Addition of a Suture Anchor for Coracoclavicular Fixation to a Superior Locking Plate Improves Stability of Type IIB Distal Clavicle Fractures

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Purpose: The purpose of this study was to determine the effect of coracoclavicular (CC) fixation on biomechanical stability in type IIB distal clavicle fractures fixed with plate and screws. Methods: Twelve fresh-frozen matched cadaveric specimens were used to create type IIB distal clavicle fractures. Dual-energy x-ray absorptiometry (DEXA) scans ensured similar bone quality. Group 1 (6 specimens) was stabilized with a superior precontoured distal clavicle locking plate and supplemental suture anchor CC fixation. Group 2 (6 specimens) followed the same construct without CC fixation. Each specimen was cyclically loaded in the coronal plane at 40 to 80 N for 17,500 cycles. Load-to-failure testing was performed on the specimens that did not fail cyclic loading. Outcome measures included mode of failure and the number of cycles or load required to create 10 mm of displacement in the construct. Results: All specimens (12 of 12) completed cyclic testing without failure and underwent load-to-failure testing. Group 1 specimens failed at a mean of 808.5 N (range, 635.4 to 952.3 N), whereas group 2 specimens failed at a mean of 401.3 N (range, 283.6 to 656.0 N) (P = .005). Group 1 specimens failed by anchor pullout without coracoid fracture (4 of 6) and distal clavicle fracture fragment fragmentation (1 of 6); one specimen did not fail at the maximal load the materials testing machine was capable of exerting (1,000 N). Group 2 specimens failed by distal clavicle fracture fragment fragmentation (3 of 6) and acromioclavicular (AC) joint displacement (1 of 6); 2 specimens did not fail at the maximal load of the materials testing machine. Conclusions: During cyclic loading, type IIB distal clavicle fractures with and without CC fixation remain stable. CC fixation adds stability to type IIB distal clavicle fractures fixed with plate and screws when loaded to failure. Clinical Relevance: CC fixation for distal clavicle fractures is a useful adjunct to plate-and-screw fixation to augment stability of the fracture.

Type II distal clavicle fractures account for 10% to 30% of all clavicle fractures and have 30% to 45% delayed and nonunion rates. Type II distal clavicle fractures are classified based on the relationship of the fracture line to the coracoclavicular (CC) ligaments and AC joint (Fig 1). Type II fractures are usually unstable because the proximal fragment is detached from the CC ligaments. The proximal fragment displaces superiorly caused by the lack of CC ligament attachment, pull of the sternocleidomastoid muscle, and weight of the arm. These fractures are responsible for most clavicle nonunions and are challenging to treat because of the small distal bony fragment attached only to the trapezoid ligament and substantial displacement.

Surgical treatment of type IIB fractures is an area of controversy. Older plate designs made it difficult and often impossible to obtain adequate fixation because the distal fragment is small and often comminuted, allowing for limited fixation with screws. Numerous fixation techniques have been described in the literature. Unfortunately, all these techniques have drawbacks, including delayed healing, nonunion, peri-implant failure of bone, or complications related to hardware.

There are several case series of patients with distal clavicle fractures that were stabilized with modern locking T-plates and suture anchors or looped suture for CC augmentation. The amount of added stability...
CC fixation adds to distal clavicle fracture fixation with modern plates is not described. The purpose of this study was to determine the effect of CC fixation on the biomechanical stability of type IIB distal clavicle fractures fixed with plate and screws. Our hypothesis was that the addition of CC fixation to the modern clavicle-specific plate-and-screw construct would add stability, resisting the superoinferior translational forces in the coronal plane that are present in type IIB clavicle fractures.

**Methods**

Twelve fresh-frozen human shoulder specimens from 6 cadavers were used to create type IIB distal clavicle fractures. The cadavers were all male, with a mean age of 61 years (range, 43 to 71 years) and were free of pathologic processes of the shoulder according to patient history and gross anatomy. Specimens were stored in a freezer at −20°C. Individual specimens were thawed overnight at room temperature in preparation for dissection and testing. Dissections were performed on the specimens to expose the scapula and clavicle, with care to preserve the AC joint and coracoacromial and CC ligaments. All other soft tissue was removed. A clavicle and scapula specimen from each cadaver was included in both group 1 and group 2 to ensure similar bone quality. Also, dual-energy x-ray absorptiometry (DEXA) scans were obtained to confirm the bone quality of the 2 groups. Each cadaveric right and left specimens were randomly assigned to each group by coin toss.

