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The Effect of Distal Clavicle Excision on In Situ Graft Forces in Coracoclavicular Ligament Reconstruction

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Background: Recently, some have suggested that the acromioclavicular articulation confers stability to the construct after coracoclavicular ligament reconstruction for acromioclavicular joint separation. Therefore, it has been suggested that distal clavicle excision should not be performed in this context to protect the graft during healing.

Hypothesis: Sectioning the acromioclavicular ligaments would significantly increase in situ forces of a coracoclavicular ligament graft, whereas performing a distal clavicle resection would not further increase in situ graft forces.

Design: Controlled laboratory study.

Methods: A simulated coracoclavicular reconstruction was performed on 5 cadaveric shoulders. Static loads of 80 N and 210 N were applied directly to the clavicle in 5 directions: anterior, anterosuperior, superior, posterosuperior, and posterior. The in situ graft force was measured using a force transducer under 3 testing conditions: (1) intact acromioclavicular ligaments, (2) sectioned acromioclavicular ligaments, and (3) distal clavicle excision.

Results: For both magnitudes of load, in all directions, in situ graft force with intact acromioclavicular ligaments was significantly less than that with sectioned acromioclavicular ligaments ($P < .001$). Distal clavicle excision did not further increase the in situ graft forces with load applied to the clavicle in an anterior, anterosuperior, or superior direction. However, in situ graft forces were increased with distal clavicle excision when the clavicle was loaded with 210 N in the posterosuperior direction (60.4 $\pm$ 6.3 N vs 52.5 $\pm$ 7.1 N; $P = .048$) and tended to be increased with posterior loading of the clavicle (71.8 $\pm$ 6.2 N vs 53.1 $\pm$ 8.8 N; $P = .125$).

Conclusion: Intact acromioclavicular ligaments protect the coracoclavicular reconstruction by decreasing the in situ graft force. The slight increase in the in situ graft force only in the posterosuperior and posterior direction after distal clavicle excision suggests only a marginal protective role of the acromioclavicular articulation. Further, the peak graft forces observed represent only a small fraction of the ultimate failure strength of the graft.

Clinical Relevance: Distal clavicle excision can perhaps be safely performed in the context of coracoclavicular ligament reconstruction without subjecting the graft to detrimental in situ force. Although the acromioclavicular articulation serves only a marginal role in protecting the coracoclavicular ligament graft, reconstruction of the acromioclavicular ligaments may serve an important role in decreasing in situ graft force during healing.

Keywords: acromioclavicular (AC) joint separation; coracoclavicular (CC) ligament reconstruction; in situ graft force; distal clavicle resection

The functional anatomy of the acromioclavicular (AC) joint has been described in detail in the orthopaedic literature. The AC capsule and ligaments, together with the coracoclavicular (CC) ligaments, serve in concert to preserve normal kinematics of the AC joint.[7,21] The AC ligaments, particularly the superior and posterior components, serve as the primary restraint to horizontal translation (Nicholson et al, unpublished data, 2002).[13,19,37,43] The conoid and trapezoid ligaments compose the CC ligament complex. The former serves as the primary restraint to vertical translation,

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while the latter serves as the primary restraint to axial compression.[13] Both participate in horizontal stability once the AC ligaments are injured or sectioned in the laboratory.[8]

Treatment strategies for the management of AC separation are based on the concept of sequential injury to the AC joint capsule and ligaments, the CC ligaments, and the deltotrapezial fascia.[2,53,60] Type I and II injuries, involving torn AC capsule and ligaments, have traditionally been treated nonoperatively.[27] In contrast, type IV through VI injuries, which involve not only the AC and CC ligaments, but also the deltotrapezial fascia, require operative intervention. Type III AC separations can be treated with a trial of nonoperative management, with operative intervention reserved for persistent symptoms.[¶]

