A Biomechanical Comparison of Distal Clavicle Fracture Reconstructive Techniques

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Abstract

Unstable fractures of the distal clavicle are often encountered in high-demand, young athletes. We evaluated biomechanical performance and mode of failure in 4 treatment methods. A Neer Type IIB distal clavicle fracture was created in fresh-frozen human cadaveric shoulders. Four fixation techniques were utilized, 5 times each on 5 different cadavers: suture fixation with a cerclage suture and coracoclavicular suture, distal clavicle locking plate, distal clavicle locking plates with suture augmentation, and distal clavicle hook plate. No significant difference in ultimate load to failure was found among groups in the treatment of the unstable distal clavicle fractures.

Fractures of the clavicle are a common injury, representing 2.6% of all fractures and 44% of all injuries to the shoulder girdle.[1,2] It has been estimated that the annual incidence rate is between 0.029% and 0.064% per 100,000 people per year.[1,3,4] Of these fractures, about 21% are of the distal clavicle.[1,3,4] Distal clavicle fractures are typically classified as stable or unstable based on the state of the coracoclavicular (CC) ligaments. Both Type I and Type III fractures are inherently stable because the fracture is lateral to both of the CC ligaments. The Type I fracture is extra-articular, while the Type III fracture extends into the acromioclavicular (AC) joint. These fractures are typically treated nonoperatively. Type II distal clavicle fractures are inherently unstable and occur just medial to the CC ligament (Type IIA) or medial to the trapezoid ligament with the conoid ligament torn from the proximal fragment (Type IIB).[5,6] Each of these results in the proximal fragment being free and subjected to the unopposed forces of the sternocleidomastoid and trapezius muscles, resulting in a cephalad displacement of the medial fragment. This can result in a buttonhole effect in which the fractured clavicle perforates through the fascia leaving the fractured end of the bone in a subcutaneous position.[7,8] The distal fragment may remain in a relatively anatomic position; however, it is still subject to the weight of the arm resulting in further separation of the fragments. The result of this unstable fracture pattern can be an unacceptably high rate of nonunions in fractures treated nonoperatively.[2,6,9-11] However, the same forces that lead to nonunion can make it difficult to achieve and maintain adequate operative reduction of the fracture fragments if surgery is undertaken. To our knowledge, there is no published documentation regarding the type of forces responsible for the traumatic sudden failure of surgical constructs that can be seen after fixation.

While distal clavicle nonunions have been shown to cause minimal functional impairment and are well-tolerated in an elderly, sedentary population,[3,7,10,12,13] many authors have recommended a surgical method of treatment for the younger, more active population.[9,10,14-16] It is believed that surgical treatment provides a more predictable outcome for active patients with high-energy injuries, reduces the potential for skin compromise, prevents significant displacement, and will prevent a symptomatic nonunion.[9,17] However, these have been notoriously troublesome fractures to address operatively and many complications have been reported with all of the techniques.[2,18-20]

Many techniques have been described to treat distal clavicle fractures, including CC stabilization with suture loop, Dacron graft (Bard, Billerica, Massachusetts), and CC screws[8,15,21,22]; cerclage with suture, K-wire with 18 gauge tension band[23,24]; intramedullary fixation with Knowles pins[25,26]; standard locking plates with and without suture augmentation[27,28]; Mersilene tape (Ethicon Inc, Somerville, New Jersey) repair of CC ligaments with wire fixation of fracture fragments[29]; and the hook plate construct.[18,19,30,31] However, it has yet to be determined which is the best method of fixation, as these techniques have varying degrees of success and many have significant complication rates. The ideal construct would not only have good biomechanical strength, but also lead to the least catastrophic type of complication if construct failure were to occur.

The purpose of this study was to compare the biomechanical strength of fixation of distal clavicle locking plates, with and without suture augmentation, to suture fixation alone with a coracoid loop and fracture cerclage, and to the hook plate. Our load to failure technique allows us to also study

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the most common method of fixation failure to determine the most catastrophic type of failure. We eliminated fixation techniques that have notorious complications, including pin breakage, pin migration, wound breakdown, and AC joint violation. Thus, we did not include K-wires, pins, figure-of-eight wire fixation, intramedullary devices, and Knowles pins. Our goal was to measure the overall strength of our construct. We hypothesized that when surgical fixation fails, it is often a sudden, traumatic force, rather than a fatigue failure due to the weight of the arm, hence our decision to evaluate the ultimate load to failure of our chosen constructs.

