USE OF TENSION BAND WIRING TECHNIQUE IN PROXIMAL ULNAR FRACTURES: A FINITE ELEMENT BIOMECHANICAL ANALYSIS

Woraphon Jaroenporn, Vajarin Phiphobmongkol, Jaruwat Vechasilp, Thanupat Kulsinsap*

Department of Orthopaedics, Police General Hospital, Pathumwan, Bangkok 10330, Thailand

Abstract

Background: Tension band wiring is considered the standard treatment for olecranon fracture. A recent study proved that it can be used for the fracture as distal to the coronoid process.

Objective: The study aimed to investigate whether tension band wiring can be used in proximal ulnar fracture fixation up to and distal to the coronoid process.

Methods: Models of simple proximal ulnar fracture including 4 intraarticular and 2 extraarticular fractures were created. Fixation was completed using tension band wiring technique, and biomechanical responses were evaluated using finite element analysis. After a physiologic load was applied, the fracture displacement, von Mises stress, and stiffness were recorded.

Results: All fracture models were able to withstand the load of daily activities with a maximum displacement of 50% of the articular surface. In addition, the von Mises stress was the highest in the middle articular fracture. The mean transcortical K-wire tension band wiring stiffness of the intra-articular and extra-articular fractures was 1144.89 N/mm and 1231.45 N/mm, respectively.

Conclusion: Tension band wiring is another option to treat proximal ulnar fractures with the ability to withstand immediate postoperative load.

Keywords: Tension band wiring, Olecranon fracture, Proximal ulnar fracture, Biomechanical study, Finite element analysis

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Correspondence to:
*Jaroenporn W, Department of Orthopaedics, Police General Hospital, Pathumwan, Bangkok 10330, Thailand
E-mail: dr.woraphon@yahoo.com

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Introduction

Proximal ulnar fracture is one of the most common upper extremity fractures, for which many surgical options have been proposed. To date, even though many studies have concluded no evidence of any perfect surgical treatment option exists for this fracture. [1-3]

A simple displaced olecranon fracture, Mayo classification type IIa (AO/OTA 2U1B1), is the most common fracture reported among olecranon fractures. (4-8) Plate fixation is increasingly used for olecranon and proximal ulnar fracture fixation. It provides greater compressive force across the fracture site, more stable fixation, lower second operation rate compared with tension band wiring (TBW), and good clinical outcomes. Nevertheless, several drawbacks exist, namely, a higher rate of infection than in TBW, and a cost as high as twice that of TBW.[7, 9-12]

Currently, TBW is still considered the surgical technique of choice for simple olecranon fractures. It possesses the benefits of being reproducible, less invasive and yields good clinical results. The most important problem is implant migration and loosening, leading to a second operation.[4, 13-15] TBW was once believed to create dynamic compression across the fracture site from the distraction force of the triceps muscle. Hence, TBW has been suggested to be used in cases with no more than 50% of articular involvement. Recently, many biomechanical studies have shown results against this principle, and authors have concluded that with the static component of the stabilization, TBW can be used for the fixation of simple olecranon fractures regardless of articular involvement.[1, 4, 16]

Although TBW has been shown to have many advantages, to our knowledge, no study has been conducted to determine the biomechanical response distal to the coronoid processes TBW can be used. Thus, this study was designed to investigate the biomechanical response of TBW using finite element analysis under physiological conditions in fractures up to and distal to the coronoid process. We hypothesized that TBW could be an effective technique for the treatment of such fractures.

Methods

This study was conducted under the Police General Hospital Ethics Committee (No. 15/2563). Informed consent was obtained from the subjects involved in the study.

Finite element modeling

The ulnar bone model was created using computed tomography (CT) of the right forearm of a healthy 40-year-old man after obtaining informed consent. The CT images from Digital Imaging and Communications in Medicine (DICOM) were imported into Mimics 10.01 (Materialize, Leuven, Belgium) to create a 3D ulnar bone geometry. The file was then transferred to PowerSHAPE 2016 (Delcam Plc, Birmingham, UK) to create a computer-aided design (CAD) model suitable for meshing. After creating the complete ulnar model, the fractures were reproduced in six models designed by dividing the olecranon in four parts with equal ranges (from the coronoid tip to the tip of the olecranon). The other two were made once and twice of the same range distal to the tip of the olecranon. All fractures were reproduced in the true axial plane **(Figure 1).**

The TBW was created using two 1.6 mm K-wires and 1 mm cerclage wire (18-gauge) as models, reflecting the surgical recommendations of the AO Foundation **(Figure 2)**.[17] As for the interaction of the K-wire system, the frictional values between the K-wire and cortical bone, cortical bone and cancellous bone were 0.5 and 0.3, respectively.[18, 19]

