texas orthopaedic journal®

ORIGINAL RESEARCH

A Biomechanical Comparison of Coracoclavicular Ligament Reconstructions Using Free Tendon Graft and Suture Augmentation

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ABSTRACT

Introduction: Acromioclavicular joint separations are among the most common injuries in the orthopaedic population. The overall AC separation incidence is 3-4 per 100,000 in the general population, with as many as half of them occurring in athletes.
Methods: Twelve cadaveric shoulders were divided into three equal groups: the intact condition, anatomic coracoclavicular reconstruction with single-loop suture augmentation, and anatomic coracoclavicular reconstruction with multiple-loop suture augmentation. The specimens were conditioned with tensile loading up to 25 N for 10 cycles, then a superiorly directed tensile load in displacement control was applied at a rate of 25 mm/min until failure. Load vs. displacement curves were generated from which stiffness, failure load, failure displacement, and displacement at 70 N were derived.
Results: There were no statistically significant differences between the intact, single-loop reconstruction, and multiple-loop reconstruction in regard to stiffness, failure displacement, or failure load. Alternatively, displacement at 70 N was significantly lower in the multiple-loop reconstruction compared with intact (p=0.042).
Discussion: This study found no significant differences between the native acromioclavicular joint and two anatomic reconstructions with different suture augmentation techniques, single loop and multiple loops, with respect to stiffness, failure displacement, and failure load. The multiple-loop group had significantly less displacement at 70 N compared with intact.
Keywords: Coracoclavicular reconstruction; Acromioclavicular separation.

INTRODUCTION

Acromioclavicular (AC) joint separations are among the most common in the orthopaedic population. There is an overall incidence of 3-4 per 100,000 in the general population with as many as 50% occurring in athletes [1-6]. Approximately 10% of all shoulder girdle injuries involve the AC joint. The most common mechanism of this injury is a fall with a direct force to the lateral aspect of the shoulder with the arm in the adducted position,

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leading to anterior-inferior displacement of the scapula relative to the clavicle which is opposed by impaction on the first rib [2,6,7].

Depending on the degree of injury to the AC joint capsule and its ligaments as well as to the coracoclavicular (CC) ligaments, these injuries are classified in increasing severity as type I through type VI [6,8]. In general type I and type II injuries are treated nonoperatively, with most patients returning to preinjury levels [3,9-14]. Alternatively acute types IV-VI, typically require surgical intervention [6,15-21]. Management of type III dislocations remains controversial as conservative and surgical methods show similar results [12,16,20,22]. Relative indications for surgical intervention in acute type III injuries may be young age, job or sport demands, and chronic symptoms of instability [23].

There are more than 60 different surgical procedures for AC joint reconstruction, dating back to 1861 when Cooper [24] used silver wire for AC joint reduction. Many early techniques relied on metallic implants, including plates, wires [25], and the coracoclavicular screw [17]. Unfortunately, these techniques often had complications requiring hardware removal. This led to a new generation of soft tissue surgeries aimed at recreating the function of the CC and AC ligaments. These include ligament transfer procedures, ligament reconstructions with autologous and allogeneic material, different fixation methods, and augmentations with different suture material. No gold standard has yet been established. Cadenat in 1917 and later Weaver and Dunn developed methods in which the native coracoacromial ligament was transferred to the clavicle to reestablish AC joint stability [26,27]. Modified Weaver-Dunn techniques have been the most popular procedures for several years, but maintaining reduction has been a crucial problem facing these operations [21,28-31]. More recent literature suggests that the transferred ligaments are not as strong as the native CC ligaments, nor do they replicate the normal anatomic configuration.

The coracoclavicular ligament complex includes the postero-medial conoid and the anterior-lateral trapezoid ligaments. The ligaments are similar in their viscoelastic properties [32,33], but each has a unique anatomic orientation that gives it a specific joint-stabilizing function [34-39]. In AC joint capsule injury, the conoid ligament has been found to be the main restraint to inferior translation of the scapulohumeral complex (approximately 60%), while the trapezoid ligament contributes more to posterior clavicular translation. For anatomic reconstruction, specific insertion points on the undersurface of the clavicle and the base of the coracoid have been distinguished [40,41]. The AC ligaments, in particular the superior and posterior, have been found to be in primary control of anterior-posterior translation. The superior ligament provides 56% of resistance to posterior translation, and the posterior ligament contributes 25% [35,37,42].

