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A biomechanical comparison of new techniques for distal clavicular fracture repair versus locked plating

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Background: Unstable distal clavicular fractures treated surgically are associated with high failure rates and hardware-related complications. Newer techniques have shown promising early clinical results with fewer hardware complications; however, their biomechanical performance has not been assessed. This study biomechanically compared a distal-third locking plate with 3 newer techniques that incorporate coracoid fixation into the construct.
Methods: The study randomized 36 adult fresh frozen cadaveric shoulders to 4 groups: (1) distal-third locking plate (P); (2) distal-third locking plate with a coracoid button augmentation (P + CB); (3) coracoclavicular button (CB); and (4) coracoclavicular button with coracoclavicular ligament reconstruction using semitendinosus allograft (CB + CC). After fixation, each specimen was stressed in the coronal plane. Cyclic displacement, load at 10-mm displacement, and ultimate load to failure were measured.
Results: All 3 experimental groups biomechanically outperformed the locking plate. Mean load to failure was significantly higher in the CB (343 ± 76 N) and CB + CC (349 ± 94 N) groups compared with the P group (193 ± 52 N). There was also significantly less cyclic displacement in the CB (4.3 ± 1.9 mm) and CB + CC (4.4 ± 1.9 mm) groups compared with the P group (8.2 ± 2.9 mm). With respect to load at 10 mm of displacement, which essentially measures a clinical failure, the P + CB (235 ± 112 N), CB (253 ± 111 N), and CB+CC (238 ± 76 N) experimental groups significantly outperformed the P group (96 ± 29 N).
Conclusions: CB and CB + CC techniques demonstrated more than 75% greater strength than the traditional locking plate alone. Coupled with greater overall construct strength and lower-profile hardware, these newer techniques may result in improved clinical outcome and fewer hardware-related complications.
Level of evidence: Basic Science Study; Biomechanics

Keywords: Distal clavicular fracture; lateral clavicle; biomechanical study; cortical button; distal-third locking plate; coracoclavicular button

Distal-third clavicular fractures represent 25% of all clavicular fractures.[22,25] Approximately 25% of these fractures are unstable and demonstrate a high symptomatic nonunion rate when treated nonoperatively.[22,25] Neer classified these fractures based on the location of the fracture line relative to the

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coracoclavicular (CC) ligaments and acromioclavicular (AC) joint.[20] Unstable distal clavicular fractures, classified by Neer as type II and V, present a unique challenge for surgical fixation due to the small size and comminution of the lateral fragment, disruption of the CC ligaments, and large deforming forces on the fracture fragments.

Although many techniques have been described to treat unstable distal clavicular fractures,[2-4,7-9,11,17,19,21,24,26,27] many techniques use plate osteosynthesis. Locked plating has recently become the treatment of choice, with several studies demonstrating high union rates in select fracture types.[27] Unfortunately, not all fracture patterns are amenable to plating. In addition, these superiorly based plates can be prominent, often necessitating a second surgical procedure for hardware removal.[5,8,12]

In response to these limitations, newer techniques have been described that are modeled conceptually after techniques used to surgically treat acromioclavicular (AC) joint dislocations. These newer techniques achieve fracture union by reducing the medial fracture fragment to the lateral fragment using low profile hardware that is fixed to the coracoid. Recently, several studies that used these CC stabilization techniques to treat unstable distal clavicular fractures have demonstrated excellent clinical and radiographic outcomes with low overall complication rates.[6,15,19,21,24,28,29] Despite these encouraging results, the biomechanical performance of these techniques has not been assessed.

The purpose of this study was to biomechanically compare a superior distal-third locking plating for distal clavicular fracture repair against 3 newer techniques that incorporate coracoid fixation into the construct: (1) distal-third locking plate with a coracoid button augmentation (P + CB); (2) coracoclavicular button (CB); and (3) coracoclavicular button with CC ligament reconstruction using semitendinosus allograft (CB + CC). The null hypothesis was that there would be no significant difference in overall strength and cyclic displacement between the constructs.

Materials and methods

Specimen preparation

This biomechanical cadaveric study, which examined methods for distal clavicular fracture fixation, used 18 pairs (17 men, 1 woman) of adult fresh frozen cadaveric shoulders. Before device implantation and testing, each specimen was thawed for 24 hours at room temperature. Specimens were dissected to remove muscular attachments, leaving the coracoacromial (CA), coracoclavicular (CC), and AC ligaments attached. Radiographic evaluation was used to ensure the absence of prior fracture or pathologic lesions that would compromise the specimen.