Materials and Methods

Specimen Preparation

The mechanical properties of 4 types of distal clavicle fracture fixation were studied in 15 fresh-frozen adult human cadaveric shoulders. The specimens were primarily male (average age, 50.8 years), frozen and stored at -20°C. The specimens contained the manubrium, clavicle, intact AC joint, and scapula.

Five days prior to testing, each shoulder specimen was placed in a refrigerator and allowed to thaw. The scapula, clavicle, and manubrium were carefully dissected free of all soft tissues except for the sternoclavicular ligaments, AC joint capsule, CC ligaments, and the coracoacromial (CA) ligament. The cadaveric shoulders were then inspected to ensure that they were free from structural defects, and each specimen was placed in a 15.24x10.16x25.4 cm acrylic box with the scapula and manubrium partially immersed in a self-curing resin (Bondo, 3M Fiberglass Resin, St. Paul, Minnesota) for 48 hours. Care was taken to assure that the sternoclavicular joint, the coracoid, and the AC joint were unrestrained. It has been shown that freezing does not affect the stiffness of the bone[21]; however, bone and ligament properties significantly change with dehydration, so proper hydration was maintained at all times through the use of dampened towels and plastic bags when the tissues were not being tested.[5]

An oblique fracture was created 1.5 cm from the distal end of each clavicle using an oscillating saw, extending from superior/lateral to medial/inferior (**Figure 1**). The CC ligaments were severed in an effort to simulate an unstable distal clavicle fracture. The specimens were then randomly assigned to one of 4 different types of reconstruction: (1) cerclage suture fixation alone, (2) distal clavicle locking plate, (3) distal clavicle locking plate with suture augmentation, or (4) hook plate fixation. Each reconstruction technique was performed on 5 different cadavers and all were loaded to failure as described below. Five shoulders were reused. After loading the specimens fixed with the suture fixation technique to failure, the suture had failed but the shoulder specimens were still intact. These 5 shoulders were reused for the locking plate fixation. Each of the other fixation techniques was tested on a unique specimen.

Surgical Reconstructions

Suture fixation. After the unstable fracture pattern was simulated, an augmentation suture (#5 FiberWire, Arthrex Inc, Naples, Florida) was placed under the coracoid and each limb, medial and lateral, was brought up through a drill hole in the clavicle, 1 cm apart. A second suture (#2 FiberWire, Arthrex Inc, Naples, Florida) was wrapped in a cerclage fashion around the proximal and distal fragment of the fracture itself.[17] The fracture was reduced and the sutures were sequentially tied to secure the reduction (**Figure 1**).

Distal clavicle locking plate. After testing the suture fixation specimens, the same 5 specimens were plated with a distal clavicle locking plate (#70-0116 and #70-0117, right and left side, respectively; Acumed, Hillsboro, Oregon) with a 1.5 cm distal flange that accommodates 4 locking screws. The plate was placed in a superior fashion. Locking screws were placed in the distal flange and 1 locking screw in the medial screw hole. The remaining screws were bicortical (**Figure 2**).

Distal clavicle locking plate with suture augmentation. After creation of the fractures, the distal clavicles of 5 different specimen fractures were plated with the same types of plates pre-

Figure 1. Placement of the medial coracoclavicular augmentation and cerclage sutures, as demonstrated by Arciero[17] in 2004. We used the same approach, but brought the augmentation sutures up through drill holes rather than wrapping around the medial clavicle. (Reprinted from Operative Techniques in Sports Medicine, Vol. 12, Arciero RA, Operative techniques for displaced distal clavicle fractures, 27-31, 2004, with permission from Elsevier.)

Figure 2. The unstable distal clavicle fracture is reduced and plated with a distal clavicle locking plate that accommodates a 1.5 cm distal flange of screws.

viously described, again in the superior fashion with the same screw configuration. Two augmentation sutures were utilized (#2 FiberWire, Arthrex Inc), placed under the coracoid and wrapped over the clavicle, avoided by any of the screws for fixation, and tied (**Figure 3**), with 1 suture medial and 1 lateral to the fracture site.

Hook plate fixation. The final 5 clavicle fractures were fixed using a hook plate (#241.064 and #241.065, right and left, respectively; Synthes Inc, West Chester, Pennsylvania). The hook was placed posterior to the AC ligaments underneath the acromion. No locking screws were utilized; bicortical screws were placed in the plate screw holes (**Figure 4**).