From a biomechanical standpoint, the significance of the AC/CC capsuloligamentous unit in controlling superior and horizontal translations has been described [33-37,39,42]. In fact, failure to replicate the conoid, trapezoid, and AC ligaments' anatomic functions may explain the observed incidence of recurrent instability and pain [36,42]. This has led to the development of anatomic coracoclavicular ligament reconstruction using stronger synthetic or biologic material.

Current literature shows a trend toward performing a separate reconstruction of the conoid and trapezoid complex to restore joint kinematics [43-49]. Techniques presented remain inconsistent and undecided concerning the best possible reconstruction material (suture vs tendon graft). Graft offers biologic scaffolding for revascularization and when used with interference screw fixation has shown stiffness levels higher than synthetic material. On the other hand, stronger suture material shows increased ultimate failure loading characteristics compared with biologic material [50].

The purpose of this study was to compare the biomechanical properties of two anatomic reconstructions of the acromioclavicular joint that utilize different suture augmentation techniques. The null hypothesis was that no biomechanical differences exist between the two AC joint reconstructions. Alternatively, it was hypothesized that an anatomic graft reconstruction with suture augmentation in a multiple-loop block and tackle pulley formation would display lower displacements, increase ultimate tensile load strength, and resist displacement at low loads when compared with an anatomic graft reconstruction with a single-loop suture augmentation.

MATERIALS & METHODS

Twelve fresh-frozen cadaveric shoulders (mean age, 90 yrs; range, 72-101 yrs; 3 male, 3 female) were randomly assigned into three groups of four: 1) intact, 2) anatomic coracoclavicular reconstruction with single-loop suture augmentation, and 3) anatomic coracoclavicular reconstruction with multiple-loop suture augmentation. The specimens were kept frozen at -4 degrees C until the day before testing. Each shoulder was disarticulated at the glenohumeral joint, and the clavicle and scapula were dissected free of all soft tissue except the acromioclavicular joint capsule and coracoclavicular ligaments. The four specimens in the intact group underwent a biomechanical testing protocol detailed below. The remaining eight specimens received the following two AC joint surgical reconstruction procedures before testing.

Surgical Reconstructions

Anatomic 2-Bundle Coracoclavicular Ligament Reconstruction with Single-Loop Suture Augmentation

Bony landmarks for ligament attachment were identified on each specimen. The anatomic centers of the attachment sites on the undersurface of the clavicle of the trapezoid and conoid ligaments can be carefully delineated after having these ligaments freshly transected. Anatomic graft reconstruction depends on a free graft that can be either autograft or allograft tissue. Lee & Nicholas [44] found no difference in peak load to failure between semitendinosus, toe extensor, and gracilis tendons for reconstruction of the coracoclavicular ligaments in a single-tunnel loop reconstruction of the coracoclavicular ligaments. Therefore, a semitendinosus tendon graft harvested from the specimens was used for reconstruction. No 2 FiberWire (Arthrex, Naples, FL) suture was woven in a baseball type fashion into the distal 2 tails of the graft. The bone tunnel for the conoid ligament was made 45 mm medial from the distal end of the clavicle in the posterior one half of the clavicle in a superior-to-inferior direction. A 6-mm transosseous tunnel was created. This same procedure was repeated to create the tunnel for the trapezoid ligament. This tunnel is a more anterior structure and is typically placed in the center point of the clavicle, approximately 20 mm medial from the distal clavicle, leaving a 25-mm bone bridge between the two tunnels. The graft was then passed under the base of the coracoid and crossed in a fashion such that the lateral limb travels posterior-medial to the tunnel made for the conoid and the medial limb travels anterior-lateral to the tunnel made for the trapezoid. A 5.5 x 15-mm PEEK bioabsorbable interference screw (Arthrex; Naples, FL) was placed into the posterior tunnel, fixing the conoid ligament. The acromioclavicular joint was reduced and held while the free ligament end was tensioned and another 5.5 x 15-mm PEEK screw placed into the trapezoid tunnel. For augmentation, No. 2 FiberWire was looped under the coracoid in a non-crossing fashion, passed through the PEEK screw holes and secured on top of the clavicle by a standard square knot, as depicted in Figure 1.

