Biomechanical properties of an intramedullary suture anchor fixation compared to tension band wiring in osteoporotic olecranon fractures- A cadaveric study[☆]

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ABSTRACT

Introduction: The aim of the study is to compare three different fixation techniques for transverse olecranon repair in cadaveric osteoporotic bone: (1) current recommended AO tension band technique with K-wire fixation; (2) Suture anchor fixation and (3) Polyester suture fixation.

Methods: Evaluated with bone densitometry, 7 osteoporotic human elbow specimens were included in the study. A transverse olecranon fracture was reduced anatomically and were fixated first using a K-wire tension band technique, second using two suture anchors, and third using polyester suture. Static simulations of the kinetics associated with active range of motion (AROM) and push up from a chair exercises were performed with cyclic loading using Instron hydraulic testing apparatus. Fracture displacement was measured using videographic analysis. Failure was defined as 2 mm fracture displacement.

Results: The biomechanical analysis found no statistical difference in displacements between the three fixation methods when testing AROM. In simulated push-up exercises, polyester suture fixation failed after 17 cycles and had significantly higher displacement compared to the other two methods. No difference between the K-Wire fixation versus Suture anchor fixation was observed, $p = 0.162$.

Conclusion: Suture anchor fixation might be a viable surgical treatment option for osteoporotic transverse elbow fractures in geriatric patients.

1. Introduction

Olecranon fractures account for approximately 10% of upper extremity fractures¹ and are currently treated with variety of open reduction and internal fixation (ORIF) methods including utilizing a tension band fixation construct, especially in transverse fracture patterns²

However, due to the subcutaneous nature of the olecranon, prominent implant is a common complaint after healed fracture sites, resulting in up to 82% re-operation rate which entails the removal of the implant³ Even though this poses a minor complication, it still remains a drawback of this treatment choice.

Intramedullary Kirschner wire (K-wire) placement has been associated with the risk of wire back-out, resulting in subcutaneous

irritation, migration, pain, and skin breakdown^{4,5} To avoid these complications, the AO (Arbeitsgemeinschaft fuer Osteosynthesefragen) has recommended transcortical wire placement by engaging the K-wires into the anterior ulnar cortex to increase the purchase and stability^{6,7} However, there is a known potential risk of neurovascular injury at the time of placement⁶ Additionally, it has been suggested that transcortical wires might impinge on the radial neck and biceps tendon, impairing the forearm rotation⁸ Many other techniques have emerged to treat olecranon fractures using various plate and screw devices^{9,10} At this time, the choice of treatment is still primarily based on the surgeon's preference.

The proposed intramedullary suture anchor fixation technique is thought to avoid prominent implants over the bone and thereby reduce the re-operation rate; however, the biomechanical properties of this

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technique have not been described. Our study aims to evaluate the biomechanical properties of three surgical treatment techniques of transverse olecranon fracture under the null hypothesis that there is no significant difference between them. These techniques involve (1) a gold standard: the current recommended AO tension band technique with K-wire fixation placed in the anterior cortex; (2) Suture anchor fixation and (3) a low cost option: Polyester suture fixation.

2. Methods

2.1. Bone mineral density measurements

We assessed bone mineral density of cadaveric elbow specimens using a 2D single slice quantitative CT scanning. The trabecular BMD was interpreted using the Felsenberg classification. In this study, we included osteoporotic elbows with < 120 mg/cc in the QCT. There were 3 female and 4 male elbows with an average age 76 ± 13 years, average bone mineral density of 0.6 ± 0.1 g/cm² and an average T score of -2.3 ± 1.0 .

2.2. Surgical techniques

All soft tissue was removed except for the ulno-humeral joint capsule, MCL and LCL, triceps, biceps, and brachialis muscles. A transverse olecranon fracture was simulated by means of a transverse osteotomy at the midpoint of the semilunar notch between the coronoid and olecranon processes with use of an oscillating saw. Reduction was obtained with the use of a towel clip and maintained while fixation was performed. First, we applied the gold standard technique, where the fractures were fixed using conventional tension band wiring technique as recommended by the AO¹¹ K-wire and tension band wiring fixation was performed using 1.6 mm diameter K-wires and an 18-gauge tension band. A 2 mm hole was created three cm distal to the osteotomy site to pass the tension band wire. It was then tightened in a figure of eight fashion, passing behind the triceps tendon and the K-wires to achieve compression. After the biomechanical testing, the fixation was removed in order to test the next fixation method.