Type IIB noncomminuted distal clavicle fractures were created with a sagittal saw in a consistent manner. Osteotomies were performed using a sagittal saw beginning approximately 1.5 cm medial to the superolateral border of the clavicle and extending 45° inferomedially to exit between the conoid and trapezoid ligaments. Subsequently, the conoid ligament medial to the osteotomy was transected, leaving the trapezoid intact to simulate a typical Neer type IIB distal clavicle injury. Specimens in both groups were stabilized with a superior 2.3-mm precontoured distal clavicle locking plate and screws (Acumed clavicle plate system, Acumed, Hillsboro, OR). Three 3.5-mm screws were used in the proximal fragment and 5 2.3-mm screws were used in the distal fragment. Group 1 had CC fixation added with a single threaded metal anchor (3.5 mm minor and 5.5 mm outer diameter) placed in the base of the coracoid and a high-strength polyethylene suture No. 5 to connect the anchor to the clavicle plate (Acumed Acu-Sinch Repair System, Acumed). Only the near cortex of the coracoid was opened with a 3.5-mm drill for anchor insertion. The suture was passed through a 2.8-mm drill hole in the clavicle and through a nonlocking slot in the clavicle plate. Each suture strand was passed through a metal suture retainer designed to fit into the nonlocking slots of the plate (Fig 2). After placement of the plate and screws, care was taken to make sure the AC joint was

![Fig 1. Neer classification of distal clavicle fractures. (Reprinted with permission from the American Academy of Orthopaedic Surgeons.)](image-url)
reduced while the suture was tied over the retainer. This was done by visualization and palpation to make sure the AC joint was not over- or under-reduced. Group 2 consisted of the same plate fixation but without suture anchor augmentation.

Custom mounting fixtures were used to secure the scapula and clavicle (Fig 3). The proximal clavicle was secured in the setup to simulate the sternoclavicular joint. The mounting fixtures were connected to a materials testing machine (Instron 8841; Instron, Norwood, MA) in a physiologic upright position. A cyclic loading protocol was carried out in the coronal plane at 40 to 80 N as described by Lee et al.19 for CC ligament reconstructions. This protocol simulates the forces transmitted by the CC ligaments as a result of the weight of the arm based on in vivo tensiometer measurements of the CC ligament forces in 6 patients with arm hanging at the side or in extension, respectively.19 The specimens were cycled through 17,500 cycles at 1 Hz. The number of cycles is an estimate of the arm swinging during the average gait in a postoperative patient for 1 week (2,500 strides per day).20 All specimens were moistened with normal saline every hour. If no failure occurred during this loading scenario, a load-to-failure test was performed in the coronal plane, pulling on the clavicle in a superior direction at a rate of 0.1 mm/sec. Radiographs were taken after failure of each specimen to visualize the clavicle, acromion, and coracoid. These images were reviewed by a senior orthopaedic resident to evaluate the method of failure, including displacement, hardware failure, or fracture. Outcome measures were the mode of failure (displacement, fracture, suture failure, or anchor pullout) and the load required to create 10 mm of displacement.

This amount was derived from the loss of reduction in a clinical setting, described as a 100% clavicle thickness displacement. Failure was declared by a combination of visual inspection, caliper measurements, radiography, and computer-generated graphs (Bluehill software, Instron, Norwood, MA) of displacement.

Statistical analysis to compare the difference in the number of cycles, load, stiffness, and deformation between the 2 groups was carried out with a paired t test at a significance level of $\alpha = .05$. Specimens that did not fail at 1,000 N (maximum limit of the testing system) were excluded from the statistical analysis. Based on the data obtained in this experiment and the observed variance, a power analysis demonstrated that a sample size of $N = 4$ specimens would suffice to show significant differences on the order of the observed 50% reduction in maximum force with ≥90% statistical power (http://www.statisticalsolutions.net/pss_calc.php).