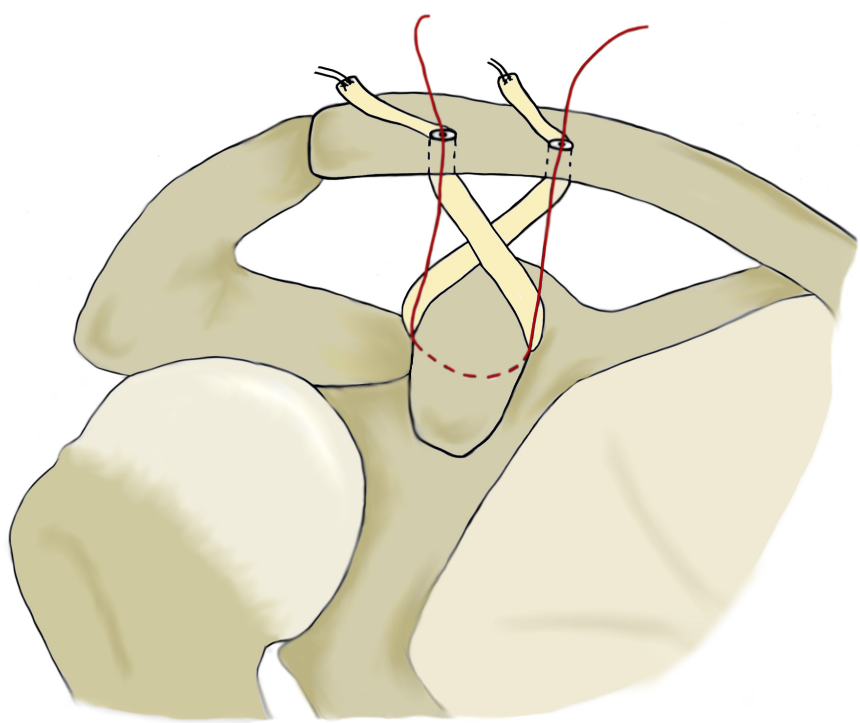

Figure 1. Anatomic 2-bundle coracoclavicular ligament reconstruction with single-loop suture augmentation. No. 2 FiberWire is looped singly under the coracoid, passed through the PEEK screw holes, and secured on top of the clavicle by a standard square knot.

Anatomic 2-Bundle Coracoclavicular Ligament Reconstruction with Multiple-Loop Suture Augmentation

Bone tunnel preparation was performed exactly as stated above but for this method No. 2 FiberWire was looped 3 times under the coracoid and through the bone tunnels in a non-crossing fashion prior to screw placement and tendon fixation, as depicted in Figure 2. After the suture was passed, the acromioclavicular joint was reduced while the suture was tensioned and secured on top of the clavicle by a standard square knot. While the suture held reduction, the tendon graft was tensioned and secured with bioabsorbable screws as stated previously.

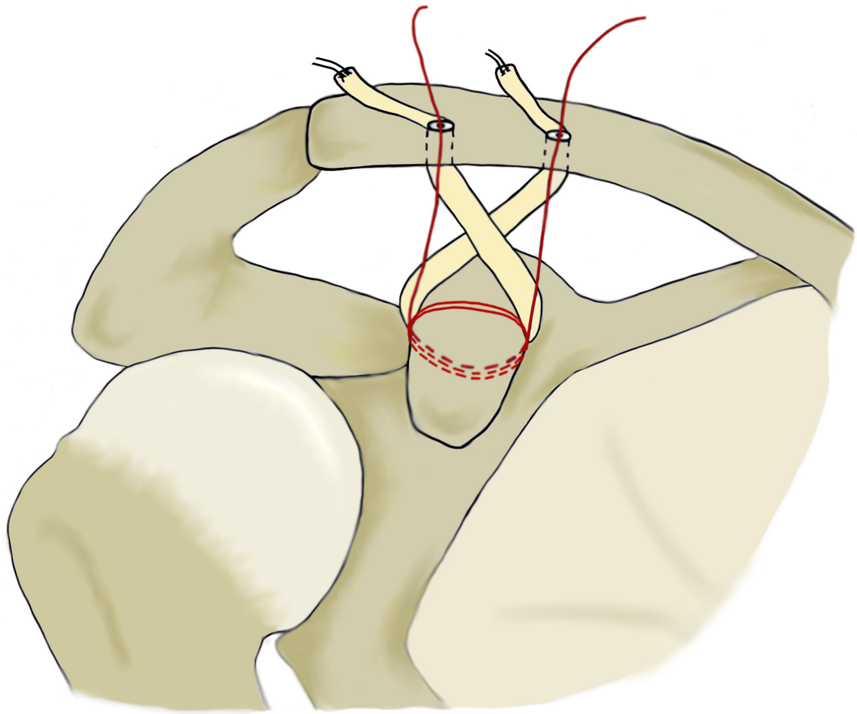

Figure 2. Anatomic 2-bundle coracoclavicular ligament reconstruction with multiple-loop suture augmentation. No. 2 FiberWire is looped 3 times under the coracoid in a non-crossing fashion prior to screw placement and tendon fixation.

