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Biomechanical comparison of tension band wiring and plate fixation with locking screws in transverse olecranon fractures

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Background: Tension band wiring (TBW) is the standard method for treating transverse olecranon fractures, but high rates of complications and reoperations have been reported. Plate fixation (PF) with locking screws has been introduced as an alternative method that may retain the fracture reduction better with a higher load to failure.

Methods: Twenty paired cadaveric elbows were used. All soft tissues except for the triceps tendon were removed. A standardized transverse fracture was created, and each pair was allocated randomly to TBW or PF with locking screws. The triceps tendon was mounted to the materials testing machine with the elbow in 90° of flexion. Construct stiffness was compared 3 times. Then, the elbows underwent a chair lift-off test by loading the triceps tendon to 300 N for 500 cycles. Finally, a load-to-failure test was performed, and failure mechanism was recorded.

Results: The construct stiffness of PF was higher in the first of 3 measurements. No difference was observed in the cyclic test or in load to failure. Hardware failure was the failure mechanism in 8 of 10 TBW constructs, and all failures occurred directly under the twists of the metal wire. Hardware failure was the cause of failure in only 1 elbow in the PF group ($P < .01$).

Conclusion: There was no difference in fracture displacement following fixation with TBW and PF with locking screws in transverse olecranon fractures. However, assessment of the mode of hardware failure identified the metal cerclage twist as the weakest link in the TBW construct.

Level of evidence: Basic Science Study; Biomechanics

Keywords: Elbow; olecranon fracture; tension band wiring; plate fixation; biomechanics; elbow surgery

Tension band wiring (TBW) is considered the standard treatment of isolated, displaced olecranon fractures. Functional outcomes following simple olecranon fractures are good; however, high rates of complications and secondary surgical procedures have been reported.[1,4,7,8,21,23]

The study was performed in accordance with the ethical standards in the 1964 Declaration of Helsinki and was approved by the Norwegian Regional Ethics Committee (REC, 2018/501).

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Therefore, alternative fixation methods have been developed, including precontoured plates with and without locking screws, intramedullary rods, olecranon sleds, tension plates, and suture techniques.[2,11,14,16,19,24] The most commonly used alternative to TBW is plate fixation (PF). In a randomized controlled trial comparing TBW and PF with nonlocking screws in 2-part olecranon fractures, Duckworth et al[7] reported no functional differences at final follow-up. However, the rate of hardware removal was higher following TBW, whereas serious complications were exclusive to the PF group. Precontoured PF with locking screws could potentially offer better fracture-retaining capabilities, especially in osteoporotic patients.[6] The main purpose of the implant in fracture surgery is stabilization of the fracture fragments, and the method of fixation should allow early active mobilization without loss of reduction. This is particularly important following elbow injuries because these patients are prone to joint stiffness, especially if immobilization is prolonged.[5,17] Fixation with PF with locking screws could permit mobilization immediately following operative treatment and thereby reduce recovery time and risk of elbow stiffness. There is a paucity of literature on the biomechanical properties of PF with locking screws in fixation of olecranon fractures.

This study aimed to compare TBW and PF with locking screws in transverse olecranon fractures. We hypothesized that PF with locking screws would provide superior capabilities to retain fracture reduction with a higher ultimate load to failure compared with TBW.

Materials and methods

In this biomechanical study, we used 20 paired fresh-frozen elbows from white female patients with no history of bone pathology (Science Care, Phoenix, AZ, USA). The elbows were stored at –80°C and thawed for 12 hours prior to computed tomography scanning to quantitatively evaluate bone mineral density in Hounsfield units per square centimeter. The elbows were kept moist during the evaluation. Bone mineral density was measured in cancellous bone of the olecranon and in cortical bone 10 cm distal to the olecranon tip.