Mechanical Testing

The mounted tissue was secured in a servohydraulic materials testing machine (Bionix 858, MTS Systems Corp, Eden Prairie, Minnesota) and a loop of plastic coated cable (3 mm diameter) was looped under the clavicle as close to the AC joint as the fixation would allow. The construct was preloaded with a 20 N vertical force and then loaded superiorly under displacement control at a rate of 0.1 mm/s until catastrophic failure of the fixation or the tissue occurred.

Statistical Analysis

The mean load to failure and standard deviation for each reconstruction group was calculated. One-way analysis of variance with post-hoc pairwise comparisons was calculated to compare the different reconstruction methods. Significance was set at $P<.05$.

Results

Statistical analysis of our tests showed no significant difference in strength of fixation between any of the techniques used. Load to failure data for all 4 fixation techniques are seen in **Table I**. Again, it should be noted that for the suture technique and the plate alone technique, the same shoulder was used for each trial. When failure occurred in the plating techniques there was almost always secondary structural damage either in the form of a second fracture or the screws pulling out of the distal fragment. The non–augmented plate fixation had 3 of 5 specimens fail by distal plate pullout, whereas all the augmented plate constructs failed by secondary fracture. While the augmented suture plate fixation was a stronger construct, this was not found to be significant (646.6 N vs 487.8 N; $P = .237$). These modes of failure are in contrast to the suture fixation technique in which only 1 of the tests resulted in a secondary fracture of the coracoid. Modes of failure are provided in **Tables I** and **II**.

Discussion

Distal clavicle fractures have always been notoriously difficult to treat, and thus, there has been debate as to the proper treatment technique. Distal clavicle fractures are known to have high rates of nonunion.[2,6,9-11] However, operative treatment has been fraught with complications and truly the best construct and fixation technique has yet to be determined. Our goal was to evaluate the biomechanical strength and mode of failure of several different fixation constructs in an effort to shed light on one aspect of distal clavicle fracture fixation.

Our data showed that there is no significant difference in the strength of fixation between any of the methods tested. While our suture augmented distal clavicle plates showed a higher load to failure than our plates without augmentation, it was not a significant difference. When we evaluated the mode of failure however, we saw differences. We found that with each of the plated techniques, failure resulted in a secondary fracture or damage to the distal fragment due to screw pullout. Both of these methods of failure would necessitate a second surgery in order to remove the retained hardware and most likely to repair the secondary damage. All 5 of the augmented plates failed via clavicle fracture, while 3 out of 5 of the non–augmented plates failed by distal screw pullout. We did not have enough specimens to determine whether this difference in mode of failure was significant. The plating results are in sharp contrast with the suture fixation technique, in which only one of the tests resulted in a secondary fracture of the coracoid. The remainder failed either by slippage of the suture

Figure 3. The fracture is reduced and plated with a similar type distal clavicle locking plate, but augmented with 2 sutures, wrapped under the coracoid and tied medial and lateral to the fracture site.

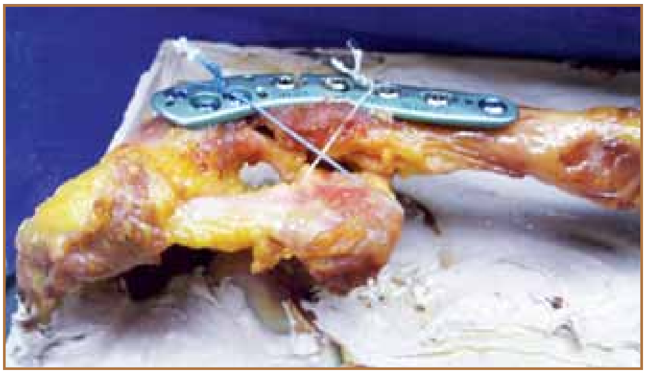

Figure 4. The fracture is reduced and plated with a distal clavicle hook plate construct.

with fracture displacement or suture failure. If these occurred clinically, the patients could be observed conservatively without revision surgery, as there is no hardware to remove. In the worst-case scenario, these patients may develop a nonunion.