### Results

The average DEXA value for group 1 was 0.579 g/cm², which was not statistically different from group 2 with 0.592 g/cm² ($P = .9$). All specimens (12 of 12) underwent cyclic testing for 17,500 cycles without failure. The baseline displacement remained constant throughout cyclic testing, confirming the stability of the fracture in fixed specimens. No failures occurred with cyclic loading in either group.

The stiffness, maximal force, and deformation of the load-to-failure results for each specimen can be seen in Table 1. A graph showing an example of load-to-failure testing can be seen in Fig 4. Group 1 had 4 specimens with CC fixation that failed at a mean of 808.5 N (range, 635.4 to 952.3), with a maximal deformation

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**Fig 2.** Example of type IIB distal clavicle fracture specimen fixed with 2.3-mm distal clavicle locking plate (Acumed clavicle plate system, Acumed) and metal suture anchor with suture retainer (Acumed Acu-Sinch Repair System, Acumed).

**Fig 3.** Specimen setup for cyclic and load-to-failure testing: (A) Instron and load cell, (B) custom mounting fixtures, (C) clavicle, CC (D) ligaments, (E) acromion attached to scapula, acromioclavicular (F) joint, and (G) simulated sternoclavicular joint. The (H) direction of load for cyclic and load-to-failure testing is illustrated by the large arrow.
of 10.1 mm (range, 9.05 to 10.67 mm) and stiffness of 98.1 N/mm (range, 71.5 to 117.0 N/mm). Group 2 had 4 specimens without CC fixation that failed at a mean of 401.3 N (range, 283.6 to 656.0 N), with a maximal deformation of 7.6 mm (range, 4.96 to 11.36 mm) and stiffness of 80.9 N/mm (range, 73.6 to 88.7 N/mm). The difference in load-to-failure testing between the groups was significant at 407.2 N (< .005) (Table 2). The differences in maximal deformation (P = .098) and stiffness (P = .12) were not significant between the groups (Table 2). Graphic representation of group 1 and group 2 load-to-failure test results is presented in Fig 5.

There were several different modes of failure noted (Fig 4). Four specimens (4 of 6) in group 1 failed by anchor pullout from the coracoid, one (one of 6) specimen failed by distal clavicle fracture fragment segmentation, and one (one of 6) did not fail at the maximal load the materials testing machine was capable of exerting (1,000 N). Radiographs and visual inspection did not reveal any coracoid fractures. Three specimens (3 of 6) in group 2 failed by distal clavicle fracture fragment segmentation, 2 specimens (2 of 6) did not fail at the maximal load the materials testing machine was capable of exerting (1,000 N), and one (one of 6) failed at the AC joint. Distal clavicle fragmentation occurred when the screws remained attached to the superior bone and a horizontal fracture occurred, leaving an inferior bone fragment attached to the remaining trapezoid ligament. AC joint failure occurred when the AC joint stretched and the distal clavicle was displaced more than 100% superior to the acromion (Fig 4).

### Discussion

Most distal clavicle fractures are managed nonoperatively because most are not displaced. The large majority of Neer type I and III fractures heal with only a brief period of immobilization. However, type II fractures are frequently displaced and have higher rates of nonunion as noted in Neer’s original series. Several authors advocate surgical treatment for displaced distal clavicle fractures. The surgical treatment for these injuries is challenging because of the displacing forces and limited bone volume in the distal fragment. These injuries often occur in elderly patients with osteoporotic bone, posing difficulties for stable fixation in surgical treatment.

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**Table 1. Summary of Tensile Failure Biomechanical Data for All Specimens**