The elbows were stored at –20°C and thawed at room temperature before soft-tissue dissection, surgery, and biomechanical testing. An online randomization service was used to randomly allocate implants with 1 elbow from each pair being assigned to either TBW ($n = 10$) or PF ($n = 10$). All soft tissues were removed, except for the triceps tendon. The ulna was transected 15 cm from the olecranon tip, ensuring sufficient length for PF and potting in polymethyl methacrylate (Fricke Dental International, Streamwood, IL, USA). A 0.4-mm-thick saw blade (DePuy Synthes, Solothurn, Switzerland) was used to create a transverse fracture in the cartilage bare area of the olecranon. The fracture was reduced, and the fragments were fixed with a reduction clamp until final osteosynthesis.

Surgical technique

Two board-certified orthopedic surgeons performed all surgical procedures together to ensure uniformity of the surgical procedures.

Tension band wiring

The TBW procedure was performed according to the recommendations by the Arbeitsgemeinschaft für Osteosynthesefragen (AO).[25] Two parallel 1.6-mm Kirschner wires (K-wires) were inserted from the olecranon tip through the anterior cortex. A 2.0-mm drill bit was then used to create a canal 40 mm distally to the fracture. A 1.25-mm wire was passed through the bone tunnel and under the triceps tendon in a figure-of-8 configuration. With close attention paid to wire tightening to ensure that each end of the wire spiraled equally, 1 twist on the lateral and medial side was tightened sequentially while the pliers were pulled to remove residual slack and achieve desired tensioning. The metal twists were cut after appropriate tensioning was achieved, leaving sufficient length to bend the knots as one would do in the clinical setting to prevent later soft-tissue irritation. Finally, the K-wires were bent, cut, and driven into the olecranon tip through an incision in the triceps tendon.

Plate fixation

VA-LCP Olecranon Plates (DePuy Synthes) were used in this study. The fracture was fixed consistently in all specimens, lining the plate along the dorsal aspect of the ulna. Three variable-angle 2.7-mm locking screws were inserted proximally, and two 3.5-mm nonlocking bicortical screws were inserted distally. The first screw inserted was a 3.5-mm bicortical screw in the oblong hole. After good positioning of the plate on the dorsal aspect of the ulna was ensured, 2 variable-angle locking screws were inserted into the proximal fragment. A second bicortical screw was inserted into the shaft eccentrically. Before the second screw was tightened, the first screw was loosened slightly to allow for compression of the fracture. The loosened screw was then retightened. Finally, a third variable-angle locking screw was inserted into the proximal fragment, crossing the fracture. The screws were inserted uniformly in all specimens.

Biomechanical testing

The distal ulna was potted in polymethyl methacrylate cement and mounted horizontally in a custom-made jig (Fig. 1). The distal humerus was placed in the olecranon to create a hypomochlion with the elbow joint at a 90° angle before the distal humerus was rigidly fixed. The triceps tendon was secured in a custom-made clamp, aligned along the longitudinal axis of the displacement direction of the hydraulic testing machine (Mini Bionix with MTS FlexTest digital controller, model 858; MTS Systems, Eden Prairie, MN, USA), to mimic a triceps contraction in elbow flexion. An extensometer (MTS Systems) was applied perpendicular to the fracture to measure increased displacement continuously along the axis of the ulnar shaft. The extensometer was fixed uniformly on each specimen with pins on both sides of the fracture. Fracture displacement was measured on the articular side using the extensometer as joint displacement was considered most clinically interesting.