Biomechanical Testing

As adapted from a previously reported biomechanical setup [45], the scapula was then potted in polymethylmethacrylate (PMMA) within a custom block from the inferior angle to the edge of the glenoid. Two holes were drilled through the clavicle on either side (medial, lateral) of the AC joint. Metal bolts then secured the clavicle to a metal plate attached to the actuator of an MTS 858 Mini-Bionix materials testing system (MTS, Inc., Eden Prairie, MN). Before testing, the load was zeroed, and the clavicle was rigidly attached to the actuator, allowing the potted scapula to float on the fixture base while the displacement of the actuator was adjusted to a zero load position, thus indicating anatomic origin of the clavicle relative to the scapula. A custom guide was used to drill a 3/8-in hole in the potting of the scapula to mate with the rigidly mounted bolt on the fixture base. The specimen was then bolted into the prescribed anatomic position, ensuring reproducibility when the specimen was reinstalled in the fixture, as shown in Figure 3.

All specimens were conditioned with tensile loading up to 25 N for 10 cycles. A tensile load in displacement control was then applied at a rate of 25 mm/min until failure. Load vs. displacement curves were generated from which stiffness, failure load, failure displacement, displacement at 70 N, and mode of failure were derived. Stiffness was calculated as the slope of the load vs. displacement curve within the linear elastic region. Failure load and failure displacement were measured at the first inflection in the load curve. Displacement at 70 N was also measured based on estimates of physiological load in a light postoperative rehab protocol,

Figure 3. Biomechanical testing setup showing the potted scapula secured to loading platform of the MTS machine. After preconditioning, a tensile load on the clavicle in the superior direction was imparted until failure of the AC joint.

as well as functional loads of tissues during activities of daily living [45,48,51]. Statistical analysis of stiffness, load and displacements for the intact condition, and the single-loop and multiple-loop reconstructions consisted of one-way analysis of variance (ANOVA) with Tukey adjustments for multiple comparisons and alpha was set at 0.05.

RESULTS

All specimens were tested to full failure of the reconstruction construct or bone breakage. A typical load vs. displacement curve is shown for each group (intact, single-loop, and multiple-loop) in Figure 4. The first failure point is marked for each and would represent a clinical failure requiring surgical management. Results for stiffness, failure displacement, failure load, and 70-N displacement are presented in Table 1. There were no statistically significant differences between the intact, single-loop reconstruction, and multiple-loop reconstruction in regard to stiffness, failure displacement, or failure load. Displacement at 70 N was significantly lower in the multiple-loop reconstruction compared with intact (p=0.042).

