

Mitigation of Triceps Avulsion Fracture After Proximal Ulna Plate Fixation

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Objectives: Triceps avulsion fractures have become an increasingly common postoperative complication of olecranon fracture repair with proximal ulna plate (PUP) fixation. The purpose of this study is to create an efficient, reproducible mechanism to mitigate this issue.

Methods: Ten matched pair cadaveric specimens underwent a complete transverse osteotomy to simulate an olecranon fracture, followed by fracture reduction with a PUP. One arm from each pair underwent an additional augmented suture repair, where the triceps tendon was sutured directly to the plate. A custom jig was used to hold the specimen in position and apply a tensile force on the triceps until mechanical failure.

Results: All control specimens (without augmented suture repair) failed through a full-thickness triceps avulsion fracture at an average force of 967.7 N. The augmented suture-repaired specimens failed at an average force of 1204.3 N through partial avulsion fractures, widening of the osteotomy site, and triceps ruptures.

Conclusions: Our study demonstrated that an augmented suture repair of PUP fixation for olecranon fractures is a simple and effective way to significantly increase fixation strength and change the potential failure mechanism.

Key Words: triceps avulsion fracture, olecranon fracture, proximal ulna plate, tension band wiring, augmented suture repair

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INTRODUCTION

Fractures of the olecranon are a common type of elbow fracture in adults.¹ The olecranon is the region of the proximal

ulna that extends from the tip of the ulna to the coronoid process distally and is the insertion site of the triceps.² Olecranon fractures typically occur as a result of a fall or direct trauma to the elbow.³ This occurs when a force drives the semilunar notch of the proximal ulna into the trochlea of the distal humerus, displacing the proximal fragment in line with the direction of the pull of the triceps muscle.³ Olecranon fractures can also occur as a result of a triceps avulsion, typically in elderly populations because of osteoporosis, where it is considered an indirect injury.^{4,5} This is a known problem that is poorly understood and under recognized.

Olecranon fractures are categorized in severity; type I olecranon fractures are undisplaced and are usually treated nonoperatively; conversely, type II (displaced, stable) and type III fractures (unstable) both have subcategories of noncomminuted and comminuted fractures and are generally treated operatively.^{1,6} A variety of surgical technique options exist including open reduction internal fixation with either tension band wiring (TBW) or proximal ulna plate (PUP) fixation.^{3,7} The goal of surgical fixation is to obtain stable anatomic reduction, promote bone healing, and provide early functional motion.^{1,6,8}

TBW fixation is associated with a high incidence of complications in the treatment of olecranon fractures.⁹ Studies have reported complication rates of 50% and reoperation rates of 71.7%.^{10,11} Most complications are related to Kirschner wires (K-wires) used with TBW, including symptomatic prominence of the K-wire in the elbow, measurable proximal migration of K-wire, and skin breakdown/infection.⁹ Given these complication and failure rates associated with TBW, open reduction internal fixation with PUP fixation is currently recommended as the optimal treatment method for olecranon fractures.¹² Furthermore, prospective randomized trials show that PUP fixation produces superior clinical outcomes and lower complication rates compared with TBW.^{13,14}

Proximal ulnar plates provide fixation to the proximal fragment of the olecranon fracture by means of screws. PUP fixation is associated with different anatomical and implant-related complications compared with TBW, such as nonunion, malunion, implant failure/loosening, implant prominence (pain), triceps avulsion fractures, and infection, with complication rates as high as 50%.^{9,15–17} Isolated triceps avulsion injuries in the absence of previous surgery are a rare injury pattern, representing less than 1% of primary upper extremity tendon injuries.^{18,19} However, these injuries are now being observed as a postoperative complication after olecranon fracture repair with PUP fixation.⁵ This is puzzling

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because the compressive strength offered by PUP fixation is superior to TBW.^{4,18,19} In TBW, the force of the triceps is carried directly by the tension band because it is applied through the region of tendon insertion, where Sharpey fibers are located, in this way unloading the proximal bony fragment and transferring the load to the distal fragment (Fig. 1A). Biomechanically, the force exerted by the triceps is parallel to the humerus, so the resultant force vector on the posterior olecranon corresponds with the position of the humerus. In PUP fixation, the pull of the triceps tendon on the proximal fragment is resisted only by screw fixation in the bone of the proximal fragment (Fig. 1B). However, when force is applied parallel to the olecranon screws, the resistance to the triceps force is only the screw pull-out strength of the screws, which may be insufficient (Fig. 1C). When the applied load is high enough, avulsion fractures can occur either through the original fracture plane or through a new plane incorporating the stress risers caused by screw insertion. It has been suggested that the addition of an off-loading triceps suture may decrease the distraction forces on the olecranon fragment, thereby preventing the avulsion fracture.⁵