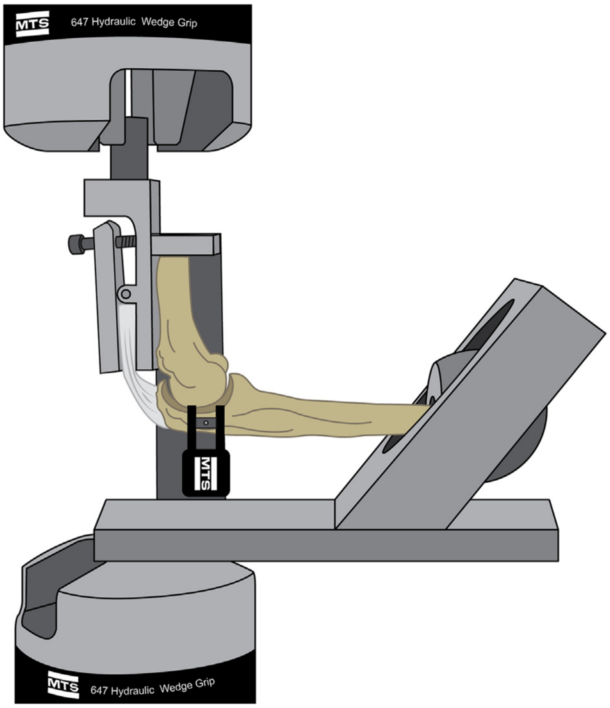

Figure 1 Illustration of test setup. A custom-made clamp secures the triceps tendon to the testing machine. The ulna and humerus are fixed in 90° of flexion. A digital extensometer measures displacement in the fracture gap.

The clamped triceps tendon was fixed to the materials testing machine, and all tests simulated contraction of the triceps muscle. The materials testing machine added increased force to the triceps tendon after pre-tensioning, thus producing a distracting force to the fracture. All specimens were tested 3 times in a nondestructive test for calculation of construct stiffness using 10 N of pre-tension and a linear force development of 100 N/s until 100 N. Cyclic loading was then performed for 500 cycles. The cyclic loading test was similar to that in previous studies and mimicked the chair push-off test.[12,13] A maximum load of 300 N in the cyclic test was chosen based on normative reference values of the elbow extensors.[15] The elbows were loaded in a sinusoidal manner from 0 to 300 N at a frequency of 0.5 Hz. Finally, all specimens underwent a load-to-failure test, adding a progressive stroke at 1 mm/s until catastrophic failure. The failure mode was recorded.

Data analysis

The data sampling strategy allowed collection of data on force, time, and displacement for final analyses in MATLAB software (The MathWorks, Natick, MA, USA). The stiffness of the construct was defined as the best-fit line of the slope of the load-deformation curve's linear elastic portion during the first 3 cycles. Deformation in the loaded end phase was chosen as the outcome of the dynamic test. Ultimate load before catastrophic failure was defined as load at failure. The mode of failure was categorized based on visual inspection.

Statistical analysis

A sample size calculation was performed (Stata/SE software, version 14.1 for Windows; StataCorp, College Station, TX, USA) in which displacement was at interest, as powering for failure rate was not feasible. A paired difference of 2 mm was assumed the minimal difference important to detect. A standard deviation for difference between means of 1.5 mm was assumed. A sample size of 9 specimens in each group was necessary to detect a difference with 90% power ($\alpha = .05$). SPSS software (version 25; IBM, Armonk, NY, USA) and Prism software (version 8; GraphPad Software, San Diego, CA, USA) were used for data analysis and graphic data visualization. The Kolmogorov-Smirnov test and Q-Q plots were used to determine normality. We used an unpaired t test to compare continuous data and the Fisher exact test to compare categorical data. Statistical significance was defined as $P < .05$.

Results

The mean age of the specimens was 71 ± 6 years, and the mean body mass index was 21 ± 2 kg/m^2. No statistically significant differences were found between the matched specimen pair cohorts (Table I).

Mean stiffness after the first cycle was 19.3 N/mm (95% confidence interval [CI], 15.9-22.6 N/mm) in the TBW group and 32.2 N/mm (95% CI, 27.8-36.6 N/mm) in the PF group. Mean stiffness after the second and third cycles was 46.2 N/mm (95% CI, 41.7-50.6 N/mm) and 50.1 N/mm (95% CI, 45.4-54.8 N/mm), respectively, in the TBW group vs. 51.9 N/mm (95% CI, 46.6-57.1 N/mm) and 53.6 N/mm (95% CI, 48.1-59.2 N/mm), respectively, in the PF group. Construct stiffness was measured in the first 3 cycles (Fig. 2), and a statistically significant difference in the first cycle was found in favor of PF ($P < .001$). Stiffness in the TBW construct increased in the following 2 cycles and was comparable to that in the PF construct after 3 cycles ($P = .23$).