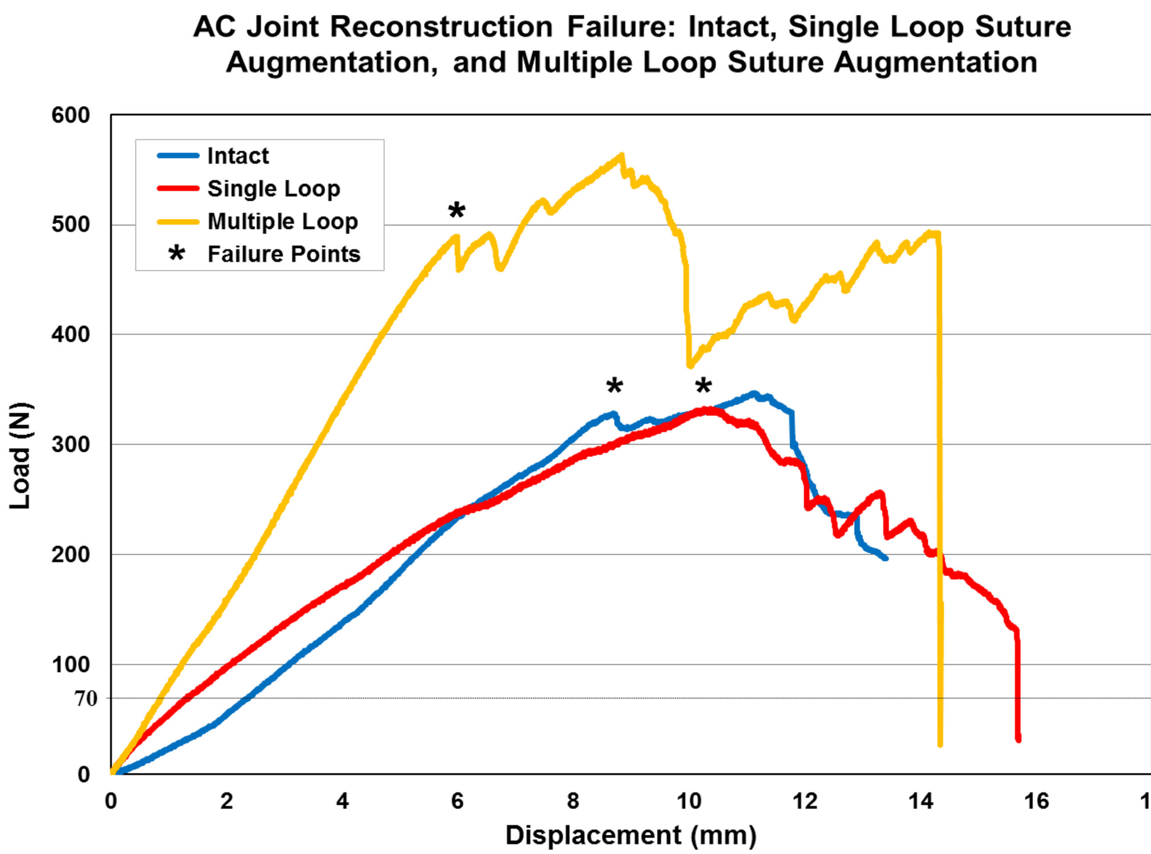

Figure 4. A typical load vs. displacement curve derived from the failure testing protocol is shown for each group (intact, single-loop, and multiple-loop). The first failure points in each would represent clinical failure requiring surgical management. Displacement was also measured and compared at the 70-N load level.

Table 1. Superiorly Directed Tensile Failure of AC Joint: Intact, Single-Loop Suture Augmentation, and Multiple-Loop Suture Augmentation

	Stiffness (N/mm)	Failure Displacement (mm)	First Failure Load (N)	Displacement at 70 N Load (mm)	Mode of Failure
Intact (N=4)	84.0±47.9	6.1±2.2	405.0±184.2	1.8±0.6	Coracoid Fx (1) Clavicle Fx (1) Ligament failure (2)
Single-Loop (N=4)	43.5±6.9	8.3±5.5	366.5±178.7	1.2±0.3	Suture breakage (3) AC disruption (1)
Multiple-Loop (N=4)	68.8±17.1	6.2±3.0	355.1±182.5	1.1±0.2*	Coracoid Fx (2) Clavicle suture bridge Fx (2)
P value	0.30	0.10	0.10	0.65	

* Significant difference between intact and multiple-loop (p=0.042)

Failure modes for the intact group were coracoid fracture in 1, clavicle fracture in 1, and ligament failure in 2 specimens. The single-loop fixation failed as suture breakage in 3 specimens, and AC disruption in 1 specimen, whereas for the multiple-loop fixation, failures were coracoid fracture in 2 and clavicle suture bridge fracture in 2 specimens.

DISCUSSION

Currently, both nonanatomic and anatomic AC reconstructions are being performed for types III-VI AC joint dislocations. Several biomechanical studies have been performed to determine which type of surgical procedure best restores the stability and strength of the AC joint. Harris & Wallace showed the initial strength of coracoacromial ligament transfer to be approximately one fourth that of normal intact coracoclavicular ligaments [33]. The relatively weak strength of this reconstruction can lead to an incomplete reduction or recurrence of subluxation in up to 30% of cases [27]. In fact, Clevenger et al. showed that the addition of a coracoacromial transfer to a nonanatomic graft reconstruction augmented with high-strength suture does not significantly improve its overall strength [52]. While comparing the modified Weaver-Dunn to other nonanatomic reconstructions, Lee & Nicholas found that the nonanatomic tendon allograft reconstruction had higher load to failure than the coracoacromial ligament transfer and was equivalent to the native CC ligaments [44]. In contrast, Costic et al. showed that anatomic allograft reconstructions had the highest load to failure and a higher stiffness when compared with the intact ligaments [45]. Even further, Mazzocca et al. revealed that anatomic allograft reconstruction was the only group to restore anterior, posterior, and superior stability to the intact state, when compared with the Weaver-Dunn and another nonanatomic arthroscopic technique [48]. Thomas et al. showed that an anatomic graft reconstruction with suture augmentation had higher load to failure than a Weaver-Dunn with augmentation, a nonanatomic graft with augmentation, and anatomic suturing techniques [53].