This study aims to identify a reproducible way to prevent triceps avulsion fractures after PUP fixation for olecranon fractures. We hypothesize that suturing the triceps directly to the PUP will increase the ultimate failure force and/or change the failure mechanism of olecranon fractures repaired with PUP fixation (Fig. 1D).

MATERIALS AND METHODS

Sample Size Calculation

An a priori sample size calculation was conducted based on pilot data (3 matched pairs) using G*Power 3.1.9.7 software. A 2-tailed *t* test ($\alpha = 0.05$) indicated the need for 9 matched pairs. A total of 10 matched pairs were tested

so that one may be excluded if an outlier was detected by the Grubbs outlier test.

Experimental Design

Ten matched pair fresh-frozen mid humerus to fingertip human cadaveric specimens (6 females, 4 males; average age: 81.1 ± 7.2 years) were used for this study (Table 1). On each matched pair, specimens were randomly assigned as either control specimens (group A) or augmented suture-repaired specimens (group B). In both experimental groups, a complete transverse osteotomy was used to simulate an olecranon fracture and fracture reduction was achieved with a PUP. The osteotomy and fracture fixation were performed by a reconstructive upper extremity surgeon. The same surgical technique and implant for proximal ulnar plate fixation was performed in both groups. In the experimental group B, the triceps tendon was also sutured directly to the PUP.

Specimen Preparation

Specimens were stored at -20°C and thawed to room temperature overnight. We performed a gross dissection of the elbow to expose the joint. The triceps muscle was removed at the myotendinous junction leaving the triceps tendon attached to the posterior olecranon. The proximal ulna was exposed and prepared for PUP placement. The plate (73-mm PUP; Skeletal Dynamics, Miami, FL) was positioned on the dorsal edge of the intact bone. The plate was provisionally secured with a compression screw through the long slot of the plate, and a minimal sized T-shaped tenotomy was made through the triceps to allow for proper positioning of the proximal part of the plate on the bone surface. The plate was then removed, and a complete transverse osteotomy was then performed through the midpoint of the olecranon using an oscillating saw and osteotome. The osteotomy was fixed by reapplying the plate to the ulna, starting with a lag compression screw placed obliquely, proximal to distal, and