Currently, several studies have evaluated the clinical outcomes of the methods of distal clavicle fixation that we studied. Arciero[17] reported his results with 7 patients who underwent plate augmentation with suture for a comminuted unstable distal clavicle fracture. Although it was a limited case series, he did report all 7 cases healed without incident. They did not, however, use a distal clavicle locking plate, but rather a small T-plate without locking screws. In a recent systematic review,[2] hook plating was shown to have a very high complication rate compared to other techniques, and the authors of the review advised against its use in distal clavicle fixation. We found that the hook plate failed most often by a secondary fracture, which is often more difficult to treat than a plate pulling out of the distal fragment. Many studies have clearly documented the need to remove the hook plate due to impingement in the subacromial space.[2,18,19,30,31] Thus, even if the fracture heals without incident, often a second surgery is necessary to remove the plate. The distal clavicle plates have not had the same reported high complication rate at this time.[17,27,28]

Traditionally, suture fixation has been reserved for cases in which the distal clavicle fragment was very small and comminuted, and thus considered too small to accept hardware for fixation.[8,17,21] However, with the advent of distal clavicle locking plates with smaller distal flanges to accommodate even smaller fragments, incorporating more screws for fixation, the concern is that they will lead to a false sense of security. Many surgeons may now push the envelope in the type of distal fragment that they attempt to plate, which could lead to higher hardware failure rates. Without rigid fixation of the fracture site, suture fixation could lead to a higher nonunion rate in vivo. This should be taken into account when choosing fixation techniques, especially when the lateral fragment is small and comminuted.

No suture material has been shown to be superior. However, less abrasive wear occurs when passing sutures through drill holes compared with suture looped over the clavicle. We had one coracoid fracture in our testing methods, however, we believe this was more likely due to the bone quality of the cadaver and would not anticipate this to occur in vivo.

This study has several limitations. First of all, it is a biomechanical cadaveric study that simulates immediate postoperative fixation, rather than an in vivo clinical trial or evaluation. We tested the ultimate strength of our construct, not the cyclic loading or fatigue failure of the construct. However, our goal was to simulate a sudden catastrophic event that would lead to construct failure. Although our mean cadaveric age was 50.8 years and all specimens were male, variability in the size of the bones and overall bone quality still exists. Ideally, all specimens would be younger than 40 and of similar size, but the ability to find and use only young cadaveric specimens is limited. A final limitation is that it may have been underpowered to determine a statistical difference, introducing a beta error.

Table I. **Load to Failure**[a]

Trials	Suture (N)	Plate Alone (N)	Plate + Suture (N)	Hook Plate (N)
1	262	496	656	1047
2	429	382	500	644
3	981	873	895	509
4	303	269	601	474
5	536	419	581	338
Average	**502.2**	**487.8**	**646.6**	**602.4**
SD	288	230	149	271

Abbreviations: N, newtons; SD, standard deviation.

[a]Load to failure is recorded for each trial for each fixation technique. Load to failure is in newtons (N) and the standard deviation is recorded.

Table II. **Modes of Failure**[a]

Fixation Type	Mode of Failure (Number of Failures)	Load to Failure
Suture fixation	Fracture displaced/suture intact (2) Suture failed/fracture displaced (2) Coracoid fracture (1)	502.2±288 N
Distal clavicle locking plate	Distal locking screws pullout (3) Midshaft clavicle fracture (1) Fracture through medial locking screw (1)	487.8±230 N
Distal clavicle locking plate + suture augmentation	Clavicle fracture through medial locking screw (4) Clavicle fracture medial to plate (1)	646.6±149 N
Hook plate	Acromion fracture (1) Hook and medial screw pullout (1) Clavicle fracture medial to plate (3)	602.4±271 N

Abbreviation: N, newtons.

[a]Mode of failure for each trial for each fixation technique is recorded, again with the average ultimate load to failure for each technique.

Conclusion

Our study has shown that among the 4 fixation methods we have evaluated for the fixation of the unstable distal clavicle fractures there was no significant difference in the biomechanical strength of the fixation techniques. However, we found the worst failures in the hook plate and suture-augmented plate groups, in which a secondary fracture almost always occurred. These types of complications necessitate removal of hardware and likely fixation of the new fracture site. Failure of the non–augmented distal clavicle plate would still require a return trip to the operating room to remove hardware, but would not in all cases absolutely require revision fixation. Because of the lower complication risk of suture fixation and the comparable strength of fixation, we believe it is at least the safest type of fixation, especially if the fracture fragment is comminuted and small, less than 1.5 cm. The next step is to evaluate clinical outcomes in a randomized, controlled trial in order to confirm what appears to be biomechanically superior in the lab.

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