Next technique included the suture anchor fixation. Two 4.75 mm biocomposite fully threaded suture anchors (Smith and Nephew, USA) were placed in the cancellous healthy bone bed of the ulna. Although the bone quality in this region of the ulna in the geriatric patient population is often questionable, adequate fixation of anchors was obtained when the anchor was placed near the dorsal cortex of the ulna. Shuttle sutures were placed trans-osseously by a free needle and used to pass the suture anchor limbs through the olecranon fracture fragment. Ultimately, three drill holes were made through the olecranon fracture fragment at a 90° manner, and sutures were shuttled through the drill sites by a suture passer. One limb from each suture was passed through the triceps tendon in a Krackow fashion and tied sequentially to the second limb. The third limb from each suture anchor was passed in a figure of eight fashion and tied to each other. The fourth limb was shuttled through the distal drill hole and served as double row fixation. Reduction was confirmed with direct visualization and if necessary, under fluoroscopic imaging. After the biomechanical testing, the fixation was removed in order to test the next fixation method.

The last fixation technique included the polyester suture fixation. The same suture tension band technique was applied as described for the suture anchor fixation; however, a #5 Ethibond suture was used instead.

2.3. Biomechanical testing

After simulating each fracture fixation, the triceps, biceps, and brachialis tendons were attached to an Instron hydraulic testing apparatus (Instron 8511, Norwood, MA, USA) with the use of a 10 mm-thick ND 25 mm wide Kevlar strap (Aerospace Composite Products, San

Leandro, CA, USA) in a 90° flexed position (with the forearm in neutral position) to allow isometric loading of the elbow. The triceps was connected to the actuator of the load frame by means of a bow string (BCY 452-X, M's Discount Archery, Oberglatt, Switzerland). Active Range of Motion (AROM) exercises and Push-up exercises were simulated in the following manner; AROM was simulated by 10 sinusoidal cycles of load-control tension with amplitude of 100 N, and the Push-up was simulated afterwards by 500 sinusoidal cycles of load-control tension with amplitude of 500 N at a frequency of 1 Hz. The test was stopped, if an osteotomy displacement of more than 4 mm at the posterior ulnar cortex occurred. The most posterior point of the ulnar cortex was used as reference for displacement measurements, and comparisons were made between baseline fixation and after 500 cycles. Displacements were recorded with a linear variable displacement transducer (Instron, Norwood, MA) and verified by capturing images of the fracture site using a high-performance microscopy camera before and after testing (PL-B681 CU, PixelINK, Ottawa, Canada).

Average mid articular displacement (mm), Posterior cortex displacement (mm) and Posterior angular displacement (degrees) was measured by placing dots on specific landmarks and following them with a high-resolution camera system. An in-house MATLAB (MathWorks, Natick, MA, USA) code was used to read the image sequence and calculate displacement values. Additionally, failure was defined as a 2 mm gap at the fracture site.

2.4. Statistical analysis

Fracture gap displacements at the peak (500 N) and minimum (10 N) of loading cycles, and the difference between the peak and trough were taken at 5, 50, and 500 cycles. Since the different constructs were performed on the same forearm specimens, the data were analyzed using paired sample statistical methods (the Wilcoxon signed-rank test). We analyzed specific contrasts between each two fixation constructs (e.g., the intramedullary K-wire tension band construct compared with the suture anchor fixation band construct) and therefore only performed the pairwise comparisons instead of the traditional analysis-of-variance hypothesis of equal means across all test conditions.

We analyzed the peak displacement to assess the combined plastic (permanent) and elastic deformation, the trough displacement to assess the plastic deformation, and the difference to assess elastic motion at the fracture site. The maximum loads to failure were acquired from the load-displacement curves, and the mean values of the suture fixation and tension band groups were compared. All statistical analyses were completed using SPSS software (IBM SPSS Statistics for Windows, Version 20.0. Armonk, NY, USA). A p-value of 0.05 is used as the cutoff for statistically significance.

3. Results

3.1. Active range of motion test

During the Active Range of Motion test, maximum displacement in the K-Wire fixation was 0.07 ± 0.03 mm, versus suture anchor fixation at 0.22 ± 0.10 mm, versus polyester suture fixation at 0.26 ± 0.11 mm (Table 1). K-wire fixation was found to be significantly stiffer when compared to both suture anchor ($p < 0.01$) and polyester suture conditions ($p < 0.01$). Suture anchor and polyester suture fixations were shown to have similar displacement measures with no statistical difference (Fig. 1). We did not find a statistical difference when measuring dorsal displacement among the three fixation groups (Fig. 2). Similarly, there was no statistical difference in the dorsal angular displacement between K-wire, suture anchor or polyester suture fixations (Fig. 3).

Table 1

Final displacements and failure cycles of different olecranon fixations. Failure is defined by a gapping of 2 mm. P-value (K-wire) refers to statistical comparisons to the K-wire fixation and P-value (Suture) refers to statistical comparisons to the Polyester Suture fixation.