Innumerable procedures have been described for the treatment of this injury.[#] Operative intervention for AC joint separation should attempt to reestablish native kinematics of the AC joint by repairing or reconstructing some or all of these structures. For some time, the mainstay of treatment had been the Weaver-Dunn reconstruction using a coracoacromial (CA) ligament transfer.[20,32,44,51,56,58] However, biomechanical studies revealed that the reconstruction possessed only 20% to 30% strength of the native CC ligaments, and that it was unable to reproduce the normal kinematics of the native AC joint, with increased primary and coupled translation.[3,15,16,22,26,28,50] In turn, suboptimal clinical results have been observed in the literature using this technique, with only 77% good-to-excellent results in chronic cases, and recurrent subluxation rates as high as 30%.[51,57]

Therefore, attention has been turned to a more anatomical approach to CC ligament reconstruction. Biomechanical investigations have demonstrated that the strength and stiffness of CC reconstruction using tendon graft resembles that of the native structures.[3,4,22,26] Further, anatomical CC reconstruction based on the native insertion of ligaments reestablishes the kinematics of the normal AC joint, with decreased horizontal translation.[26,37,38] Consequently, CC ligament reconstruction using tendon graft has been associated with improved outcomes in several clinical series (Arciero RA, unpublished data, 2009).[30,33,49-51]

Recently, controversy has arisen regarding the treatment of the distal clavicle when performing a reconstruction for AC separation. Previous work has documented the incidence of radiographic degeneration of the AC joint following separation, although its clinical relevance is still unknown.[10,47,48] Other literature has demonstrated that a significant proportion of patients who sustain even low-grade AC joint separations subsequently develop posttraumatic AC joint pain, even in the absence of radiographic arthrosis.[27] Moreover, biomechanical investigation has shown that CC ligament reconstruction may increase the AC joint contact force, further predisposing these patients to AC joint pain and arthrosis.[16] Thus, distal clavicle excision is often performed as an adjunct to CC ligament reconstruction. Recently, some have suggested that the distal clavicle should be preserved, theorizing that the AC articulation provides some stability to the construct, thus protecting the tendon graft during healing.[5,16,25] Certainly, the importance of the AC capsule and ligaments to AC joint stability has been established.[8,13,19] However, the importance of the AC articulation itself has not yet been conclusively demonstrated. This study examines the in situ graft forces of a simulated CC ligament reconstruction (1) with intact AC ligaments, (2) with sectioned AC ligaments and an intact AC articulation, and (3) after distal clavicle resection, to determine the relative roles of the AC ligaments and the AC joint in protecting the graft during healing. It was hypothesized that sectioning the AC ligaments would significantly increase in situ graft forces, whereas performing a distal clavicle resection would not further increase these forces.

METHODS

Five male fresh-frozen whole cadaveric shoulders (average age, 36 ± 13 years) were thawed at room temperature and thoroughly dissected. The specimens were disarticulated at the glenohumeral joint, and the scapula and clavicle were dissected free of all soft tissue except the CA ligament, the AC joint capsule and ligaments, and the CC ligaments. The specimens were kept moist with a saline solution throughout the experiment to reproduce physiologic conditions.

The scapula was mounted to a custom testing apparatus using an external fixation system (Stryker, Mahwah, New Jersey), and the clavicle was attached to a pulley system. The configuration of the external fixation construct consisted of two 5-mm pins in the scapular spine, two 5-mm pins in the glenoid subchondral bone, and one 4-mm pin in the inferior angle. All pins were connected to each other using a series of pin-to-rod couplings, 8-mm carbon rods, and rod-to-rod couplings, and the scapula was then connected to the custom testing apparatus with multiple points of fixation (Figure 1). This established a rigid construct, and isolated the load transmission to the AC joint itself. The apparatus allowed the application of linear force to the clavicle relative to the scapula, and by adjusting the position of the scapula on the apparatus, the force could be exerted in any desired direction.

The native CC ligaments were sectioned, and a CC ligament reconstruction was then simulated using No. 2 FiberWire suture (Arthrex, Naples, Florida) in place of the tendon graft, according to a previously described reconstruction technique.[3,22,30] A 4-mm drill hole was created immediately superior to the coracoid, between the middle and posterior thirds of the clavicle. The suture was passed beneath the coracoid. The medial limb was then passed through the drill hole from inferior to superior. This limb was then brought anterior to the clavicle and tied to the lateral limb using a surgeon's knot followed by alternating half-hitches. The suture was attached to a force transducer to directly measure in situ graft force (Figures 2 and 3).