The proximal clavicle and the scapula of the specimens were potted in polymethyl-methacrylate in an upright position to simulate the natural position of the shoulder in the beach chair position. Distal fixation was achieved with the scapula secured in the distal jig (Fig. 1). All specimens were treated with a separate individual fixation construct, so that no one fixation construct was reused for testing.

Figure 1 Setup for cyclical testing and load to failure in axial compression.

Study groups and surgical technique

A sagittal saw was used to create an oblique osteotomy 15 mm medial to the AC joint to simulate a distal clavicular fracture. The trapezoid and conoid ligaments were transected to create instability of the medial fragment, and the cadavers underwent the respective fixation techniques. The 36 specimens were randomly assigned to 4 different groups: (1) distal-third locking plate (P); (2) distal-third locking plate with a coracoid button augmentation (P + CB); (3) coracoclavicular button (CB); and (4) coracoclavicular button with CC ligament reconstruction using semitendinosus allograft (CB + CC; Fig. 2).

The technique in group 1 used a precontoured distal clavicle locking plate (Arthrex Inc., Naples, FL, USA). The plate was placed on the superior aspect of the clavicle. The 5 distal 2.7-mm locking screw holes were drilled bicortically and secured with bicortical locking screws, and three 3.5-mm bicortical nonlocking screws were placed In the proximal screw holes.

The group 2 repair was identical to group 1, with the addition of drilling a hole through the clavicle and coracoid with a 2.4-mm cannulated drill. The hole was drilled through 1 of the plate holes directly superior to the coracoid. A cloverleaf-shaped button (Dog Bone; Arthrex Inc.) was attached to two 2-mm tape sutures and passed through the 2.4-mm bone tunnels in the coracoid and clavicle. The cloverleaf-shaped button was seated underneath the coracoid. The limbs of each tape suture were then passed through a specialized plate button (Arthrex Inc.), and the plate button was slid down the tape sutures and clipped into the clavicle plate. The tape sutures were tied over a post in the plate button to secure the construct.

The group 3 technique used just 2 cloverleaf-shaped buttons (Dog Bone) with 2 tape sutures. A 2.4-mm cannulated drill was drilled bicortically through the clavicle and the coracoid. The hole was drilled 15 mm medial to the clavicular fracture line. Two 2-mm tape sutures preattached to a cloverleaf-shaped button were then passed up through the coracoid and clavicle. The button was seated underneath the coracoid, and a second cloverleaf-shaped button was used on the clavicle side. The limbs of the tape sutures were passed over the central post of the button and the sutures tied to secure the construct.