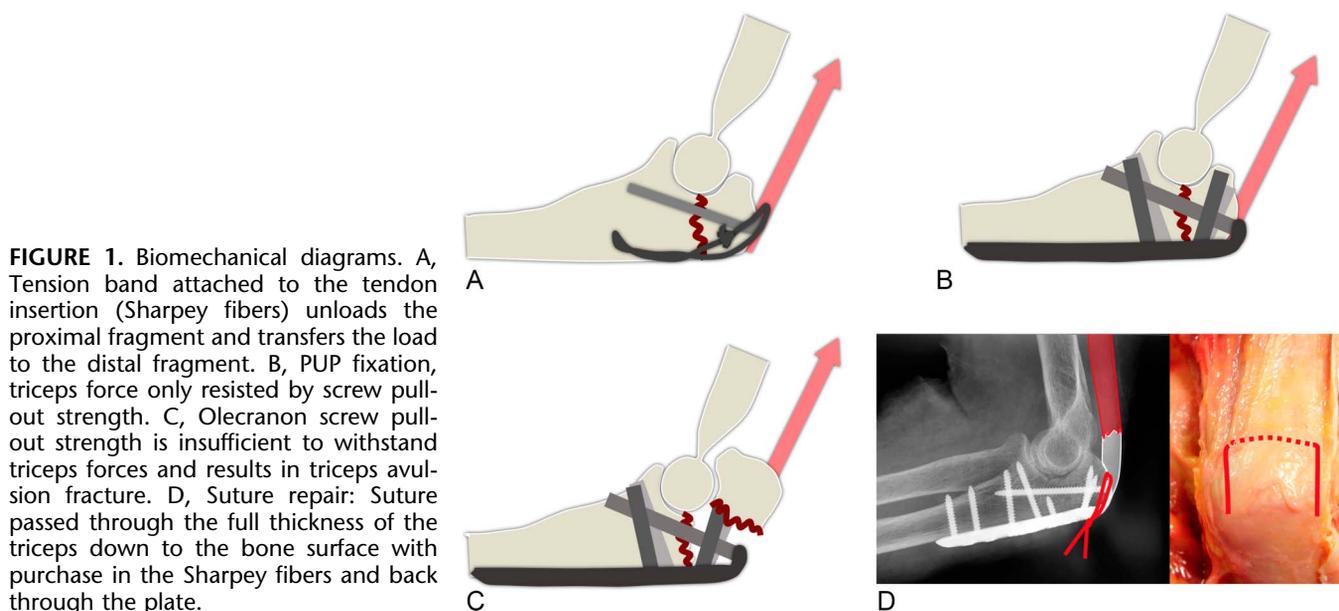


TABLE 1. Demographic Information

ID #	Gender	Age, y	Height, inch	Weight, lbs
1	Female	73	67	240
2	Female	89	65	138
3	Male	80	71	184
4	Female	79	65	144
5	Male	76	67	246
6	Female	95	59	75
7	Female	87	62	150
8	Female	81	68	80
9	Male	78	72	153
10	Male	73	68	160
	Average	81.1	66.4	157.0
	SD	7.2	3.9	56.6

fixing the olecranon to the anterior coronoid cortex. This was followed by locking screws into the olecranon and compression screws into the ulna. The arm was taken through full range of motion to confirm no impingement. Screw length and fracture reduction were confirmed radiographically.

The triceps tendon of one specimen from each matched pair (group B) was then sutured directly to the PUP with #2 FiberWire (FiberWire Blue Suture with Tapered Needle #2; Arthrex, Naples, FL). With the elbow in approximately 90 degrees flexion, the suture was passed through one of the plate's proximal triceps suture hole, through the triceps itself, and back through the plate's opposite triceps suture hole. For optimal triceps capture, the suture was passed through the full thickness of the triceps down to the olecranon bone surface to gain purchase on Sharpey fibers and then back up through the triceps. The suture was passed from superficial to deep, across and back to superficial approximately at half the distance from the plate to the olecranon tip. The intention was to place the suture between the insertion of the long and lateral heads and the medial head of the triceps (Fig. 1D). The suture was tightened until there was no slack in the suture. The suture was tied with a double sliding knot known as a SMC knot (see Video, Supplemental Digital Content 1, <https://www.dropbox.com/s/ehx9fnzv7j52dpc/JOT%20triceps.mov?dl=0>).²⁰ It is imperative that the knot is made as tight as possible, flush to the plate, with no visible slack in the suture. Seven additional alternating half-hitch stitches were used to secure the knot.

Fluoroscopic images of the specimens were taken before mechanical testing. Prepared specimens were stored in a 4°C refrigerator for no longer than 24 hours before mechanical testing; the triceps was kept moist with normal saline solution.

Mechanical Testing

We designed and built a custom jig to hold the specimen in position and apply a tensile force on the triceps (Fig. 2A). We designed and built a custom cryo-clamp to hold the proximal triceps (Fig. 2B), featuring a central vice with teeth to hold the triceps and 2 chambers packed with dry ice. The cryo-clamp was attached to a Mark-10 force gauge

(ESM301L; Copiague, NY). To maintain the cryo-clamp's grip on the tendon, the internal surface of the vice must be maintained below -20°C .

The specimen was placed in the jig with the forearm rigidly fixed in pronation and the elbow in flexion. The triceps was secured in the cryo-clamp at 60 degrees of flexion. We displaced the triceps at 100 mm/min and measured the resulting force. The specimens were loaded until failure. Photographs and radiographic images of the specimens were taken after mechanical testing.

Statistical Analysis

A paired Student *t* test with a *P* value <0.05 was used to determine statistical significance. All data are reported as an average plus or minus SD. Correlation coefficients were calculated to evaluate the correlation between ultimate failure load and patient's age, height, and weight. A Grubbs outlier test was run to evaluate potential outliers; no outliers were detected.