Static loads of 80 N and 210 N were applied directly to the clavicle in 5 directions: anterior, anterosuperior, superior, posterosuperior, and posterior. These magnitudes

¶References 11, 14, 24, 31, 34-36, 42, 45, 54.

#References 1, 3, 6, 9, 14, 17, 18, 23, 39-42, 46, 52, 55, 59.

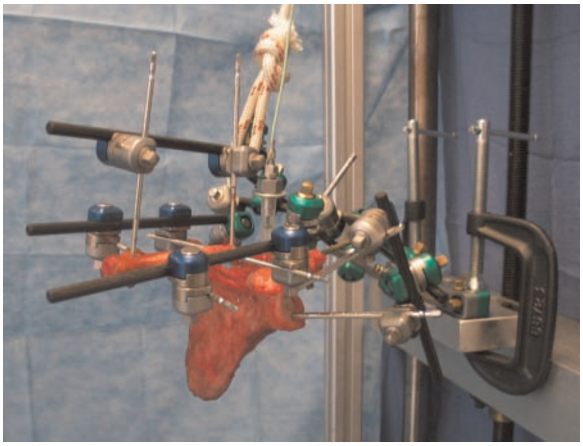

Figure 1. Illustration of the scapula mounted to the custom testing apparatus with external fixation, and of the clavicle attached to a pulley system.

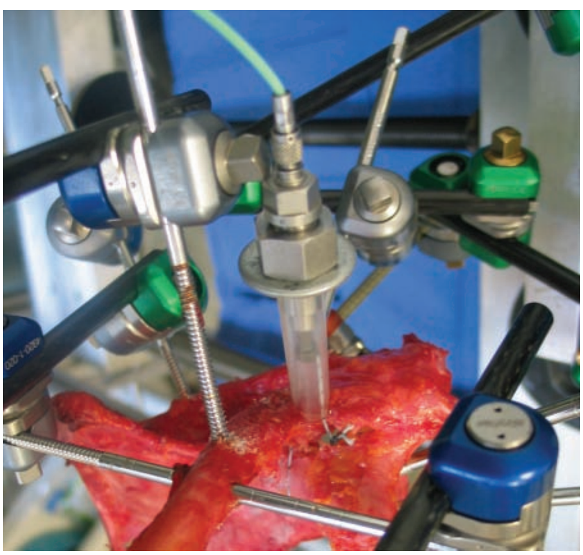

Figure 2. The simulated coracoclavicular ligament reconstruction was attached to a force transducer to directly measure in situ graft force.

represent values previously used in biomechanical studies of AC joint reconstruction techniques.[3,22] A load of 80 N represents the highest load exerted upon the CC ligament graft attributed to the weight of the arm. A load of 210 N represents approximately 75% of the tensile strength of the suture material. The in situ graft force was measured under 3 testing conditions: (1) intact AC ligaments, (2) sectioned AC ligaments with an intact articulation, and (3) sectioned AC ligaments with a distal clavicle excision. Distal clavicle excision was performed using an oscillating saw, removing 10 mm of bone perpendicular to the plane of the AC joint. Measurements were made in all 5 directions for each testing condition before establishing and testing the next condition. For the first testing condition, force was applied in the following order: anterior,

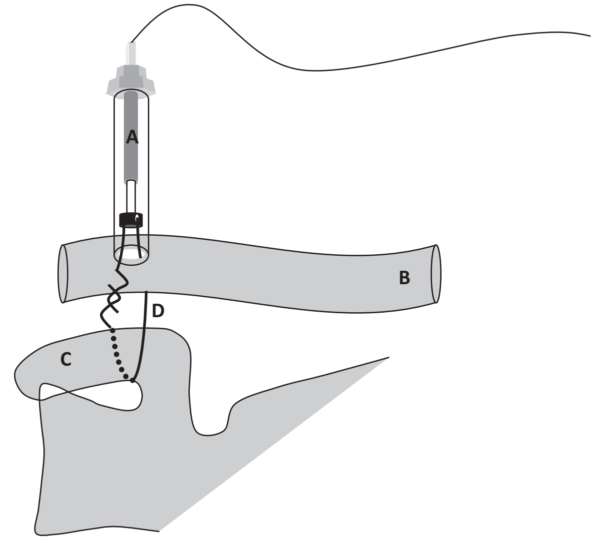

Figure 3. Schematic diagram illustrating the simulated coracoclavicular ligament reconstruction. A, force tranducer; B, clavicle; C, coracoid; D, No. 2 FiberWire suture.

anterosuperior, superior, posterosuperior, and posterior. For each subsequent testing condition, force was applied to the clavicle in reverse sequence.