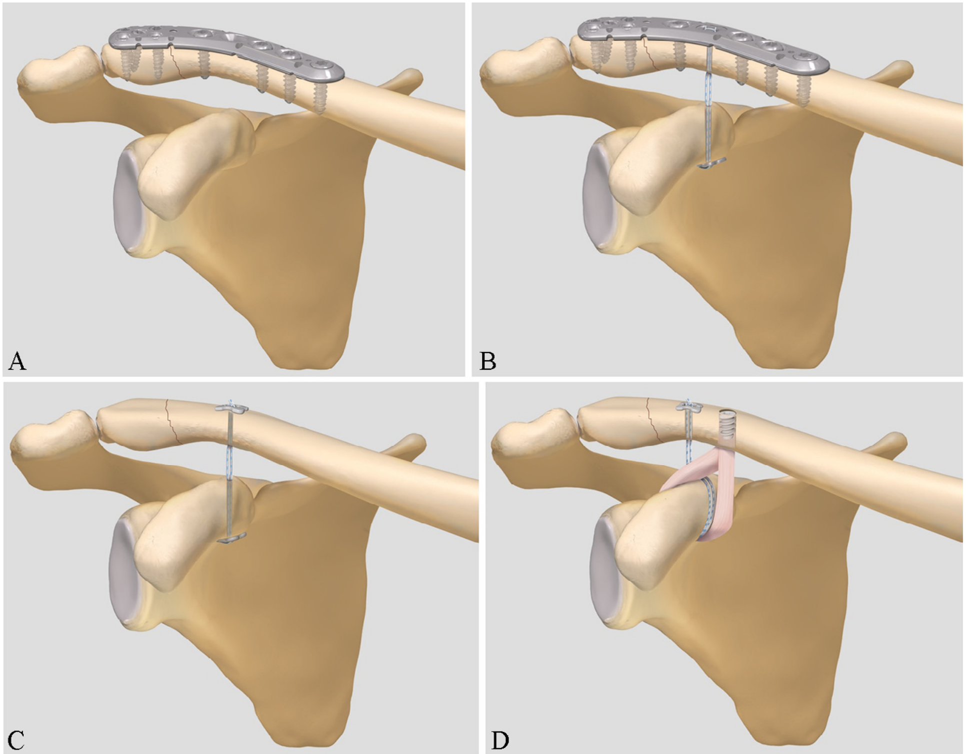

Figure 2 Fixation constructs demonstrating **(A)** distal-third locking plate (P), **(B)** distal-third locking plate with a coracoid button augmentation (P + CB), **(C)** coracoclavicular button (CB); and **(D)** coracoclavicular button with coracoclavicular ligament reconstruction using semitendinosus allograft (CB + CC). These images were provided courtesy of Arthrex, Inc., Naples, FL, USA.

Group 4 specimens were prepared according to the technique described by Yagnik et al.[31] A 7-mm × 240-mm semitendinosus allograft was prepared by whipstitching either end with #2 nonabsorbable suture. Two differently colored suture tapes (FiberTape) and the graft were passed around the inferior aspect of the coracoid. A 2.4-mm bicortical drill tunnel was made 5 mm from the distal end of the medial fracture fragment, and a second 6-mm tunnel was drilled 15 mm medial to the prior tunnel to provide an adequate bone bridge. The 4 limbs of the suture tape were passed through the 2.4-mm tunnel and tied over a cloverleaf-shaped cortical button (Dog Bone). The graft was passed through the medial clavicular tunnel, tensioned, and secured with an interference screw.

Mechanical testing

Biomechanical testing was conducted in an axial compression mode on the Instron E10000 (Instron, Norwood, MA, USA) using WaveMatrix Software (Instron) for testing control and data acquisition. During cyclical loading, specimens were preconditioned for 10 cycles at 25 N in the superior-inferior plane to eliminate viscoelastic creep, following a prior study protocol by Mazzocca et al.[18] The specimen was then cycled to 70 N for 500 cycles at a rate of 1 Hz while cyclic displacement in the coronal plane of the 2 fracture fragments was recorded.[1,18] Cyclic testing was followed by a load-to-failure tensile test at 120 mm/min in the axial plane, and the ultimate tensile load was recorded (defined by a marked decrease in the load displacement curve). To represent a clinical failure, load at 10 mm displacement was recorded. The mode of failure for each construct was recorded by inspection. Displacement was recorded at the beginning and end of cyclical testing before load-to-failure testing. Displacement was measured through the data acquisition system and was measured as the axial position of the actuator at the maximum load subtracted from the initial position of the actuator.

Statistical analysis

Differences in ultimate load to failure, cyclical displacement, and load at 10 mm displacement were analyzed with a 1-way analysis of variance. Inferences were made at a significance of .05, with no correction for multiple comparisons.

Results

The specimens were a mean age of 59.7 years (range, 35-82 years). Radiographic screening of the specimens showed no pathology.

Cyclic loading data

The amount of displacement after cyclic loading is summarized in Table I and depicted in Fig. 3. In summary, the terminal displacement among the groups demonstrated that there was significantly less cyclic displacement in the CB (4.3 ± 1.9 mm) and CB + CC (4.4 ± 1.9 mm) groups compared with the P (8.2 ± 2.9 mm) group (P = .03). The difference

Table I Cyclic displacement

Groups	Displacement Mean ± SD, mm
P	8.27 ± 2.96
P + CB	5.02 ± 3.83
CB	4.33 ± 1.94
CB + CC	4.42 ± 1.91

SD, standard deviation; *P*, distal-third locking plate; *P ± CB*, distal-third locking plate with a coracoid button augmentation; *CB*, coracoclavicular button; *CB + CC*, coracoclavicular button with coracoclavicular ligament.

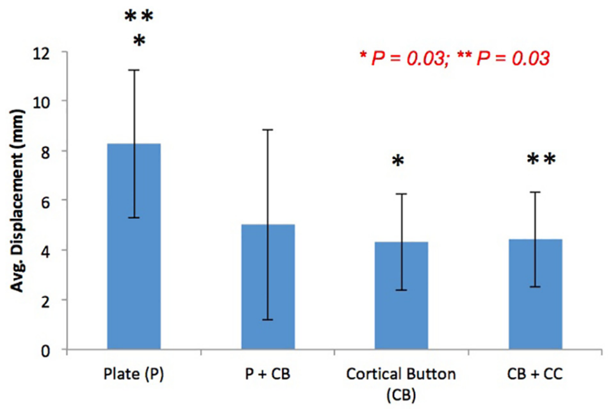

Figure 3 Cyclical displacement. Data are presented as the average ± standard deviation (*error bars*).

in displacement between the P + CB (5.02 mm) and the P (8.27 mm) groups was not statistically significant ($P = .07$).