RESULTS

Mechanical Testing

The ultimate failure force was measured by displacing the triceps until failure. All control specimens (group A) failed through a full-thickness triceps avulsion fracture at an average force of $967.7 \text{ N} \pm 307.6 \text{ N}$ (Fig. 3). The augmented suture-repaired specimens (group B) failed at an average force of $1204.3 \text{ N} \pm 372.9 \text{ N}$; 4 failed through partial avulsion fractures, 2 failed through widening of the osteotomy site $<2 \text{ mm}$ with remaining triceps in continuity, and 4 failed through a triceps rupture. Nine of the specimens in group B failed at a higher force than the specimens in group A ($P < 0.05$), and the failure mechanism was different between testing groups in all 10 specimens (Table 2).



FIGURE 2. Custom jig used to stabilize the specimens for mechanical testing. A, The forearm is held with brackets in pronation and the elbow in flexion. The line of pull of the triceps is 60 degrees to the ulna and in line with the olecranon screws. B, A cryo-clamp was developed with dry ice-filled chambers to secure the triceps.

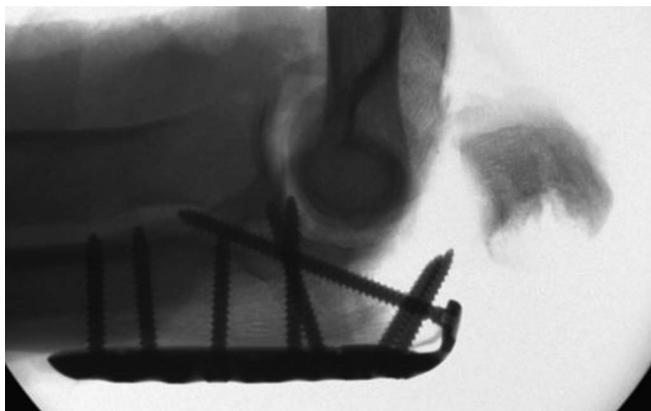


FIGURE 3. Results. Control specimens that failed through a full-thickness avulsion fracture.

Correlation analysis showed that age was highly correlated with the ultimate failure force of the control specimens (−0.84), followed by height (0.79) and weight (0.75).

An intact triceps tendon fails at around 1700 N.²¹

DISCUSSION

The fixation techniques of olecranon fractures range from tension band constructs to posterior plating systems.^{1–3} A 2011 biomechanical study by Wilson et al compared mean compression force across the fracture plane of olecranon fractures for TBW (77 N) and PUP fixation (812 N). During cyclical contraction of the triceps, the mean compression was reduced in both groups and negligible articular tension was noted. The authors concluded that precontoured plates provide significantly greater compression compared with TBW in the surgical treatment of transverse olecranon fractures.⁴

The findings from this study suggest that the addition of a tight single tension band suture to PUP fixation can increase the threshold for causing postoperative triceps avulsion fractures. The repaired group had an average failure force of 1204.3 ± 372.9 N, whereas the control group had an average failure force of 967.7 N, a difference of 24.4% (*P* < 0.05). The change in failure mode suggests that our

augmented suture repair can successfully transfer the forces applied by the triceps from the bone to the plate, strengthening the repair and potentially avoiding the triceps avulsion complication. In a similar study, Wild et al²² used matched pair specimens to compare an augmented suture repair for olecranon fractures using a modified Krackow stitch. The authors observed a 48% increase in median load-to-failure force between the control and augmented suture repair group and concluded that suture augmentation is an effective, inexpensive, and simple way to increase fixation strength for proximal olecranon fractures with the use of plate fixation. Although the Wild study reports higher percentage increase in the ultimate failure load achieved with their modified Krackow repair, the failure mode only changed in one of their augmented suture repair specimens (where it failed at the triceps attachment to the test fixture). Furthermore, it should be noted that to apply the plate in their study, Wild et al did a more extensive dissection where the triceps inserts onto the olecranon and the resulting ultimate failure loads of their augmented suture repair group (905 N) were comparable with the ultimate failure loads of the control group in our study (967.7 N). This suggests as much of the native triceps insertion should be preserved and the minimal possible tenotomy should be used to access the bone surface for plate application.

