies that matched the criteria: the name of the first author, year of publication, study design, number of specimens in each treatment group, specimens/age, reconstructive procedures, and biomechanical outcomes.

Outcome Measures

The primary outcome was biomechanical stability parameters including load to failure and superior/anterior/posterior translation.

RESULTS

Biomechanical Study

Translation Test

The specimen characteristics, translation test results, and load-to-failure test results between the 2 groups (endobutton and the modified Weaver-Dunn groups) are shown in Table 1. Both specimen groups had similar ages ($P > 0.999$). No significant difference in the superior or anterior translation between 2 groups was observed before reconstruction (superior translation, 4.79 vs 5.41 mm, $P = 0.258$; anterior translation, 5.70 vs 7.81 mm, $P = 0.076$). However, the triple endobutton group showed significantly less posterior translation compared with the modified Weaver-Dunn group before reconstruction (7.16 vs 10.11 mm, $P = 0.012$).

The average superior, anterior, and posterior displacements under a 70 N load for the intact specimens before triple button reconstruction were 5.41, 7.81, and 7.16 mm, respectively. After ligament reconstruction, the triple button technique demonstrated superior, anterior, and posterior displacements of 5.19, 8.72, and 8.03 mm respectively. There was no significant change compared with the intact state ($P > 0.05$).

In the modified Weaver-Dunn reconstruction group, the intact state had average superior, anterior, and posterior translations of 4.79, 5.70, and 10.11 mm, respectively. The average displacement after the modified Weaver-Dunn reconstruction was 5.59, 37.03, and 14.85 mm, respectively. There was significantly greater anterior ($P < 0.001$) and posterior translation ($P = 0.003$) after the Weaver-Dunn procedure. In addition, the triple button CC ligament reconstruction had significantly less anterior translation (8.72 vs 37.03 mm, $P < 0.001$) than the Weaver-Dunn procedure. With adjustment for posterior translation before reconstruction, no significant group difference was observed in posterior translation after reconstruction ($P = 0.101$).

Load-to-Failure Test

No significant difference in failure load between 2 groups was observed before reconstruction (640.86 vs. 684.9 N, $P = 0.689$). After reconstruction, the failure load of the triple endobutton group showed no significant change compared with the intact state (686.88 vs. 684.9 N, $P > 0.05$). However, the failure load after the modified Weaver-Dunn reconstruction was significantly decreased compared with the intact state (171.64 vs. 640.86 N, $P < 0.001$).

The mode of failure for all intact specimens was CC ligament rupture. For triple endobutton group, there were four endobuttons pull through coracoid bone tunnel, with one coracoid process and one clavicle fractured through medial bone tunnel. For the modified Weaver-Dunn reconstruction, all augmented suture ruptured, as there were 4 acromioclavicular ligaments ruptured and 2 stitched sutures broken at the knot.

Systematic Review

Literature Search

From the initial 404 records that were identified through the search of 4 databases, 379 articles were excluded. After full-text reviewing of the remaining 25 studies, we excluded 2 studies for using the porcine metatarsal model, 1 study for its use of a sawbone clavicle, and 1 study for not reporting a reconstruction method. The reasons for exclusion are summarized in a flowchart for study selection (Figure 4).

TABLE 1. Specimen Characteristics, Translation Test Results, and Load-to-Failure Test Results Between the 2 Groups

		Group		P value
		The Modified Weaver-Dunn Procedure (n = 6)	Triple Endobutton Technique (n = 6)	
Specimen age, y		62.83 (5.85)	62.83 (8.73)	>0.999
Superior translation, mm	Intact	4.79 (0.72)	5.41 (1.05)	0.258
	Reconstructed	5.59 (1.38)	5.19 (1.27)	0.607
Anterior translation, mm	Intact	5.70 (1.18)	7.81 (2.22)	0.076
	Reconstructed	37.03 (5.05) [‡]	8.72 (1.41)	<0.001*
Posterior translation, mm	Intact	10.11 (0.94)	7.16 (1.95)	0.012*
	Reconstructed	14.85 (1.89) [‡]	8.03 (3.68)	0.101 [†]
Failure load, N	Intact	640.86 (110.37)	684.90 (233.86)	0.689
	Reconstructed	171.64 (9.27) [‡]	686.88 (115.00)	<0.001*

Data are represented as mean and standard deviation.