Load displacement

Load at 10-mm displacement is summarized in Table II. The P group (96 ± 29 N) required significantly less force to reach 10 mm of displacement compared with the 3 experimental groups: P + CB (236 ± 113 N, $P = .014$), CB (254 ± 112 N, $P = .007$), and CB + CC (238 ± 77 N, $P = .015$).

Table II Load at 10-mm displacement

Groups	Load at 10-mm displacement Mean ± SD, N
P	96.41 ± 29.18
P + CB	235.53 ± 112.91
CB	253.88 ± 111.91
CB + CC	238.38 ± 76.51

SD, standard deviation; *P*, distal-third locking plate; *P ± CB*, distal-third locking plate with a coracoid button augmentation; *CB*, coracoclavicular button; *CB + CC*, coracoclavicular button with coracoclavicular ligament.

Load to failure

Fig. 4 illustrates the ultimate load to failure for each of the 4 constructs. Head-to-head comparisons yielded significant differences between the constructs. The mean load to failure was significantly higher in the CB (343 ± 76 N) and CB + CC (349 ± 94 N) groups than in the P (193 ± 52 N) group ($P = .02$). Ultimately, no significant difference was noted between constructs containing a CB. No significant difference in ultimate load to failure was noted between the P + CB (287 ± 132 N) and the P (193 ± 52 N) groups ($P = .15$;Table III).

Modes of failure

Modes of failure of each construct were recorded. The primary mode of failure in the P group was screw pull out (4 specimens). In the remaining P specimens, the modes of failure were failure at potting interface in 2, failure of clavicle near the plate in 2, and displacement limit reached in 1. In the P + CB, most specimens (n = 8) failed at the potting interface, whereas in 1 specimen, the clavicle broke near the plate. Nearly all constructs containing a CB failed at the potting interface with the exception of 2 specimens (7.4%). Of these 2 specimens, 1 failed when the coracoid fractured, and in the other, the displacement limit was

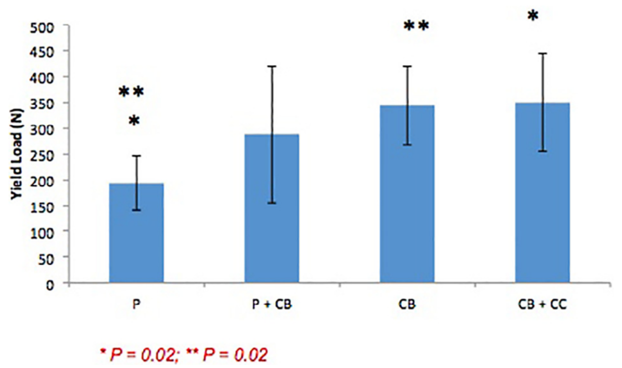

Figure 4 Load to failure. Data are presented as the average ± standard deviation (*error bars*).

Table III Load to failure

Groups	Load to failure Mean ± SD, N
P	193.47 ± 52.67
P + CB	287.16 ± 132.15
CB	343.86 ± 76.45
CB + CC	349.50 ± 94.50

SD, standard deviation; *P*, distal-third locking plate; *P ± CB*, distal-third locking plate with a coracoid button augmentation; *CB*, coracoclavicular button; *CB + CC*, coracoclavicular button with coracoclavicular ligament.

reached. In the CB + CC group, all specimens failed at the potting interface.

Discussion

A variety of surgical techniques have been used to address unstable distal clavicular fractures; however, various complications have been associated with many of these constructs.[2,4,9,10,13,30] Although more robust fixation is often necessary to treat these unstable fractures, this occurs at the expense of hardware irritation, pin migration, acromion fracture, or arthrosis of the AC joint.[4,5,7-9,16] On the contrary, lower-profile fixation has resulted in failure of fixation and nonunion.[8,10,13,14] Ideal fixation of an unstable distal clavicular fracture would provide enough stability to promote fracture healing and oppose the large deforming forces on the fracture while avoiding hardware irritation and the need for subsequent hardware removal. The purpose of this study was to compare distal clavicular fracture fixation techniques that do not cross or violate the AC joint. Thus, although hooked plating may still be considered the gold standard, this technique was not included in the study.