The current biomechanical study compared properties of the native coracoclavicular ligaments of the AC joint with two types of augmentation for anatomic reconstruction. It was hypothesized that the multiple-loop augmentation would show greater stability and failure strength compared with a single loop. The results showed both single- and multiple-loop augmentations to restore mean stiffness, failure displacement, and failure load to intact levels with no statistical differences.

The multiple-loop augmentation did show significantly less displacement than the intact condition at 70-N loads. This decreased displacement with the multiple-loop augment could provide a protective mechanism during the low-load early postoperative and rehabilitation period. Assuming that revascularization will occur with AC reconstruction as previously shown for ulnar collateral ligament (elbow) and anterior collateral ligament (knee) surgeries, it may lead to a temporary weakening of the tendon graft during the first 6 to 10 weeks, when compared with its initial fixation strength. Animal models have shown that this is even more profound with allograft tissue use. Therefore, protecting the biologic material through this period of healing and remodeling would be beneficial. The multiple-loop augmentation showed decreased displacement at loads previously reported to be an important limit for forces seen during early rehab that may allow the graft to potentially heal in a less elongated position and better maintain AC joint reduction. It also may allow more advanced rehabilitation protocols than are currently used. As seen in the loading curves (Figure 4), 70 N occurs well below the first failure inflection, and within the elastic region for all constructs. While this trend is interesting, this study cannot conclusively state that the multiple loop suture would provide this benefit.

Some qualitative observations can be made from the modes of failure observed [46,49]. While 3 of the 4 specimens in the single loop augmentation failed by initial suture rupture, no specimens in the multiple-loop group failed as a result of suture rupture or graft stretching. It appears that the addition of high-strength cerclage sutures, while improving these properties, may transfer the mode of failure from the graft to the bone through a stiffer construct.

The stronger biomechanical constructs may not be superior in the clinical setting, and many valid clinical issues are taken into account in choosing the optimal fixation. One prospective randomized study by Tauber at al. [54] compared the Weaver-Dunn to an anatomic reconstruction, but we do not know of any comparative clinical studies on augmented anatomic reconstructions. The scarcity of prospective clinical studies precludes establishing determinants of best clinical outcome. As a limiting factor in the present cadaveric study, our specimen age was certainly higher than the typical age of a patient undergoing an AC joint reconstruction. The constraints of acquiring cadaveric specimens did not make it possible to obtain specimens from younger donors, which may have influenced the modes of failure inn our study. Age may have been an important factor in failure mode and ultimate failure strength in the multiple-loop group.

With only 4 specimens per group, this study was underpowered and the possibility for Type II error is rather high, particularly for stiffness. Post hoc analysis showed that the samples required to detect differences between the two reconstructions in stiffness, failure displacement, failure load, and 70-N displacement at 0.80 power were 6, 72, >3000, and 41, respectively.

Another limitation in the present study is that the strength of fixation was tested in only the superior direction. Typical failure methods are from an acute blow to the lateral shoulder causing vertical stress to the AC joint but persistent pain after reconstruction may be the result of horizontal plane instability. This would be better addressed by adding anterior and posterior cyclic testing. More anatomic fixation was developed in part to more closely replicate the true multidirectional functions of the CC ligaments. Previous studies have already elucidated that anatomic reconstructions better replicate the AC joint stability in the anterior and posterior directions. Our goal was to isolate augmentation techniques to acute, high-load failure modes commonly seen with lateral shoulder impact.

CONCLUSIONS

This biomechanical cadaver study found no significant differences between the native acromioclavicular joint and two anatomic reconstructions with different suture augmentation techniques, single loop and multiple loops, with respect to stiffness, failure displacement, and failure load.

REFERENCES

[1] Allman FL. Fractures and ligamentous injuries of the clavicle and its articulation. J Bone Joint Surg Am. 1967;49(4):774-84.

[2] Dias JJ, Gregg PJ. Acromioclavicular joint injuries in sport. Recommendations for treatment. Sports Med. 1991;11(2):125-32.

[3] Lemos MJ. The evaluation and treatment of the injured acromioclavicular joint in athletes. Am J Sports Med. 1998;26(1):137-44.

[4] Meister K. Injuries to the shoulder in the throwing athlete, part 1: biomechanics/pathophysiology/classification of injury. Am J Sports Med. 2000;28(2):265-75.

[5] Meister K. Injuries to the shoulder in the throwing athlete, part 2: evaluation/treatment. Am J Sports Med. 2000;28(4):587-601.