Trial	Fixation	Max Displacement (mm)	Failure Cycle	P value(K-wire)	P value (Suture)
AROM	K-wire	0.17	–	–	0.201
	Polyester Suture	0.26	–	0.201	–
	Suture Anchor	0.22	–	0.604	0.433
Push-up	K-Wire	0.50	–	–	< 0.001
	Polyester Suture	3.47	17	< 0.001	–
	Suture Anchor	1.53	–	0.162	0.008

Fig. 1. Displacement vs. Cycles for the three different fixation conditions. Cyclic loading of 'AROM' movement with amplitude of 100 N. No statistical difference was seen between all groups.

Fig. 3. Angular displacement facing from ventral to dorsal aspect of fracture.

Error bars are reported as SEM. End displacements seen after 'AROM' loading cycles. High load is 110 N, Low Load is 10 N.

Fig. 2. Dorsal displacement of distal aspect of fracture.

Error bars are reported as SEM. End displacements seen after 'AROM' loading cycles. High load is 110 N, Low Load is 10 N.

3.2. Push-up test

In the Push-up condition, maximum displacements in the K-wire fixation was 0.50 ± 0.14 mm, versus suture anchor fixation at 1.53 ± 0.57 mm, versus polyester suture fixation at $3.47 \text{ mm} \pm 0.79$. Polyester suture fixation failed after 17 cycles (Table 1) and was shown to have a significantly higher displacement compared to both suture anchor ($p < 0.001$) and K-wire fixations ($p < 0.0001$) (Fig. 4). There was no statistically significant difference between K-wire and suture

Fig. 4. Displacement vs. Cycles for different fixation conditions.

Cyclic loading of 'Push-up' movement with amplitude of 500 N. K-wire and Suture Anchor conditions were significant from Polyester Suture fixations, $P < 0.01$.

anchor fixations in the Push-up condition ($p = 0.162$). We did not find a statistical difference when measuring dorsal displacement among the three fixation groups in low loading cycles, however, during high loading conditions the polyester suture method had higher dorsal displacement compared to both K-wire fixation ($p < 0.01$) and suture anchor fixation ($p = 0.027$) (Fig. 5). There was no statistical difference in the dorsal angular displacement between K-wire, suture anchor or polyester suture fixations (Fig. 6).

Fig. 5. Dorsal displacement of distal aspect of fracture.

Error bars are reported as SEM. End displacements seen after 'Push-up' loading cycles. High load is 550 N, low load is 50 N. Significant difference is seen only after high loading conditions. There is a significant difference between K-wire and Polyester Suture fixations ($P < 0.01$), and between Polyester Suture and Suture Anchor fixations ($P = 0.027$).

Fig. 6. Angular displacement facing from ventral to dorsal aspect of fracture.

Error bars are reported as SEM. End displacements seen after 'Push-up' loading cycles. High load is 550 N, Low Load is 50 N.

3.3. Load to failure

When comparing force with displacement, failure was observed in the polyester suture fixation group only. This failure occurred at 129.1 N on average. Polyester suture fixation was found to have significant displacement when compared to K-wire and suture anchor fixations. End displacements at maximum loading are shown in Table 2 and Fig. 7.

Table 2

Maximum displacements at maximum loading condition. Failure is defined by a gapping of 2 mm. P-value (K-wire) refers to statistical comparisons to the K-wire fixation and P-value (Suture) refers to statistical comparisons to the Polyester Suture fixation.

Force Profiles	Max Displacement (mm)	Failure Load (N)	P-value (K-wire)	P-value (Suture)
K-Wire	0.51	–	–	< 0.001
Polyester Suture	3.52	129.1	< 0.001	–
Suture Anchor	1.55	–	0.162	0.008

Fig. 7. Force versus Displacement plot during the final cycle of high cyclic loading.

Displacements above 2

mm are considered failure for a fixation. Polyester Suture fixation is significantly different from the others ($p < 0.01$).

4. Discussion

Olecranon fractures have been traditionally associated with a high re-operation rate, either due to implant failure or irritating implants. Therefore, numerous studies have attempted to modify the traditional tension band fixation^{12–17} Most biomechanical studies of olecranon fractures have been performed in non-osteoporotic cadaveric bone. We believe to be the first to assess the biomechanical strength of traditional tension band technique with K-wire fixation in osteoporotic bone and compare it to a new suture anchor fixation method and a regular polyester suture repair. We attempted to closely replicate the methods previously described by Hutchinson et al.¹³ who used cyclic loading via the triceps tendon. This may simulate the physiologic state most closely. Our experiments simulated two clinically relevant situations in the geriatric population: active range of motion and the chair push-up.

Our analysis demonstrated that there was no statistically significant difference in all three groups in the active range of motion testing. The tension band technique with K-wire fixation provided the most stable method in push-up experiment followed by suture anchor fixation where no significant difference was found between the two methods. The polyester suture fixation failed after 17 cycles on average during the push-up technique and had significantly higher displacement compared to the two other methods.