<table>
<thead>
<tr>
<th>Maximal Force, N</th>
<th>Maximal Deformation, mm</th>
<th>Stiffness, N/mm</th>
<th>Mode of Failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1 specimens</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 952.3</td>
<td>10.5</td>
<td>117.0</td>
<td>Anchor pullout</td>
</tr>
<tr>
<td>2 794.3</td>
<td>10.0</td>
<td>97.3</td>
<td>Anchor pullout</td>
</tr>
<tr>
<td>3 635.4</td>
<td>9.0</td>
<td>71.5</td>
<td>Distal clavicle split</td>
</tr>
<tr>
<td>4 852.8</td>
<td>8.5</td>
<td>178.1</td>
<td>Anchor pullout</td>
</tr>
<tr>
<td>5 852.1</td>
<td>10.7</td>
<td>106.7</td>
<td>Anchor pullout</td>
</tr>
<tr>
<td>6 DNF</td>
<td>DNF</td>
<td>DNF</td>
<td>DNF</td>
</tr>
<tr>
<td>Group 2 specimens</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 656.0</td>
<td>11.4</td>
<td>86.6</td>
<td>Distal clavicle split</td>
</tr>
<tr>
<td>2 283.6</td>
<td>6.0</td>
<td>73.6</td>
<td>Distal clavicle split</td>
</tr>
<tr>
<td>3 346.9</td>
<td>8.1</td>
<td>88.7</td>
<td>Distal clavicle split</td>
</tr>
<tr>
<td>4 DNF</td>
<td>DNF</td>
<td>DNF</td>
<td>DNF</td>
</tr>
<tr>
<td>5 318.8</td>
<td>5.0</td>
<td>74.8</td>
<td>AC joint</td>
</tr>
<tr>
<td>6 DNF</td>
<td>DNF</td>
<td>DNF</td>
<td>DNF</td>
</tr>
</tbody>
</table>

The 3 specimens that did not fail (DNF) are included and labeled as such.

AC, acromioclavicular; DNF, did not fail.
Several fixation techniques have been described in the literature, including transacromial Kirschner wires,8,9 CC screws,10,11 plates,8,12,13 dynamic transfers,14 polyester tape or PDS cord or tape (Ethicon, Somerville, NJ) for CC reconstruction,12 tension wires,15 or hooked plates.16 All these techniques have drawbacks, including either delayed healing and nonunion or complications related to hardware. The use of Kirschner wires for CC stabilization is of particular concern because of reports of pin migration and breakage of hardware.24 Techniques for fixation that span the AC joint require a second operation for removal of hardware.16,25 The CC fixation alone or in combination with wire fixation can be associated with delayed union22 or stress fracture of the clavicle caused by bone erosion from the suture.26

The advent of precontoured plates for the distal clavicle allows increased purchase in the distal fragment, improved rigid fixation options without the potential need to violate the AC joint, and a second procedure. Many of these benefits were shown in a retrospective study comparing hook plates to superior locked plates; more peri-implant fractures, hardware failures, and hardware removal were seen in patients treated with hook plates.27 The need for CC fixation to neutralize the distracting forces in the coronal plane in the setting of modern implants and improved fixation in the distal fragment is unknown. There is potential risk to neurovascular structures, risk of patient morbidity, and increased surgical time and instrumentation cost involved with the addition of CC fixation to a plate construct for distal clavicle fractures. There are several studies that show good results treating distal clavicle fractures with CC ligament repair or reconstruction.7,17,18 However, the biomechanical role of CC fixation in augmenting stability for distal clavicle fractures fixed with a plate construct is unknown.

Several small retrospective studies have looked at the treatment of distal clavicle fractures treated with locking plates with and without CC augmentation. Kalamaras et al.17 looked at 9 patients with type II distal clavicle fractures treated with distal radius locking plates, 6 of which were augmented with looped fiber wire around the coracoid. Herrmann et al.18 treated 8 patients with type IIB fractures using locking T-plates and suture anchor in the coracoid. Klein et al.27 reviewed 16 patients with type II fractures treated with locking plates and CC fixation with looped suture or suture anchors. Andersen et al.28 treated 20 patients with type II fractures using locked plates, and 9 of these patients received looped suture around the coracoid or suture anchors. All these studies showed greater than 94% union rates with few complications, which included 3 infections, one malreduction, and one peri-implant fracture. The need for CC fixation in these studies is not clear. They describe generally successful outcomes but lack a control group to assess the role of CC fixation.