[6] Rockwood CA. Disorders of the AC joint. In: Rockwood CA, Matsen F (eds). The Shoulder. 2nd ed. Philadelphia, PA: WB Saunders. 1990. pp.483-543.

[7] Cox JS. Acromioclavicular joint injuries and their management principles. Ann Chir Gynaecol. 1991;80:155-9.

8] Tossy JD, Mead NC, Sigmond HM. Acromioclavicular separations: useful and practical classification for treatment. Clin Orthop Relat Res. 1963;28:111-9.

[9] Cox JS. The fate of the acromioclavicular joint in athletic injuries. Am J Sports Med. 1981;9(1):50-3.

[10] Dawe CJ. Acromioclavicular joint injuries. J Bone Joint Surg Br. 1980;62:269.

[11] Dias JJ. The conservative treatment of acromioclavicular dislocation: review after five years. J Bone Joint Surg Br. 1987;69(5):719-22.

[12] Galpin RD. A comparative analysis of operative versus nonoperative treatment of grade III acromioclavicular separations. Clin Orthop Rel Res. 1985;193:150-5.

[13] Bergfeld JA. Andrish JT, Clancy WG. Evaluation of the acromioclavicular joint following first and second-degree sprains. Am J Sports Med. 1978;6(4):153-9.

[14] Mouhsine E, Garofalo R, Crevoisier X, Farron A. Grade I and II acromioclavicular dislocations: results of conservative treatment. J Shoulder Elbow Surg. 2003;12(6):599-602.

[15] Ahstrom JP. Surgical repair of complete acromioclavicular separation. JAMA. 1971;217(6):785-9.

[16] Bannister GC. The management of acute acromioclavicular dislocation: a randomized prospective controlled trial. J Bone Joint Surg Br. 1989;71(5):848-50.

[17] Bosworth BM. Acromioclavicular separation: new method of repair. Surg Gynecol Obstet. 1941;73:866-71.

[18] Bunnell S. Fascial graft for dislocation of the acromioclavicular joint. Surg Gynecol Obstet. 1928;46:563-4.

[19] Kennedy JC, Cameron H. Complete dislocation of the acromioclavicular joint. J Bone Joint Surg Br. 1954;36(2):202-8.

[20] Larsen E. Conservative or surgical treatment of acromioclavicular dislocation: a prospective, controlled, randomized study. J Bone Joint Surg Am. 1986;68(2):552-5.

[21] Tienen TG, Oyen JF, Eggen PJ. A modified technique of reconstruction for complete acromioclavicular dislocation: a prospective study. Am J Sports Med. 2003;31(5):655-9.

[22] Wojtys EM, Nelson G. Conservative treatment of grade III acromioclavicular dislocations. Clin Orthop Rel Res. 1991;268:112-9.

[23] Simovitch R, Sanders B. Acromioclavicular joint injuries: diagnosis and management. J Am Acad Orthop Surg. 2009;17(4):207-19.

[24] Cooper E. New method of treating long standing dislocations of the scapuloclavicular articulation. Am J Med Sci. 1861:41.

[25] Murray G. Fixation of dislocations of the acromioclavicular joint and rupture of the coracoclavicular ligaments. Can Med Assoc J. 1940;43(3):270-1.

[26] Cadenat F. The treatment of dislocation and fractures of the outer end of the clavicle. Int Clin. 1917;1:145-69.

[27] Weaver JK, Dunn HK. Treatment of acromioclavicular injuries, especially complete acromioclavicular separation. J Bone Joint Surg Am. 1972;54(6):1187-94.

[28] Weinstein DM, McCann PD. Surgical treatment of complete acromioclavicular dislocations. Am J Sports Med. 1995;23(3):324-31.

[29] Deshmukh AV, Wilson DR. Stability of acromioclavicular joint reconstruction: biomechanical testing of various surgical techniques in a cadaveric model. Am J Sports Med. 2004;32(6):1492-8.

[30] Baker JE, Nicandri GT. A cadaveric study examining acromioclavicular joint congruity after different methods of coracoclavicular loop repair. J Shoulder Elbow Surg. 2003;12(6):595-8.

[31] Wilson DR, Moses JM. Mechanics of coracoacromial ligament transfer augmentation for acromioclavicular joint injuries. J Biomech. 2005;38(3):615-9.

[32] Costic RS, Vangura A, Debski RE. Viscoelastic behavior and structural properties of the coracoclavicular ligaments. Scand J Med Sci Sports. 2003;13:305-10.