* $P < 0.05$ indicates that a significant group difference was observed.

[†] The P value was performed by analysis of covariance model with a covariate of posterior translation before reconstruction.

[‡] Indicates a significant change after reconstruction compared with intact state within groups.

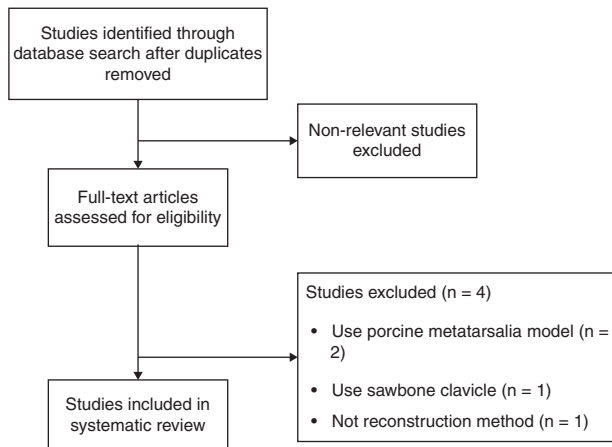


FIGURE 4. Flowchart of literature selection.

The remaining 21 articles involving reconstructive methods for CC ligament or AC joint using the cadaveric model were included in the final analysis. The characteristics of all 30 studies are summarized in Table 2.

Study Characteristics and Clinical Outcomes

As shown in Table 2, 6/21 studies involved comparison of the modified Weaver-Dunn technique versus arthroscopic reconstruction, double-bundle, 2-tunnel anatomical reconstruction of the CC ligaments,²⁴ intact state,^{21,25} free-tissue graft,¹⁸ and anatomic versus nonanatomic allograft and GraftRope,²⁶ and CC and AC ligament reconstruction technique utilizing a single continuous intramedullary free tendon graft.²⁷ Results from 5/6 studies showed that the modified Weaver-Dunn procedure had significantly ($P < 0.05$) greater laxity than the anatomical CC reconstruction,²⁴ intact state,²¹ free-tissue graft,¹⁸ arthroscopic reconstruction, or single continuous intramedullary free tendon graft.²⁷ Only 1/21 studies compared the modified Weaver-Dunn procedure to the endobutton technique.²⁸ Beitzel et al²⁸ showed that reconstruction using a cortical button combined with a biological augmentation (semitendinosus allograft) had improved stability when compared with the modified Weaver-Dunn procedure. In 1 other study utilizing the endobutton technique combined with the AC cerclage,²⁹ Saier et al³⁰ compared isolated CC reconstruction using 2 suture-button devices, with CC reconstruction using 2 suture-button devices and an AC cerclage. They found that only combined AC and CC reconstruction could adequately reestablish physiological horizontal AC joint stability.

The remaining 12 studies involved techniques unrelated to either endobutton or the modified Weaver-Dunn method. Clevenger et al³¹ performed a biomechanical comparison of AC joint reconstructions using CC tendon grafts with and without CA ligament transfers. Tashjian et al³² compared square knot versus interference screw fixation. Shu et al³³ compared AC reconstructions with and without augmentation using a “reverse” CA ligament transfer versus an intramedullary AC tendon graft. Staron et al³⁴ compared the modified knot fixation technique to the anatomical double-bundle technique. Shin et al³⁵ compared single tendon anatomic AC–CC reconstruction to isolated coracoid cerclage reconstruction. Rieser et al² and Läderrmann et al²⁵ compared TightRope (Arthrex) to various locking plates. Martetschläger et al³⁶ evaluated CC

ligament reconstruction using CC polydioxansulfate (PDS) cerclage and Garg et al³⁷ evaluated free-tissue graft reconstruction of the AC joint.

Three other studies involved the evaluation of intact shoulder and sectioned state. They compared them with TightRope devices,²⁶ coracoid tunnel and free tendon graft reconstruction,³⁸ and intramedullary free semitendinosus graft reconstruction.³⁹ Beitzel et al⁴⁰ evaluated progressive amounts of resection of the distal clavicle on horizontal translation of the clavicle.

DISCUSSION

After ligament reconstruction, the triple endobutton technique demonstrated superior, anterior, and posterior displacements similar to that of the intact state ($P > 0.05$). On the other hand, there was significantly greater anterior ($P < 0.001$) and posterior ($P = 0.003$) translation after ligament reconstruction in the modified Weaver-Dunn reconstruction group.