Carofino et al.¹² used a high-strength suture tension band for olecranon fracture repair. The FiberWire tension band was formed from two strands of No. 2 FiberWire. Under both testing conditions (active motion and chair push-up), they found no difference in fixation between the FiberWire and metal gauge wire tension bands when used with either K-wires or intramedullary screws. The stability of our suture anchor fixation was similar to their findings using the FiberWire technique. This may be an additional point of evidence supporting the use of braided suture material as an alternative to the traditional use of wire

for the tension band technique.

Prayson et al.¹⁶ also used a cyclic loading model; however, they analyzed different metal implant configurations. They compared transcortical K-wire tension band construct with an intramedullary K-wire tension band and found the stability of a transcortical K-wire tension band construct to be significantly better than that of an intramedullary K-wire tension band construct ($p = 0.04$). We did not elect to expand our experiments to intramedullary K-wire fixation due to their findings, particularly since intramedullary K-wire fixation may have a higher incidence of wire backing out, and the goal of this new technique is to reduce the necessity for re-operations.

Fyfe et al.¹⁸ compared five methods for stabilizing the proximal ulna in a cadaveric model using a steady and slow distraction force to generate force-displacement data. In contrast, our biomechanical analysis was performed by cyclic loading, including active range of motion exercises and push-up out of chair exercises. We believe it is important to closely simulate postoperative rehabilitation needs of the geriatric population and therefore did not perform a slow distraction force. However, our analysis included a load to failure experiment that demonstrated that regular suture repair only withheld 129 N before fracture displacement was greater than 2 mm and therefore may not be suitable even for low demand patients.

Our results indicate, in an osteoporotic cadaveric model, that suture anchor fixation may be sufficient for the early rehabilitation in comparison to the traditional tension band technique with K-wire fixation. There was no significant difference in the total displacement during cycle 500 between the two groups simulating push-up exercises. However, comparison of our data with those of other biomechanical studies on olecranon fractures should be done with caution, since we solely used bones from osteoporotic cadavers that may act differently when compared to bones from non-osteoporotic donors. The potential downside of using a suture anchor fixation method is in the occurrence of infection. Implant infection with K-wires may resolve with removal and antibiotics treatment. In the setting of an infected suture anchor, a thorough debridement is most likely warranted that may cause significant bone loss. This may compromise future reconstruction efforts. It is unknown whether the cost of the suture anchor may be cost-effective when compared to the traditional K-wire tension band fixation. Future clinical decision analysis models or cost-effectiveness studies may help orthopaedic surgeons in their treatment choice.

4.1. Limitations

There are some limitations associated with the present work. The experiments were set up to simulate pure tension at the olecranon; however, there may have been a certain degree of rotational and shear forces that could not be quantified. This may be similar to physiological stress during postoperative rehabilitation process. It is also noteworthy that we tested a non-comminuted transverse fracture model only, and therefore our data cannot be extrapolated to all patterns of olecranon fractures. Another potential flaw to this study was the reuse of seven elbows for three testing periods. After each experiment, we analyzed the specimen for gross macroscopic evidence of erosion. We were concerned about this and specifically looked for bone failure at the edges of the drill tunnel after each test. We did not observe any macroscopic bone failure. It is certainly possible that microscopic damage or rounding of the tunnel edges occurred, but we did not examine the tunnels microscopically and so could not quantify this. Another biomechanical study on olecranon tension band wiring also reused specimens when not testing to failure.¹³ However, we tested the gold standard method first prior to the suture anchor fixation, and therefore the later would be at a disadvantage, whereas we did not observe any significant differences and can therefore conclude that suture anchor fixation may be considered as an alternative. The goal of all methods of open reduction and internal fixation for olecranon fractures is to obtain and maintain a reduction without complications until healing is

achieved. Limiting our biomechanical testing to only 500 cycles may be a flaw to the study design.^{19,20} However, several other studies of olecranon fixation used the same cyclical loading protocol with fracture gap displacement at various numbers of cycles as the primary outcome^{12,13,21} and the current biomechanical model does not take into account callus or healing bone, which would increasingly bear load relative to the fixation construct within the first 3 weeks of minimal loading to the fracture elbow. We believe that 500 cycles at up to 500 N triceps force may be sufficient to test the fixation construct relative to in vivo loading in the geriatric population.

5. Conclusion

We found no significant difference between the three treatment groups when comparing displacements after active range of motion testing. During the push-up testing, polyester suture fixation failed after 17 cycles and had higher displacement compared to the other two methods. There was no significant difference between the K-wire tension band fixation and suture anchor fixation. While we were able to demonstrate that suture anchor fixation may be suitable for the repair of transverse olecranon fractures in osteoporotic cadaveric bone model, clinical trials are warranted to verify this finding in a clinical setting.

Conflicts of interest

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jor.2019.08.002>.

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