The principal findings of this study are that the 3 groups in which coracoid fixation was incorporated into their construct for distal clavicular fracture fixation outperformed the distal clavicle locking plate alone. Based on the load-to-failure data, the CB and CB + CC techniques demonstrated more than 75% greater construct strength than the P technique. The mean displacement after cyclic loading was also 47% less in the CB and CB + CC groups compared with the P group. The addition of a CB to the locking plate improved the overall biomechanical performance of the plate, as demonstrated in the load displacement data. In this data set, all 3 experimental groups required approximately 2.5 times the amount of load to create 10 mm of displacement compared with the P technique alone. It can therefore be concluded that the addition of a CB provides the greatest contribution to the overall stability of these constructs.

Other biomechanical studies have supported the importance of the coracoid fixation in the treatment of distal clavicular fractures. In a cadaveric study, Madsen et al[17] compared the biomechanical performance of a superior precontoured distal clavicle locking plate to the same construct with supplemental suture anchor CC fixation. The authors found that the addition of CC fixation increased the construct strength by more than 100%. In a different cadaveric study, Rieser et al[23] compared the use of a distal-third locking plate to CC TightRope (Arthrex Inc.). They reported that the combination of a locking plate and TightRope was biomechanically superior to either construct alone.[23]

Our results differed slightly, in that our CB group performed as well as our P + CB group. One theory for this difference may be related to different CB constructs that were used. Our CB construct used two 2-mm suture tapes and a broad cloverleaf-shaped cortical button (Dog Bone) This construct may provide more strength and stiffness compared with the traditional TightRope used in the Rieser study, thus explaining the difference in our results.

A recent study by Alaee et al[1] compared 4 methods used for CC repair (CB, suture anchor and plate button, suture anchor alone, and suture around coracoid). All constructs were also managed with a distal locking plate. They found no difference in load to failure among all groups; however, all groups were significantly stronger than the native CC ligament. The results of our study also demonstrate a significant improvement in construct strength with the addition of coracoid fixation.

Several recent clinical studies have reported that arthroscopically assisted or open CC stabilization using a suture button device or cerclage technique for unstable distal clavicular fractures have resulted in excellent radiographic and clinical outcomes with low complication rates.[6,15,19,21,24,28,29] These techniques have several advantages compared with plating. The primary advantage is that they can be used in most distal clavicular fracture patterns, including fractures with small or comminuted lateral fragments. The lower-profile hardware also requires less soft tissue stripping of the superior clavicle and results in less postoperative hardware irritation and subsequent surgery for implant removal. Our study provides biomechanical support for the use of CC stabilization as a stand-alone procedure for the treatment of unstable distal clavicular fractures.

We note, however, that coracoid fixation comes with its own set of potential complications, including coracoid fracture, neurovascular injury secondary to dissection around the coracoid, and increased cost and operative time. In addition, this procedure may not be suitable for all distal clavicular fracture patterns, including highly comminuted or long oblique fractures. Further clinical studies are necessary to better evaluate these potential complications and to identify the ideal fracture patterns that can be treated with coracoid stabilization alone.

This study has several limitations. The biomechanical results of this cadaveric study may not directly translate to clinical outcomes.

Another limitation is that the specimens were visually and radiographically inspected for bone health, but bone density scans were not performed. This potential variation in overall bone quality could account for some of the differences seen during biomechanical testing.

In most samples, the clavicle broke at the potting interface. It is important to note, however, that in the plate construct alone, 50% of the samples failed due to screw pullout before clavicular fracture. This suggests that the plate construct is notably weaker than the other constructs.

Another limitation to our study is that it was underpowered to detect significant differences within the 3 groups that incorporated coracoid fixation into their construct. We are therefore unable to recommend one CC stabilization technique over the other.

The final limitation of our study is that displacement was only tested in the coronal plane. Although we believe that the primary deforming forces act in the coronal plane, we acknowledge that horizontal and rotational forces could contribute to construct failure and that these forces were not simulated in this model. It is possible that CB and CB + CC groups would have demonstrated significantly more displacement if tested in the anterior-posterior and rotational plane than the groups that included plates.

Conclusion

Biomechanical testing of modern fixation options for distal clavicular fractures demonstrate that locking plate fixation alone performed significantly inferior than constructs containing CC cortical button fixation. Based on the load-to-failure data, the CB and CB + CC techniques demonstrated more than 75% greater construct strength than the traditional locking plate alone. Coupled with greater overall construct strength and lower profile hardware, these newer techniques may result in improved clinical outcome and less hardware related complications.

Disclaimer

Arthrex Inc. (Naples, FL, USA) generously donated the cadavers and materials for testing and also provided illustrations. This company was not involved in or influenced the methods, analysis, or conclusions of the study or preparation of the manuscript.

The authors, their immediate families, and any research foundations with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

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