In addition, there was no significant difference between failure load of the triple endobutton group and that of the intact state (686.88 vs 684.9 N, $P > 0.05$) after reconstruction, whereas the failure load after the modified Weaver-Dunn reconstruction was significantly decreased when compared with the intact state (171.64 vs 640.86 N, $P < 0.001$). These results demonstrate that the triple endobutton reconstruction of the CC ligament is superior to the modified Weaver-Dunn reconstruction in controlling both superior and anteroposterior displacements with a failure load that approximates the intact ligament. The triple endobutton reconstruction proved superior to the modified Weaver-Dunn technique in restoration of AC joint stability and strength, and this result was also reflected in the findings from our systematic review.

From our review of over 20 studies, we found that in those studies that involved the comparison of the modified Weaver-Dunn technique to other methods including arthroscopic reconstruction, double-bundle, 2-tunnel anatomical reconstruction of the CC ligaments,²⁴ intact state,^{21,25} free-tissue graft,¹⁸ and CC and AC ligament reconstruction technique utilizing a single continuous intramedullary free tendon graft,²⁷ the modified Weaver-Dunn procedure showed significantly ($P < 0.05$) greater laxity. Only 1/21 studies compared the modified Weaver-Dunn procedure with the endobutton technique.²⁸ Beitzel et al²⁸ showed that reconstruction using a cortical button combined with a biological augmentation (semitendinosus allograft) demonstrated improved stability when compared with the modified Weaver-Dunn procedure.

The AC joint is a diarthrosis joint and its stability is maintained predominantly by the surrounding ligamentous structures, specifically the CC ligament (conoid and trapezoid ligaments) and the AC joint ligament and capsule. The upper extremity is suspended from the distal clavicle via the CC ligament and this ligament helps to couple glenohumeral abduction and flexion to scapular rotation on the thorax. Thus, overhead elevation of the arm cannot be accomplished with incomplete AC joint dislocation. Operative intervention is recommended for complete AC joint dislocation to restore AC stability, but what is the best operative technique to perform still remains controversial.

The surgical techniques typically include either fixation of AC joint using pins, screws, or hook plates, or reconstruction of CC ligament with various techniques. Primarily fixation of the AC joint with trans-AC pins or CC screws is out of favor as such a rigid fixation is not in line with the physiological function of the joint and can cause implant migration, breakage, pain, AC

TABLE 2. Characteristics and Outcomes of Included Studies in Systematic Review

First Author (Publication Year)	No. of Specimens	Age of Specimens Mean (SD)	Load to failure, N	Elongation, mm	Stiffness, N/mm	Anterior Translation	Posterior Translation	Superior Translation
Mazzocca (2006)	14	72.8 (13.4)	463.16 (200.05)	—	—	SS (less than Weaver-Dunn procedure)	NS	NS
	14		396.4 (136.42)	—	—	SS (less than Weaver-Dunn procedure)	SS (less than Weaver-Dunn procedure)	NS
Luis (2007) ⁴⁸	14	354.3 (100.26)	801 (76) (Superior)	—	—	NS	SS (more than intact ligament)	NS
	9	35 (11)	118 (23) (Superior)	—	79 (9) (Superior)	—	—	—
	9		161 (19) (Superior)	—	6 (0) (Superior)	—	—	—
	9		573 (88) (Superior)	—	15 (1) (Superior)	—	—	—
	9		397 (46) (Superior)	—	121 (16) (Superior)	—	—	—
	9		276 (46) (Superior)	—	25 (3) (Superior)	—	—	—
LaPrade (2008) ⁴⁹	6	62 (range, 48–73)	—	—	—	NS	NS	NS
	6		—	—	—	SS (more than intact)	SS (more than intact)	SS (more than intact)
	6		—	—	—	SS (less than transected)	SS (less than transected)	SS (less than transected)
Walz (2008)	10	NA	598 (range, 409–687)	10 (range, 6–14)	99 (range, 67–130)	—	—	—
	10		338 (range, 186–561)	4 (range, 3–7)	140 (range, 70–210)	—	—	—
	10		982 (range, 584–1330)	4 (range, 3–6)	80 (range, 67–105)	—	—	—
	10		627 (range, 364–973)	6.5 (range, 4–10)	78 (range, 46–120)	—	—	—
Yoo (2010)	10	49 (14)	—	—	—	SS (lower than AC-deficient state)	NS	NS
	10		—	—	—	—	NS	NS
Michlitsch (2010) ⁵⁰	6	63.2 (range, 53–76)	—	—	—	SS (more than free-tissue graft)	SS (more than free-tissue graft)	SS (more than free-tissue graft)