Mean displacement following 3 cycles to 100 N was 0.13 mm (95% CI, 0.04-0.22 mm) for TBW and 0.09 mm (95% CI, 0.01-0.16 mm) for PF ($P = .38$). No statistically significant difference in mean displacement was found following 500 cycles to 300 N ($P = .07$). Mean displacement in the fracture was 1.05 mm (95% CI, 0.25-1.86 mm) for TBW and 0.33 mm (95% CI, 0.03-0.64 mm) for PF (Fig. 3).

Ultimate load to failure was 861 N (95% CI, 719-1003 N) for TBW and 943 N (95% CI, 767-1119 N) for PF ($P = .42$) (Fig. 4). The data and biomechanical properties are summarized in Table I. Three types of failure at ultimate load were identified: (1) triceps tendon rupture, (2) olecranon fragmentation, and (3) hardware failure (Table II). A statistically significant difference in failure mode was found between TBW and PF ($P < .01$). All hardware failures in the TBW group occurred in the metal wire, directly under the metal twists.

Table I Summary of BMD and biomechanical properties

	TBW, mean ± SD	PF, mean ± SD	*P* value
BMD, HU/cm^2			
Olecranon	84 ± 48	84 ± 35	.98
Shaft	1418 ± 269	1342 ± 147	.45
Mean stiffness after 3 cycles, N/mm	50.1 ± 6.6	53.6 ± 7.6	.23
Mean displacement after 500 cycles, mm	1.05 ± 1.12	0.33 ± 0.42	.07
Load to failure, N	861 ± 198	943 ± 146	.42

TBW, tension band wiring; *SD*, standard deviation; *PF*, plate fixation; *BMD*, bone mineral density; *HU*, Hounsfield units.

Discussion

The main finding of this study was that no difference in displacement between TBW and PF with locking screws after 500 cycles simulating a chair lift-off test was observed. Both methods retained reduction at time zero within the clinically acceptable limit of 2 mm. In addition, we noted no statistically significant difference in load to failure. However, the mode-of-failure analysis identified the metal wire cerclage, directly under the twist, as the weakest link in the TBW construct.

Only 1 study has compared fracture displacement of TBW and PF in olecranon osteotomies: Fyfe et al[10] compared TBW and one-third tubular PF in transverse, oblique, and comminuted osteotomies. A statistically significant difference was only observed in comminuted osteotomies favoring PF; however, the mean displacement in both groups was less than 0.3 mm, which can be considered negligible. The limited load applied (10 N) in the study may explain the minimal displacement observed. The authors did not find any statistically significant difference comparing transverse fractures.

The present study is, to our knowledge, the first biomechanical comparison of TBW and PF with locking screws. No statistically significant difference was observed following the cyclic test mimicking a chair lift-off test using both arms. Immediate active mobilization with limited resistance would put considerably less distracting force on the proximal olecranon compared with the chair lift-off test, and routine immobilization to protect the fracture reduction may be unnecessary.

Mean displacement in the TBW group was 0.91 mm after the first 100 cycles. However, for the next 300 cycles, minimal displacement was observed. Carofino et al[3] demonstrated a similar displacement pattern. Remaining slack in the figure-of-8 loop may explain the initial displacement. We used 2 twists to ensure equal tension of the wire as recommended by the Arbeitsgemeinschaft für Osteosynthesefragen (AO) Foundation,[25] but the initial displacement found in the TBW group may demonstrate the difficulty in achieving the desired tensioning to ensure compression over the fracture site. Wilson et al[26] compared