Friedman tests (nonparametric test for within-subject analysis on an independent variable with more than 2 levels) were used to examine effects of AC joint integrity (intact AC ligaments, sectioned AC ligaments with intact articulation, and distal clavicle resection) and direction of load on the clavicle (anterior, anterosuperior, superior, posterosuperior, posterior). Wilcoxon signed rank tests (nonparametric test for within-subject pairwise comparisons) were subsequently used to compare in situ graft forces between any 2 particular conditions where the Friedman test was significant. Differences between in situ graft forces for intact versus sectioned AC ligaments, and sectioned AC ligaments versus distal clavicle resection, were assessed using 1-tailed Wilcoxon tests because graft force could either increase or stay the same but could not logically decrease between conditions. Two-tailed tests were used for assessing effects of the direction of load on the clavicle. Statistical significance was set at $P < .05$.

RESULTS

The in situ graft force data for each testing condition, when averaged across all 5 directions, are shown in Table 1 and Figures 4 and 5. With an intact AC capsule and ligaments, the in situ graft force with 80 N and 210 N of load applied to the clavicle was 5.0 ± 0.6 N and 15.1 ± 2.5 N, respectively. When the AC capsule and ligaments were sectioned, then in situ graft force increased to 15.9 ± 2.1 N and 54.1 ± 3.0 N, respectively ($P < .001$). Finally, when the distal clavicle excision was performed, the in situ graft force with 80 N and 210 N of load applied were 16.7 ± 1.2 N

TABLE 1
In Situ Graft Force Averaged Across All 5 Directions, in Newtons[a]

Condition	80 N	210 N
Intact	5.0 ± 0.6	15.1 ± 2.5
Sectioned	15.9 ± 2.1	54.1 ± 3.0
DCE	16.7 ± 1.2	58.2 ± 2.8

[a]Intact, intact acromioclavicular capsule and ligaments; sectioned, sectioned acromioclavicular capsule and ligaments; DCE, distal clavicle excision.

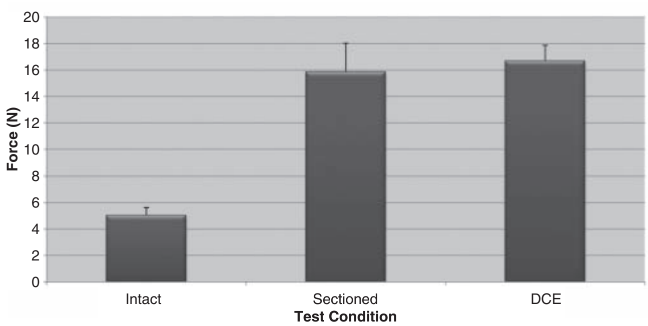

Figure 4. In situ graft force for 80 N of load, averaged across all 5 directions. Intact, intact acromioclavicular capsule and ligaments; sectioned, sectioned acromioclavicular capsule and ligaments; DCE, distal clavicle excision.

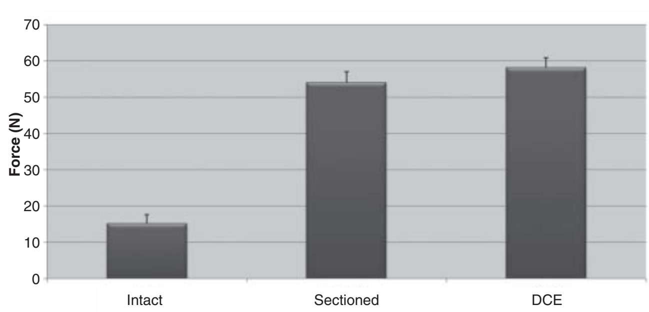

Figure 5. In situ graft force for 210 N of load, averaged across all 5 directions. Intact, intact acromioclavicular capsule and ligaments; sectioned, sectioned acromioclavicular capsule and ligaments; DCE, distal clavicle excision.

and 58.2 ± 2.8 N, respectively, which did not represent a significant further increase. In summary, for both loading conditions, in all directions, in situ graft force with sectioned AC ligaments was significantly more than that with intact ligaments. However, subsequently performing a distal clavicle excision did not lead to any further statistically significant increase in this force.