First Author (Publication Year)	No. of Specimens	Age of Specimens, Mean (SD)	Load to failure, N	Elongation, mm	Stiffness, N/mm	Anterior Translation	Posterior Translation	Superior Translation
	6	—	—	—	—	SS (less than modified Weaver-Dunn)	SS (less than modified Weaver-Dunn)	SS (less than modified Weaver-Dunn)
Freedman (2010)	6	66.8 (7.1)	462.77 (43.38)	19.58 (2.61)	32.31 (4.11)	—	—	—
	6	189.82 (22.74)	15.85 (1.74)	15.54 (0.49)	—	SS (lower than before reconstruction)	SS (lower than before reconstruction)	SS (lower than before reconstruction)
Clevenger (2011)	7	NA	970.3 (361.03)	—	50.6 (6.14)	—	—	—
	7	952.7 (296.89)	—	65.6 (18.45)	—	—	—	—
Thomas (2011)	5	54 (range, 43–63)	523 (98.6)	—	—	—	—	—
	5	591 (65.6)	—	—	—	—	—	—
	5	948 (148)	—	—	—	—	—	—
	5	578 (195.3)	—	—	—	—	—	—
	5	646 (167.4)	—	—	—	—	—	—
	5	1331 (447)	—	—	—	—	—	—
Beitzel (2012) ^a	8	NA	469.7 (175.1)	1.13 (0.19)	39.1 (10.7)	—	—	—
	8	614.8 (124.6)	—	2.17 (0.23)	—	—	—	—
	8	510.7 (55.8)	—	1.36 (0.18)	42.6 (11.2)	—	—	—
Shu (2012)	6	79 (range, 63–94)	—	—	—	SS (lower than CC recon structure alone)	SS (lower than CC recon structure alone)	NS
	6	—	—	—	—	SS (lower than CC recon structure alone)	SS (lower than CC recon structure alone)	NS
Beitzel (2012) ^b	18	55.9 (9.6)	—	—	—	NS	NS	NS
	15	54.8 (4.8)	—	—	—	NS	NS	SS (lower than native)
	8	61.4 (8.7)	—	—	—	NS	NS	NS
Abrams (2013)	10	66.7 (12.3)	416.3 (63.6)	—	40.4 (4.8)	SS (higher than GR-ST and GR-DT)	SS (higher than native, GR-ST and GR-DT)	NS
	6	58.7 (8.9)	—	—	—	SS (higher than control)	SS (higher than control)	NS

First Author (Publication Year)	No. of Specimens	Age of Specimens, Mean (SD)	Load to failure, N	Elongation, mm	Stiffness, N/mm	Anterior Translation	Posterior Translation	Superior Translation
	10	293.8 (35.2)	—	—	44.9 (8.2)	NS	NS	NS
Staron (2013)	8	43 (range, 19–65)	326.9 (40.6)	—	22.5 (1.7)	—	—	—
Shin (2013)	9	43.8 (range, 19–65)	347.5 (26.4)	—	21.9 (1.9)	—	—	—
	6	54.8 (7.8)	443.2 (51.2)	—	24.6 (3.7)	NS	NS	NS
	6	295.4 (9.5)	—	—	32.6 (2.9)	SS (more than intact state)	SS	NS
Rieser (2013)	7	68.3 (11.7)	396 (120)	—	31 (10)	—	—	—
	7	312 (134)	—	—	27 (5)	—	—	—
	7	459 (171)	—	—	53 (12)	—	—	—
Lädermann (2013)	9	89 (range, 76–100)	—	—	73.77 (range, 37.36–126.42)	—	—	—
	9	—	—	—	59.74 (range, 33.69–97.93)	—	—	—
	9	—	—	—	24.09 (range, 14.27–46.55)	—	—	—
Martetschläger (2013)	12	79 (range, 65–96)	590.1 (95.8)	13.4 (2.05)	48.7 (12)	—	—	—
	12	569.9 (97.9)	—	18.8 (4.7)	37.9 (8)	—	—	—
Garg (2013)	6	63.8 (range, 57–74)	499.3 (120.4)	17.9 (4.6)	50.1 (22.6)	NS	NS	NS
	6	355.0 (123.1)	—	21.8 (7.4)	29.2 (12.5)	NS	NS	NS
Saier (2014)	6	59 (13)	—	—	—	SS (lower than native specimens with dissected AC ligament)	SS (lower than native specimens with dissected AC ligament)	—
	6	—	—	—	—	SS (lower than native specimens with dissected AC ligament)	SS (lower than native specimens with dissected AC ligament)	—