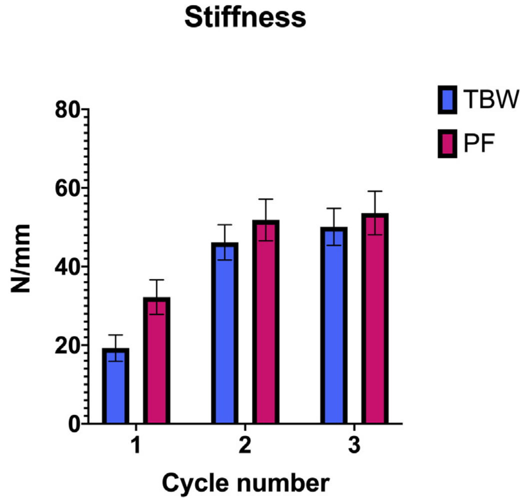

Figure 2 Stiffness in the tension band wiring (*TBW*) and plate fixation (*PF*) groups was measured in the first 3 cycles of the test at 100 N. The *brackets* indicate 95% confidence intervals.

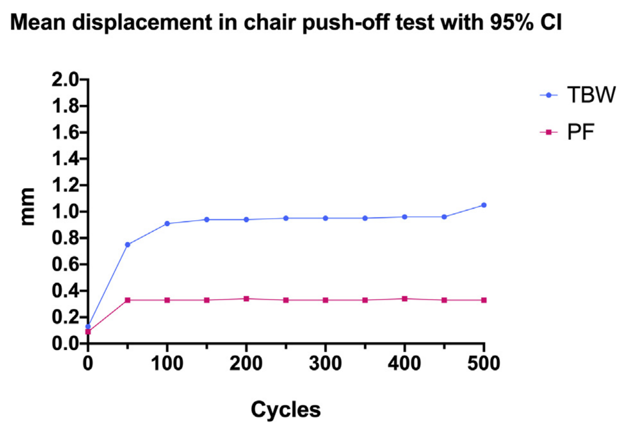

Figure 3 The first 3 cycles were performed at 100 N, and displacement after the third cycle was 0.13 mm for tension band wiring (*TBW*) and 0.09 mm for plate fixation (*PF*). Mean displacement is shown when 300 N was applied for the cyclic test, simulating the chair push-off test for 500 cycles. Displacement was minimal in the TBW group after 100 cycles but increased after 450 cycles. In the PF group, minimal displacement was observed throughout the entire cyclic test. *CI*, confidence interval.

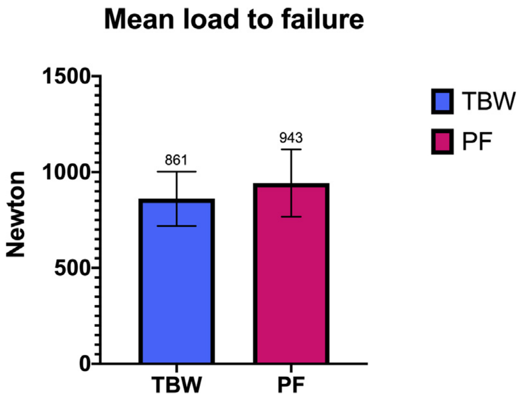

Figure 4 Load to failure in tension band wiring (*TBW*) and plate fixation (*PF*) groups. The *brackets* indicate 95% confidence intervals, with mean load to failure shown above them.

the interfragmentary pressure following TBW and PF of transverse osteotomies in synthetic ulnas. They found mean compression of 819 N across the fracture gap in the PF group vs. 77 N in the TBW group ($P = .039$). Mean compression on the articular side following TBW was 1 N and articular compression was unchanged when simulating movement, causing the authors to question the tension band principle. Unfortunately, they did not report how the TBW was performed, specifically the dimensions of the K-wires and metal wire cerclage, or whether 1 or 2 metal twists were used to tension the construct. Moreover, no information was provided on plate and screw type (locking or nonlocking).

TBW of transverse olecranon fractures is considered a simple procedure; however, as Schneider et al[22] demonstrated, the TBW method is associated with numerous pitfalls. In their review of 233 patients treated with TBW, they found that over 40% of the procedures had imperfections and concluded that TBW is not as simple as perceived by clinicians.