The in situ graft force data for each testing condition, broken down into each of the 5 directions of load applied to the clavicle, are shown in Table 2. With 80 N of load applied to the clavicle, the graft experienced in situ force ranging from 1.4 to 10.2 N, depending on the direction of load. For each direction of load applied to the clavicle, sectioning the AC capsule and ligaments significantly increased the in situ graft force, whereas no additional increase in the in situ graft force occurred when the distal clavicle excision was performed (Figure 6).

Application of a 210-N load to the clavicle markedly increased in situ graft forces compared with 80 N, regardless of direction of load ($P < .05$) (Table 2). With an intact AC capsule and ligaments, the in situ graft forces were 29.1 N with superior clavicle load, 27.3 N with posterosuperior clavicle load, and less than 10 N for all other directions. For each direction of load applied to the clavicle, sectioning the AC capsule and ligaments significantly increased the in situ graft force ($P < .05$). Distal clavicle excision did not further increase the in situ graft forces with anterior, anterosuperior, and superior loads applied to the clavicle. However, in situ graft forces were increased with distal clavicle excision when the clavicle was loaded in the posterosuperior direction (60.4 ± 6.3 N vs 52.5 ± 7.1 N; $P = .048$), and tended to be increased with posterior loading of the clavicle (71.8 ± 6.2 N vs 53.1 ± 8.8 N; $P = .125$), as shown in Figure 7.

DISCUSSION

The critical importance of the AC capsule and ligaments to AC joint stability has previously been clearly demonstrated,[8,13,19] establishing that these structures serve as the primary restraint to horizontal translation. Further, these studies revealed that sectioning the AC ligaments leads to an increase in the in situ force of the CC ligaments, confirming the importance of the AC ligaments in protecting the CC ligament graft during healing. This investigation confirmed these findings in the context of CC ligament reconstruction. With 210 N of applied force, the in situ force increased from 15.1 to 54.1 N, representing a 3.6-fold increase. These findings support the notion offered by Fukuda et al[13] that " . . . if maximum strength of healing after an injury to the acromioclavicular joint is the goal, all ligaments should be allowed to participate in the healing process . . ." including the AC ligaments.

However, the role of the AC articulation itself in conferring stability to the construct, and subsequently protecting the graft during healing, has not yet been addressed specifically in the literature. Some have suggested that compressive load at the articulation between the acromion and distal clavicle confers stability to this joint, and thus may serve to decrease pathologic translation therein.[4,5,16] Thus, this compressive load may prove beneficial in CC ligament reconstruction by protecting the CC ligament graft. In turn, distal clavicle excision is discouraged in this context. Costic et al[4] found that compressive load of 70 N at the AC articulation led to substantially decreased translation of the distal clavicle as compared with 10 N of compressive load. More recently, Dawson et al[5] demonstrated that compressive load of 30 N at the AC joint was

TABLE 2
In Situ Graft Force Broken Down by Direction of Load, in Newtons[a]

	Intact		Sectioned		DCE	
	80 N	210 N	80 N	210 N	80 N	210 N
Anterior	2.3 ± 1.0	3.3 ± 2.1	12.4 ± 2.9	50.1 ± 3.5	12.4 ± 2.2	46.7 ± 8.2
Anterosuperior	1.4 ± 0.8	9.9 ± 4.5	18.8 ± 1.7	56.1 ± 4.4	20.4 ± 2.2	57.8 ± 5.7
Superior	10.2 ± 3.2	29.1 ± 9.3	16.4 ± 3.5	58.8 ± 3.5	15.5 ± 2.9	54.1 ± 4.3
Posterosuperior	7.0 ± 2.7	27.3 ± 5.3	15.5 ± 3.2	52.4 ± 7.1	15.8 ± 4.3	60.4 ± 6.3
Posterior	4.1 ± 2.0	6.0 ± 2.7	16.1 ± 4.1	53.1 ± 8.8	19.2 ± 3.8	71.9 ± 6.2

[a]Intact, intact acromioclavicular capsule and ligaments; sectioned, sectioned acromioclavicular capsule and ligaments; DCE, distal clavicle excision.