AC = acromioclavicular, CA = coracoclavicular, CC = coracoacromial, CC = coracoclavicular, GR-DT = double clavicle tunnel graft, GR-ST = single clavicle tunnel graft, LCP = superior anterior clavicle plate, NA = not available, NS = no statistical significance, PDS = polydioxanulfate, SD = standard deviation, SS = statistical significance.

joint arthritis, and other complications. For CC ligament reconstruction, Weaver-Dunn CA ligament transfer is commonly used for both acute and chronic AC joint injuries. However, its biomechanical properties including transfer and strength have come into question. Studies have shown that nonaugmented reconstructions with the modified Weaver-Dunn procedure have only 25% of the biomechanical strength of the native ligament complex.⁴¹ This led to a variety of augmentations using absorbable or nonabsorbable suture, tape, screws, or grafts to achieve sufficient strength. Mazzocca et al¹⁸ showed a No. 2 FiberWire augmented the modified Weaver-Dunn had a failure load of 354.3 N. The use of a No.5 Ethibond suture for augmentation demonstrated a failure load of 483 N by Grutter et al.⁴² The reconstruction strength of a hook plate augmentation was measured 397 N, and a 4.5 mm CC screw had the strength of 573 N²¹. These studies demonstrated that the strength of a Weaver-Dunn reconstruction could be significantly improved with sufficient materials. Unfortunately, anterior–posterior translation of the distal clavicle after a Weaver-Dunn procedure was not effectively controlled by these augmentations.^{18,41,43} It can be an important cause of postoperative pain and incongruity of the shoulder. Furthermore, as the CA arch (an important superior stabilizer of glenohumeral joint) is sabotaged during CA ligament transfer, CA ligament transfer may be a potential cause of glenohumeral joint problems as the patient gets older.

To restore multiplanar stability of the AC joint, surgeons have attempted to reconstruct the anatomic structures of the joint by emphasizing the CC ligament.^{17,20,22,42} Mazzocca et al¹⁸ described a technique for anatomic reconstruction of the CC ligament with a free graft. The graft was fixed to the coracoid process using an interference screw, and the 2 free tails were passed through clavicular bone tunnels unto the superior aspect of the clavicle to simulate conoid and trapezoid ligaments and were also fixed with interference screws. They demonstrated that this reconstruction had superior anterior–posterior stability compared with the modified Weaver-Dunn. Thomas et al¹³ tested a similar reconstructive technique using the semitendinosus except that the graft was passed beneath the coracoid without a bone tunnel. They concluded that their anatomic allograft reconstruction was superior in initial biomechanical properties compared with the modified Weaver-Dunn, non-anatomic allograft, anatomic suture, and GraftRope techniques.

To more exactly reconstruct the conoid and trapezoid ligaments, Walz et al¹⁷ used 2 TightRope devices for CC ligament replacement, and their *in vitro* biomechanical study showed this procedure had equal or even higher strength than native ligaments. However, this technique placed 2 bone tunnels on the relatively small coracoid process, resulting in a higher risk for coracoid fractures.

Most of the anatomic AC joint reconstruction procedures described required autograft or allograft material, however, in our country, the use of an autograft or allograft is uncommon during AC joint surgery. Therefore, we promoted the use of a synthetic ligament fixed by 3 endobuttons. This triple endobutton technique can anatomically reconstruct the conoid and trapezoid ligaments, which then can control both superior and anteroposterior displacements, with a failure load that approximates the intact state, and this is the novelty of our study.