[33] Harris RI, Wallace AL. Structural properties of the intact and the reconstructed coracoclavicular ligament complex. Am J Sports Med. 2000;28(1):103-8.

[34] Harris RI, Vu DH. Anatomic variance of the coracoclavicular ligaments. J Shoulder Elbow Surg. 2001;10(6):585-8.

[35] Fukuda K, Craig EV. Biomechanical study of the ligamentous system of the acromioclavicular joint. J Bone Joint Surg Am. 1986;68(3):434-440.

[36] Jari R, Costic RS, Debski RE. Biomechanical function of surgical procedures for acromioclavicular joint dislocation. Arthroscopy. 2004;20(3):237-45.

[37] Lee KW, Debski RE, Fu F. Functional evaluation of the ligaments at the acromioclavicular joint during anteroposterior and superoinferior translation. Am J Sports Med. 1997;25(6):858-62.

[38] Debski RE, Parsons IM, Fu F. Ligament mechanics during three degree-of-freedom motion at the acromioclavicular joint. Ann Biomed Eng. 2000;28(6):612-8.

[39] Debski RE, Parsons IM. Effect of capsular injury on acromioclavicular joint mechanics. J Bone Joint Surg Am. 2001;83:1344-51.

[40] Rios CG, Arciero RA, Mazzocca AD. Anatomy of the clavicle and coracoid process for reconstruction of the coracoclavicular ligaments. Am J Sports Med. 2007;35(5):811-7.

[41] Salzmann GM, Paul J. The coracoidal insertion of the coracoclavicular ligaments: an anatomic study. Am J Sports Med. 2008;36(12):2392-7.

[42] Klimkiewicz JJ, Williams GR. The acromioclavicular capsule as a restraint to posterior translation of the clavicle:A biomechanical analysis. J Shoulder Elbow Surg. 1999;8(2):119-24.

[43] Jones HP, Lemos MJ. Salvage of failed acromioclavicular joint reconstruction using autogenous semitendinosus tendon from the knee. Surgical technique and case report. Am J Sports Med. 2001;29(2):234-7.

[44] Lee SJ, Nicholas SJ. Reconstruction of the coracoclavicular ligaments with tendon grafts: a comparative biomechanical study. Am J Sports Med. 2003;31(5):639-55.

[45] Costic RS, Labriola JE, Debski RE. Biomechanical rationale for development of anatomical reconstructions of coracoclavicular ligaments after complete acromioclavicular joint dislocation. Am J Sports Med. 2004;32(8):1929-36.

[46] Grutter PW, Petersen SA. Anatomic acromioclavicular ligament reconstruction: a biomechanical comparison of reconstructive techniques of the acromioclavicular joint. Am J Sports Med. 2005;33(11):1723-8.

[47] LaPrade RF, Hilger B. Coracoclavicular ligament reconstruction using semitendinosus graft for failed acromioclavicular separation surgery. Arthroscopy. 2005;21(10):1277.

[48] Mazzocca AD, Santangelo SA, Rios CG. A biomechanical evaluation of an anatomical coracoclavicular ligament reconstruction. Am J Sports Med. 2006;34(2):236-46.

[49] Carofino BC, Mazzocca AD. The anatomic coracoclavicular ligament reconstruction:-Surgical technique and indications. J Shoulder Elbow Surg. 2010;19(Suppl2):37-46.

[50] Walz L, Salzmann GM. The anatomic reconstruction of acromioclavicular joint dislocations using 2 TightRope devices: a biomechanical study. Am J Sports Med. 2008;36(12):2398-406.

[51] Wellman M, Kempa JP. Coracoclavicular ligament reconstruction: biomechanical comparison of tendon graft repairs to a synthetic double bundle augmentation. Knee Surg Sports Traumatol Arthrosc. 2009;17:521-8.

[52] Clevenger T, Vance RE, Bachus KN, Burks RT, Tashjian RZ. Biomechanical comparison of acromioclavicular joint reconstructions using coracoclavicular tendon grafts with and without coracoacromial ligament transfer. Arthroscopy. 2011;27(1):24-30.

[53] Thomas K, Litsky A, Jones G, Bishop JY. Biomechanical comparison of coracoclavicular reconstructive techniques. Am J Sports Med. 2011;39(4):804-10.

[54] Tauber M, Gordon K, Koller H, Fox M, Resch H. Semitendinosus tendon graft versus a modified Weaver-Dunn procedure for acromioclavicular joint reconstruction in chronic cases: Am J Sports Med. 2009;37(1):181-90.