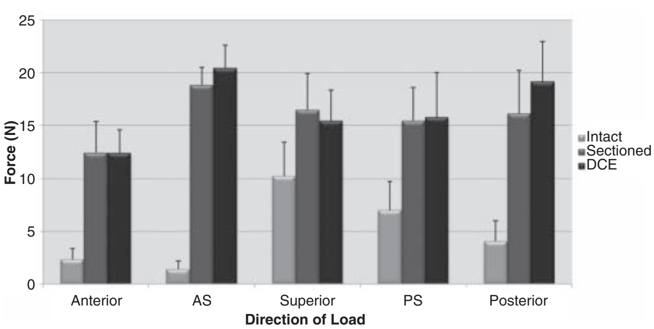

Figure 6. In situ graft force for 80 N, broken down by direction of load. Intact, intact acromioclavicular capsule and ligaments; sectioned, sectioned acromioclavicular capsule and ligaments; DCE, distal clavicle excision. AS, anterosuperior; PS, posterosuperior.

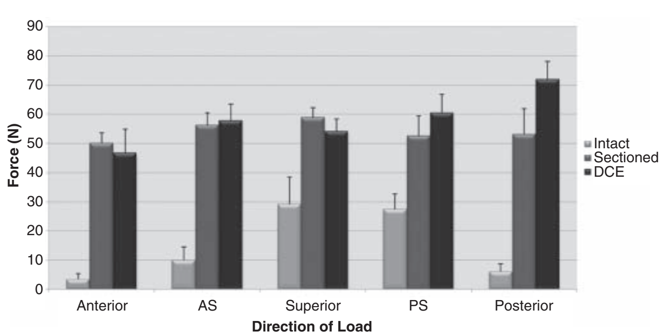

Figure 7. In situ graft force for 210 N, broken down by direction of load. Intact, intact acromioclavicular capsule and ligaments; sectioned, sectioned acromioclavicular capsule and ligaments; DCE, distal clavicle excision. AS, anterosuperior; PS, posterosuperior.

associated with significantly less translation of the distal clavicle compared with 10 N of compressive load. They conclude that "the distal clavicle may play an important role in AC joint stability and that leaving the distal clavicle intact may improve surgical outcomes." However, compressive load at the AC joint in normal specimens ranged from 3 to 18 N, well below the 30- to 70-N loads examined in these studies.[16] Therefore, the magnitude of compressive load required to exert a beneficial stabilizing effect on the AC joint is likely never encountered under physiologic conditions. Furthermore, while beneficial from the perspective of stability, these loads that exceed those observed in normal specimens would likely exert a detrimental effect on the articular cartilage, and may predispose to early painful arthrosis.

Still other authors have suggested that perhaps the articulation does serve to decrease the in situ force of the CC ligament graft after reconstruction, and therefore advocate deferring the distal clavicle excision for this reason.[16] Jari et al[16] examined 3 procedures for AC separation, including a CC sling procedure using No. 5 polyester suture, Rockwood screw fixation, and a CA ligament transfer with augmentation using No. 5 polyester suture. They compared these procedures with respect to several biomechanical parameters, including primary and coupled translation and in situ graft force. The augmented CA ligament transfer demonstrated significantly increased primary and coupled translation of 100% to 360% and 140% to 930%, respectively. In addition, these authors observed a 200% increase in the in situ graft force after this procedure, which included a distal clavicle excision. The authors suggest that these findings could be the result of the distal clavicle excision, and therefore advocate that perhaps preserving the articulating surfaces provides enhanced stability to the construct, thus minimizing the in situ graft force. However, the same investigation demonstrated that the CC sling procedure, which was not performed with a distal clavicle excision, resulted in a significant increase in primary translation, coupled translation, and the in situ graft force of 110% to 330%, 170% to 1000%, and 180%, respectively. Consequently, it is not clear from this study that the distal clavicle excision itself is the root cause of these altered kinematics and increased in situ graft force.