Mazzocca et al¹⁸ tested a procedure that independently reconstructed conoid and trapezoid ligaments using the semitendinosus fixed by an interference screw. They found that this technique had anterior and posterior displacement values that approximated those observed in the intact specimen, which is

similar to our findings. In our study, the anterior and posterior translations for triple endobutton technique were 8.72 ± 1.41 mm and 8.03 ± 3.68 mm, respectively, not significantly increased compared with those in the intact state (7.81 ± 2.22 mm and 7.16 ± 1.95 mm, respectively; $P > 0.05$; Table 1). Anatomical reconstruction procedures involving both conoid and trapezoid ligaments appear to have the ability to control anterior–posterior translation without the need to reconstruct the AC capsular ligaments.

This is an interesting finding as AC ligament and joint capsule were reported to be the main restraints of horizontal translation. One explanation may be in the different orientations of conoid and trapezoid ligaments, which help to maintain the horizontal stability of the AC joint. This explanation was supported by Debeski et al,⁴⁴ who found that after resection of AC capsular ligaments, the mean *in situ* force in the conoid increased 227% under an anterior load, and the force in the trapezoid increased 66% in response to a posterior load, whereas the mean force in the conoid increased only 9%. In addition, Gonzalez et al⁴⁵ also found that a sling-type CC reconstruction did not significantly increase anterior–posterior translation compared with intact shoulders, but they also demonstrated that an intramedullary AC ligament reconstruction can improve horizontal stability using an isolated CC ligament reconstruction and restore stability of AC joint. More biomechanical and clinical studies are needed to decide whether one more AC ligament reconstruction procedure is necessary for anatomical CC reconstruction.

All 6 specimens after triple-endobutton reconstruction demonstrated bony failure, including 4 endobuttons that pulled through coracoid bone tunnel, 1 coracoid process that fractured, and 1 clavicle that fractured through the medial bone tunnel. This implied that the reconstruction devices were stronger than the bony structures under the testing conditions. This can partly be explained by the age of the specimens used because age-related osteopenia is common. Another possible explanation may lie in the diminished strength of bony structures because of previous failure test simulating AC joint dislocation. Costic et al⁴⁶ reported that after the simulated dislocation and failure of the normal CC ligament complex, the bending stiffness of the clavicle showed a 40% decrease. Compared with similar studies, bony failure is not uncommon. Wellmann et al⁴⁷ tested a reconstruction method using double 1.0-mm polyester fixed with clavicular and subcoracoidal flip button and found bony failures in all 8 specimens under a 927 ± 155 N ultimate load. Walz et al¹⁷ used 2 TightRope devices connecting a No. 5 nonabsorbable FiberWire suture for CC reconstruction and found 4/10 bony failures had a median failure load of 982 N. All of the techniques described had several bone tunnels on clavicle and coracoid, which may have made them susceptible to bony failure. If used clinically, the high rate of bony failure should remind the surgeon that the patients treated with these techniques may have bony failure instead of ligament failure, in cases of secondary trauma.

Our study had several limitations including the small number of specimens (ie, 12 cadaveric shoulders, consisting of right and left shoulders from each of 6 male cadavers) and their advanced age (average age, 62.8 ± 7.8 years), as there were significant constraints in obtaining younger cadaveric specimens. In addition, the reconstruction techniques were tested sequentially after testing was performed on the intact specimen. This may have influenced the failure mode and its magnitude. On the other hand, the failure test of native specimens may more closely simulate the condition of a traumatic

dislocation. Our testing sequence may more closely resemble the time zero stability and strength of the reconstruction, which only a cadaveric study can achieve. Finally, because our study was a cadaveric study, we were unable to evaluate whether any soft tissue formed around the artificial ligaments and whether the CC ligament healed sufficiently. Although many prosthetic devices are used to treat AC dislocation, no direct evidence is available to answer the above questions. More in vivo studies are needed to address these issues.

In conclusion, the triple endobutton technique for anatomic reconstruction of the CC ligament with synthetic materials appears a good choice for acute AC joint dislocation. We demonstrated that this reconstruction technique can better control anterior–posterior displacement and better approximate the native ligament complex than a modified Weaver-Dunn procedure. The reconstruction also had an initial failure load close to the intact specimen. These advantages may eliminate recurrent subluxation and lower the incidence of postoperative pain caused by residual anterior–posterior instability.