In our study, only minimal displacement was observed after residual slack in the metal wire was taken out. Of note, increased displacement was observed after 450 cycles. The increasing displacement may indicate fatigue in the TBW construct, a tendency not observed in the PF group. The cyclic test was limited to 500 cycles, as we believed this represented the initial phase in which bone healing is sparse and does not contribute to the overall strength of the fracture fixation construct.[20]

Table II Mode of failure

	TBW (n = 10)	PF (n = 10)
Hardware failure	8	1
Bony fragmentation	1	0
Tendon rupture	1	9

TBW, tension band wiring; *PF*, plate fixation.
All hardware failures in the TBW group occurred directly under the metal twist. The proximal fragment pulled out and fragmented in 1 elbow in the TBW group. Rupture of the triceps tendon caused failure in all but 1 elbow in the PF group. In 1 specimen in the PF group, plate loosening caused hardware failure.

Although we did not find any statistically significant difference in ultimate load to failure, there were interesting observations on failure modes. All hardware failures in the TBW group occurred in relation to the metal twist, specifically directly under the metal twist. Excessive tensioning of the metal wire may contribute to further weakening and increase the risk of hardware failure. Prayson et al[18] used a torque screwdriver to tension the metal wire in a biomechanical study. We did not use any device to determine correct tension in the wire, reflecting the surgical challenge when treating patients with the TBW method. Replacing the metal wire with ultrahigh-molecular-weight polyethylene suture could reduce the risk of cerclage breakage and reduce the rate of hardware irritation caused by the metal knots. Lalliss and Branstetter[13] demonstrated comparable fracture-retaining capabilities in a biomechanical comparison of metal wire and ultrahigh-molecular-weight polyethylene sutures in TBW of transverse olecranon osteotomies.

The findings of our study suggest that remaining slack in the metal wire caused the initial fracture displacement. Moreover, the cyclic tests showed signs of increasing displacement after 450 cycles, which may indicate fatigue of the TBW construct. The cost of precontoured PF with locking screws is higher than that of TBW, even when higher rates of hardware removal following TBW are considered.[9] However, the challenges associated with the TBW method are numerous,[22] in addition to the need for optimal tensioning of the metal wire cerclage and concern of implant fatigue as demonstrated in the present study. The statistically significant difference in failure mode is of interest as only 1 of 10 PF specimens failed owing to hardware failure. PF with locking screw fixation may represent a more reliable method without the specific pitfalls associated with the TBW construct.

The clinical applicability of biomechanical studies has limitations. First, simulation of physiological muscle interaction is difficult to reproduce. We removed all soft tissue but the triceps muscle, and our model may be a simplification of the distracting forces in olecranon fractures. Second, we did not standardize tensioning of the metal knots in the TBW fixation. Sufficient tensioning of the metal knots in TBW can be challenging, as under-tensioning may reduce the capability of maintaining fracture reduction whereas over-tensioning may increase the risk of sudden hardware failure. However, all procedures in this study were performed by board-certified orthopedic surgeons and reflect the challenge of adequate wire tensioning. Third, maximum force in the cyclic test was 300 N rather than 500 N, which has previously been used to simulate the chair push-off test. However, we believe our choice was justified based on the normative isometric values.[15] Last, a larger study sample would increase the power of our findings and reduce the risk of a type II error.

Conclusion

Despite somewhat increased fracture displacement in the TBW group at the start and end of the cyclic test, no statistically significant difference in fracture displacement or ultimate load to failure was revealed comparing TBW and PF with locking screws in fixation of transverse olecranon fractures. These observations indicate residual slack in the TBW construct and later construct fatigue. The metal wire directly under the twist was identified as the weakest link in the TBW construct. Though no difference in displacement or load to failure was shown, PF with locking screws may represent a more reliable fixation alternative for transverse olecranon fractures as the TBW fixation method is associated with numerous pitfalls.

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