In a case series by Izzi and Athwal, a similar triceps suture technique was used successfully in osteoporotic patients with olecranon fractures. In their series of 9 patients treated with PUP fixation with augmented triceps suture repair, all fractures healed with no loss of reduction or fixation failure.⁵

One of the main differences between our study and previously reported studies is the suturing technique used. Our study uses a tight suture placed directly on the tendon–bone interface, engaging Sharpey fibers and acting as a true tension band to anchor the triceps to the plate, whereas Wild et al used multiple modified Krakow stitches and Izzi and Athwal used a running locking stitch. For suture augmentation to protect the proximal olecranon from fracturing, the suture must unload the tendon–bone interface and rigidly transfer load from tendon to plate while avoiding elongation. Sutures that depend on locking suture configurations have a high compliance (low stiffness). They therefore elongate more as load is applied and may prove unsuccessful at fully transferring the triceps load to the plate before the tendon fibers become taught. Sutures that purchase directly on the tendon–bone interface have less compliance and therefore unload the triceps more effectively.

These fractures are more common in individuals with poor bone quality. This technique is useful in those patients in whom the fracture fragment is small and proximal and the plate does not capture the comminuted olecranon tip. This technique should be used in situations where the olecranon fracture has comminution and contains within the fracture pattern, a small proximal piece.

In addition to stitch configuration, the suture material is important. The suture must be strong enough to transfer the load without stretching. For our study, we selected a #2 FiberWire because of its strength and rigidity. Kin, Yoo,

TABLE 2. Failure Mechanism

ID #	Control	Repaired
1	Triceps avulsion	Partial fracture
2	Triceps avulsion	Partial fracture
3	Triceps avulsion	Triceps rupture
4	Triceps avulsion	Triceps rupture
5	Triceps avulsion	Triceps tear; widening of the osteotomy site <2 mm
6	Triceps avulsion	Triceps tear; widening of the osteotomy site <2 mm
7	Triceps avulsion	Partial fracture
8	Triceps avulsion	Partial fracture
9	Triceps avulsion	Triceps rupture
10	Triceps avulsion	Triceps rupture

and Wang indicated in a 2005 study that the knot used in this study, the SMC knot, required an additional half-hitch suture to plateau cyclic load-to-failure force on a hydraulic testing system.²³ Furthermore, a 2006 study conducted by Abbi, Espinoza, and Odell et al indicated that knots tied using a high-strength suture (FiberWire; Arthrex, Naples FL) slipped at loads significantly below the expected failure level during cyclic testing.²⁴ To avoid the suture from loosening, we used 7 additional half-hitch sutures after our primary knot to secure our augmented repair. Another important consideration is knot location. We tied our knot over the plate itself, giving us the opportunity to maximize the tension on the triceps and secure the suture as tightly as possible.

Fixation failure (including triceps avulsions) is a postoperative complication that is common in older osteoporotic patients.^{5,24} Although we did not evaluate bone quality, all specimens in our study were at least 70 years old and the ultimate failure force of the specimens was most highly (inversely) correlated with age. This is consistent with the load-to-failure data published by Wild et al,²² where the ultimate failure force was inversely related to the age of the specimen, with their youngest specimen failing at the triceps/MTS interface not through an avulsion fracture. This may be due to decreased bone quality and density with age, suggesting bone quality might be a reasonable predictor of individuals who could be susceptible to the postoperative avulsion fracture complication and therefore most likely to benefit from the augmented suture repair.²⁵

Another predictive factor for who is most likely to benefit from the augmented suture repair might be sex. In this study, the failure mechanism was changed in all 10 specimens; however, 4 of the specimens still failed with partial avulsion fractures; all the partial avulsion fractures occurred in female specimens. Again, this may be due to decreased bone quality in women as they age, with higher rates of osteoporosis occurring in women.²⁵

Our study has several limitations inherent to small cadaveric studies, for example, anatomical variations and small sample size. This study looks at ultimate load to failure and does not address the attritional effects of cyclic loading or fatigue that may affect the repair's efficacy over time. In addition, our study only measured ultimate failure loads in one position that we believe represented the plate's weakest biomechanical fixation. Furthermore, we used a single osteotomy site to represent olecranon fractures; the effectiveness of this repair may differ based on the fracture pattern that it is used to augment. Finally, we tested a single suture material, with a single type of repair, which may not represent the optimal clinical solution.

In summary, triceps avulsion fractures are a problem associated with PUP fixation that is not found in TBW fixation. Our study demonstrated that an augmented suture repair of PUP fixation for olecranon fractures is a simple and effective way to increased fixation strength and change the potential failure mechanism.

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