REFERENCES

- Bishop JY, Kaeding C. Treatment of the acute traumatic acromioclavicular separation. *Sports Med Arthrosc*. 2006;14:237–245.
- Rieser GR, Edwards K, Gould GC, et al. Distal-third clavicle fracture fixation: a biomechanical evaluation of fixation. *J Shoulder Elbow Surg*. 2013;22:848–855.
- Chillemi C, Franceschini V, Dei Giudici L, et al. Epidemiology of isolated acromioclavicular joint dislocation. *Emerg Med Int*. 2013;2013:171609.
- Mouhsine E, Garofalo R, Crevoisier X, et al. Grade I and II acromioclavicular dislocations: results of conservative treatment. *J Shoulder Elbow Surg*. 2003;12:599–602.
- Garcia ESJ, Owens BD. Anatomic approach to reconstruction of the unstable acromioclavicular joint. *Curr Orthop Pract Jan/Feb*. 2010;21:43–48.
- Smith TO, Chester R, Pearse EO, et al. Operative versus non-operative management following Rockwood grade III acromioclavicular separation: a meta-analysis of the current evidence base. *J Orthop Traumatol*. 2011;12:19–27.
- Geaney LE, Miller MD, Ticker JB, et al. Management of the failed AC joint reconstruction causation and treatment. *Sports Med Arthrosc*. 2010;18:167–172.
- Tamaoki MJS, Belloti JC, Lenza M, et al. Surgical versus conservative interventions for treating acromioclavicular dislocation of the shoulder in adults. *Cochrane Database Syst Rev*. 2010;8:CD007429.
- Weaver JK, Dunn HK. Treatment of acromioclavicular injuries, especially complete acromioclavicular separation. *J Bone Joint Surg Am*. 1972;54:1187–1194.
- Jones HP, Lemos MJ, Schepsis AA. Salvage of failed acromioclavicular joint reconstruction using autogenous semitendinosus tendon from the knee. Surgical technique and case report. *Am J Sports Med*. 2001;29:234–237.
- Dawson PA, Adamson GJ, Pink MM, et al. Relative contribution of acromioclavicular joint capsule and coracoclavicular ligaments to acromioclavicular stability. *J Shoulder Elbow Surg*. 2009;18:237–244.
- Lee KW, Debski RE, Chen CH, et al. Functional evaluation of the ligaments at the acromioclavicular joint during anteroposterior and superior-inferior translation. *Am J Sports Med*. 1997;25:858–862.
- Thomas KMD, Litsky AMDS, Jones GMD, et al. Biomechanical comparison of coracoclavicular reconstructive techniques. *Am J Sports Med*. 2011;39:804–810.
- Ladermann A, Grosclaude M, Lubbeke A, et al. Acromioclavicular and coracoclavicular cerclage reconstruction for acute acromioclavicular joint dislocations. *J Shoulder Elbow Surg*. 2011;20:401–408.
- Yoo J-CMD, Ahn J-HMD, Yoon J-RMD, et al. Clinical results of single-tunnel coracoclavicular ligament reconstruction using autogenous semitendinosus tendon. *Am J Sports Med*. 2010;38:950–957.
- Salzmann GMM, Walz LMD, et al. Arthroscopically assisted 2-bundle anatomical reduction of acute acromioclavicular joint separations. *Am J Sports Med*. 2010;38:1179–1187.
- Walz LMD, Salzmann GMM, Fabbro TP, et al. The anatomic reconstruction of acromioclavicular joint dislocations using 2 tight-rope devices: a biomechanical study. *Am J Sports Med*. 2008;36:2398–2406.
- 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.
- 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.
- Wei H-F, Chen Y-F, Zeng B-F, et al. Triple endobutton technique for the treatment of acute complete acromioclavicular joint dislocations: preliminary results. *Int Orthop*. 2011;35:555–559.
- Lim YW. Triple endobutton technique in acromioclavicular joint reduction and reconstruction. *Ann Acad Med Singapore*. 2008;37:294–299.
- Wei HF, Chen YF, Zeng BF, et al. Triple endobutton technique for the treatment of acute complete acromioclavicular joint dislocations: preliminary results. *Int Orthop*. 2011;35:555–559.
- Dong SZ. Digital image correlation: theory and applications. *J Med Biomechanics [in Chinese]*. 2009;24:85–88.
- Mazzocca AD, Conway JE, Johnson S, et al. The anatomic coracoclavicular ligament reconstruction. *Oper Tech Sports Med*. 2004;12:56–61.
- 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.
- Thomas K, Litsky A, Jones G, et al. Biomechanical comparison of coracoclavicular reconstructive techniques. *Am J Sports Med*. 2011;39:804–810.
- 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.
- 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.
- Rockwood CA, Williams GR, Young DC. Disorders of the acromioclavicular joint. In: Rockwood CA, Matsen FA, eds. *The Shoulder*. 3rd ed. Philadelphia: WB Saunders; 2004. 521.
- Saier T, Venjakob AJ, Minzlaff P, et al. Value of additional acromioclavicular cerclage for horizontal stability in complete acromioclavicular separation: a biomechanical study. *Knee Surg Sports Traumatol Arthrosc*. 2014. Doi: <http://dx.doi.org/10.1007/s00167-014-2895-7>.
- Clevenger T, Vance RE, Bachus KN, et al. Biomechanical comparison of acromioclavicular joint reconstructions using coracoclavicular tendon grafts with and without coracoacromial ligament transfer. *Arthroscopy*. 2011;27:24–30.