This study shows that fixation with a precontoured distal clavicle plate-and-screw construct alone is sufficient to withstand the moderate forces (40 to 80 N) expected to be seen from 1 week of simulated rehabilitation. This, however, may be inadequate to withstand the forces seen during accelerated rehabilitation protocols or from recurrent trauma such as a fall. The

### Table 2. Summary of Tensile Failure Biomechanical Data

<table>
<thead>
<tr>
<th></th>
<th>Group 1</th>
<th>Group 2</th>
<th>Significance (t Test)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximal force, N</td>
<td>808.5 ± 132.6</td>
<td>401.3 ± 171.7</td>
<td>P &lt; .005</td>
</tr>
<tr>
<td>Maximal Deformation, mm</td>
<td>10.1 ± 0.73</td>
<td>7.6 ± 2.8</td>
<td>P = .098</td>
</tr>
<tr>
<td>Stiffness, N/mm</td>
<td>98.1 ± 19.5</td>
<td>80.9 ± 7.8</td>
<td>P = .12</td>
</tr>
</tbody>
</table>

NOTE. Specimens that did not fail were excluded. Data are shown as mean ± standard deviation. To compare matched pairs in the final analysis, specimens 4 and 6 from both groups (see Table 1) were excluded from calculations of the mean and standard deviation values.

### Effects of CC Fixation

*Fig 5.* Group 1 (with CC fixation) and group 2 (without CC fixation) maximal failure force, stiffness, and maximal displacement from load-to-failure testing.
addition of CC fixation increased the strength of the construct by more than 100% in this study. In fact, the CC fixation in group 1 specimens was consistently stronger than native CC ligaments that failed at around 600 N in other studies.29,30

The number of screws needed to obtain adequate fixation in distal clavicle fractures is not known. The locking plate constructs used in this study offer smaller diameter locking screws angled in variable planes in the distal 1-centimeter portion of the plate to increase purchase in the bone. All specimens were fixed with only 5 2.3-mm locking screws in the distal segment. Depending on the amount of comminution in the distal fragment, it may not be possible to obtain fixation with 5 screws. We believe that CC fixation is very important in these situations.

Failure after fixation of type IIB clavicle fractures by screw pullout from the distal fragment is a major clinical concern. Revision surgery for this complication is difficult given the comminution in the distal fragment and further violation of the bone by screw pullout. We did not observe screw pullout from the distal fragment in any of the specimens fixed with CC fixation. These data suggest that CC fixation with 5 locking screws in the distal fragment provides adequate fixation, with failure usually by anchor pullout from the coracoid, but more research is needed to confirm this suggestion. Coracoid fractures did not occur as a result of anchor pullout in this study. This is a very relevant finding. Maintenance of coracoid integrity is important for potential revision procedures. Also, fixation methods for a broken coracoid are challenging and often lead to complications and nonunion. This device may cause a coracoid fracture if placed improperly: eccentrically, distally, or bicortically. The fact that the device penetrates only one cortex in the coracoid should help prevent fractures.

In our experience we have seen failures during the postoperative period of type IIB distal clavicle fractures fixed with superiorly placed locking plate and screws without CC fixation at the AC joint. This situation can arise when the remaining trapezoid ligament is incompetent (Neer type V fracture pattern) as a result of the original accident, repeated trauma, or iatrogenic injury during exposure of the fracture. This difficult clinical situation could possibly be addressed with augmenting plate fixation with the CC fixation used in this study.

Limitations

There are limitations to this study. It is a cadaver study that may not recreate the exact physiology and kinematics in postoperative patients. There were 3 specimens (1 of 6 in group 1 and 2 of 6 in group 2) that did not fail at the materials testing machine’s maximal load. A possible explanation for this may be variable osteologic features of the distal clavicle with variable cortical thickness in the areas of CC ligament origins. It is possible that minor variations in screw orientation during fixation account for variability in the strength of fixation. We thought that 1,000 N, the maximal load the materials testing machine was capable of exerting, would have been sufficient because other studies showed that the maximal load to failure of the native CC ligaments is around 700 N.29,30 The 3 specimens that did not fail were tested at later stages of the study, and to maintain consistency, another machine with a higher maximal load capacity was not used. We strongly believe this would not have changed the conclusion of our results. Overall, the fixation was consistently more superior in the CC fixation group in the paired specimens in this study.

Conclusions

During cyclic loading, type IIB distal clavicle fractures with and without CC fixation remain stable. CC fixation adds stability to type IIB distal clavicle fractures fixed with plate and screws when loaded to failure.

References