In the present investigation, distal clavicle excision in the context of CC ligament reconstruction resulted only in a slight increase in the in situ graft force, only at higher load (210 N), and only with load in the posterosuperior and posterior directions. With load in the posterosuperior direction, the in situ graft force increased only 8.0 N, representing an increase of only 15.3%. With load in the posterior direction, the in situ graft force increased only 18.8 N, or 35.4%, and this increase was not statistically significant. Moreover, the observed peak graft force was still far less than the ultimate failure strength of the tendon graft as demonstrated in previous work at this institution.[3,22] In the posterosuperior direction, the peak graft force was 60.4 N, representing only 10% to 12% of the ultimate failure strength. In the posterior direction, the peak force was 71.9 N, accounting for 12% to 14% of the ultimate failure strength of the graft material. Furthermore, previous investigation demonstrated that when cyclically loaded from 40 to 80 N, the CC ligament reconstruction survived at least 2500 cycles, and the peak graft forces observed in the present study lie well within these limits.

The primary strength of this investigation is in the direct measurement of in situ graft force. Further, this study is the first to compare the in situ graft force using a single reconstruction technique with and without distal clavicle excision, which avoids potentially confounded results observed in previous investigations. Certain weaknesses of this investigation warrant discussion. This study utilized a custom testing apparatus and cadaver model in which the testing conditions may not reproduce in vivo conditions. In addition, a simulated CC ligament reconstruction was performed, which relied on a surrogate to measure in situ graft force. Suture was utilized in place of tendon graft to allow attachment of the material to a force transducer to directly measure in situ force, which would not have been possible if tendon graft was used for the reconstruction. However, using suture in place of the graft is justified in this case because the investigation seeks to examine in situ force exerted upon the graft, rather than the properties or behavior of the graft material itself. A limitation of this study is the small sample size, with the primary issue being an increased risk of type II error. To find a statistically significant difference between conditions (eg, sectioned AC ligaments vs distal clavicle excision), each of the 5 specimens must show the same direction of change (eg, greater in situ graft force with distal clavicle excision vs sectioned AC ligaments) regardless of the magnitude of the change (Wilcoxon signed rank test). Based on the variability of the change in the in situ graft forces with the distal clavicle excision versus sectioned AC ligaments, for all directions of force, post hoc analysis revealed that there was 80% power to detect a 20-N (or 35%) increase in the in situ graft force with distal clavicle excision at $P < .05$. Thus there was sufficient power to detect a clinically meaningful effect. The fact that a smaller effect was apparent with loading in the posterosuperior direction indicates a less variable effect in that condition. The magnitude of the effect (15% increase in force after distal clavicle excision) is of questionable clinical significance.

In conclusion, this investigation determined that the AC articulation itself provides only a marginal protective effect by decreasing the in situ graft force in the context of CC ligament reconstruction. This effect is observed only at higher load, and with load only in a posterosuperior and posterior direction. Therefore, distal clavicle excision can perhaps be safely performed in the context of CC ligament reconstruction without subjecting the graft to detrimental in situ force. However, this study did confirm that the AC capsule and ligaments do serve to significantly decrease the in situ forces of the CC ligament graft. Therefore, perhaps careful attention should be paid to reconstruction not only of the CC ligaments, but also of AC ligaments, when pursuing operative intervention for AC separation. Various techniques have been described to reconstruct the AC ligaments after distal clavicle excision, including transfer of the CA ligament from its coracoid insertion, utilizing the excess tails from the graft used to reconstruct CC ligaments, or intramedullary graft reconstruction from the acromion to the coracoids (Gonzalez-Lomas G et al, unpublished data, 2010).[12,25,29] The efficacy of these methods in decreasing in situ graft force following CC reconstruction has not yet been examined; therefore, further study is warranted.

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