32. 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.
33. 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.
34. 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:e1047–1052.
35. Shin SJ, Campbell S, Scott J, et al. Simultaneous anatomic reconstruction of the acromioclavicular and coracoclavicular ligaments using a single tendon graft. *Knee Surg Sports Traumatol Arthrosc.* 2013. Doi: <http://dx.doi.org/10.1007/s00167-013-2569-x>.
36. 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.
37. Garg R, Adamson GJ, Javidan P, et al. Biomechanical comparison of an intramedullary and extramedullary free-tissue graft reconstruction of the acromioclavicular joint complex. *Clin Orthop Surg.* 2013;5:298–305.
38. Yoo JC, Ahn JH, Yoon JR, et al. Clinical results of single-tunnel coracoclavicular ligament reconstruction using autogenous semitendinosus tendon. *Am J Sports Med.* 2010;38:950–957.
39. Freedman JA, Adamson GJ, Bui C, et al. Biomechanical evaluation of the acromioclavicular capsular ligaments and reconstruction with an intramedullary free tissue graft. *Am J Sports Med.* 2010;38:958–964.
40. Beitzel K, Sablan N, Chowanec 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.
41. Deshmukh AV, Wilson DR, Zilberfarb JL, et al. Stability of acromioclavicular joint reconstruction: biomechanical testing of various surgical techniques in a cadaveric model. *Am J Sports Med.* 2004;32:1492–1498.
42. Grutter PW, Petersen SA. Anatomical acromioclavicular ligament reconstruction: a biomechanical comparison of reconstructive techniques of the acromioclavicular joint. *Am J Sports Med.* 2005;33:1723–1728.
43. Zooker CCMD, Parks BGM, White KLBS, et al. TightRope versus fiber mesh tape augmentation of acromioclavicular joint reconstruction: a biomechanical study. *Am J Sports Med.* 2010;38:1204–1208.
44. Debski RE, Parsons IMT, Woo SL, et al. Effect of capsular injury on acromioclavicular joint mechanics. *J Bone Joint Surg Am.* 2001;83-A:1344–1351.
45. Gonzalez-Lomas G, Javidan P, Lin T, et al. Intramedullary acromioclavicular ligament reconstruction strengthens isolated coracoclavicular ligament reconstruction in acromioclavicular dislocations. *Am J Sports Med.* 2010;38:2113–2122.
46. Costic RS, Labriola JE, Rodosky MW, et al. Biomechanical rationale for development of anatomical reconstructions of coracoclavicular ligaments after complete acromioclavicular joint dislocations. *Am J Sports Med.* 2004;32:1929–1936.
47. 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.
48. Luis GE, Yong CK, Singh DA, Sengupta S, Choon DS. Acromioclavicular joint dislocation: a comparative biomechanical study of the palmaris longus tendon graft reconstruction with other augmentative methods in cadaveric models. *J Orthop Surg Res.* 2007;2:22.
49. LaPrade RF, Wickum DJ, Griffith CJ, Ludewig PM. Kinematic evaluation of the modified Weaver-Dunn acromioclavicular joint reconstruction. *Am J Sports Med.* 2008;36 (11):2216–2221.
50. Michlitsch MG, Adamson GJ, Pink M, Estess A, Shankwiler JA, Lee TQ. Biomechanical comparison of a modified Weaver-Dunn and a free-tissue graft reconstruction of the acromioclavicular joint complex. *Am J Sports Med.* 2010;38:1196–1203.