Convergence test and model validation

The Ulnar finite element models were meshed with 1, 2, and 3 mm element sizes using quadratic tetrahedral elements (Solid 92) in ANSYS 15.0 (Ansys Inc., Canonsburg, PN, USA). The cancellous and cortical bones were considered isotropic, linear and elastic, with elastic moduli of 1.3 GPa and 17 GPa, respectively.The Poisson's ratio was set to 0.3. [20, 21] A surface-to-surface gluing contact parameter was inserted at the interface of the cortical and cancellous bones, to prevent movement between the meshes of these regions at the interface. The elastic

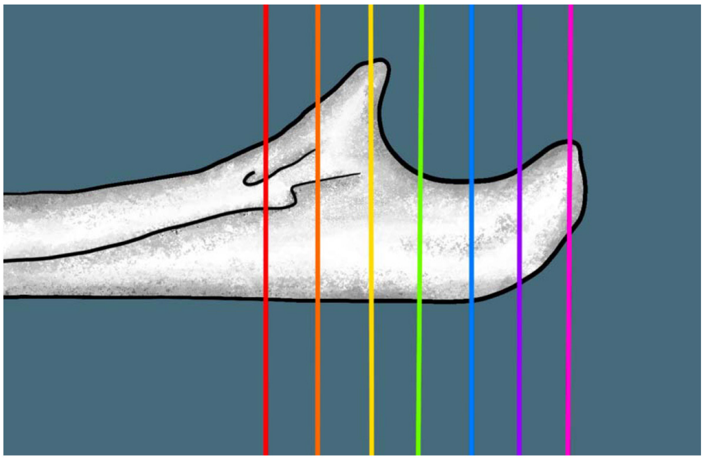


Figure 1. Fracture locations: purple, blue, green and yellow lines were simulated as intra-articular fractures, and orange and red lines were simulated as extra-articular fractures. The olecranon process to the coronoid process represents 100% articular surface. Intra-articular fracture patterns were divided in four parts [25% (purple), 50% (blue), 75% (green) and 100% (yellow) articular surfaces]. For extra-articular fracture, we measured the 25% articular surface (orange) and 50% of articular surfaces (red) distal to the coronoid process.

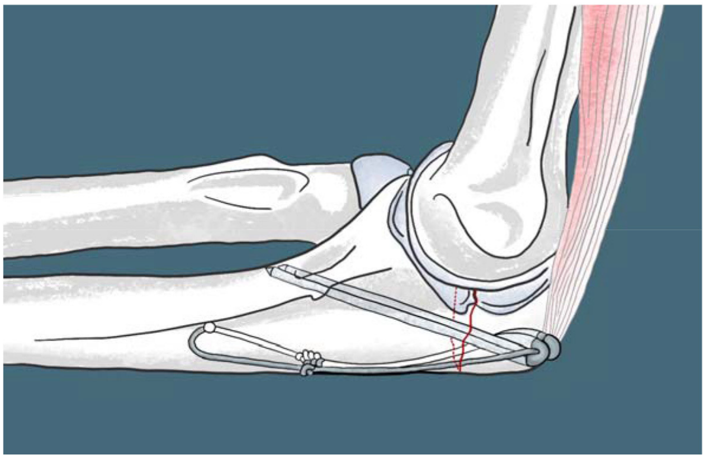


Figure 2. The tension band wiring was created using two 1.6 mm K-wires and an 18-gauge cerclage wire as recommended by AO Foundation's surgical guidelines.[17]

modulus and Poisson's ratio of stainless steel were 210 GPa and 0.3, respectively. [20, 22, 23] The figure-of-eight loop was placed close to the bone, as the TBW became more stable while turning over the adjacent bone surface.[24] For extra-articular fracture, the entry and the exit points of the K-wire were located at the tip of the olecranon and 2.7 cm distal to the fracture site, respectively.

The distal end of the ulnar model was fixed, and the traction force of 150 N was applied at the tip of the olecranon in all fracture patterns. The maximum displacement, maximum strain and maximum von Mises stress value at the fracture gap were evaluated for convergence in all models. The tolerance level was set within 5%.

The model was validated by comparison with the results from a cadaveric study. The authors found that a mean force of 490 N created a displacement of 2 mm.[13] To simulate the setting, the model of the olecranon fracture with 50% articular involvement was fixed with TBW under the boundary condition and the material properties used in the convergence test. These studies applied the force of 484 N to create a displacement of 2 mm indicating that the ulnar model had a response similar to that of the human ulnar bone under the same conditions.

Finite element analysis

To investigate the biomechanical responses from the TBW in simple olecranon fractures under the simulation of the magnitudes and directions of physiologic loads during active elbow joint movement of daily activities, six finite element models with different fracture locations (four intra-articular and two extra-articular) were fixed with TBW. An axial force of 150 N to imitate the triceps tendon was applied at the tip of the olecranon at one movement cycle.(13) The biomechanical properties of the implants, the von Mises stress value and displacement of the fracture gap were recorded.

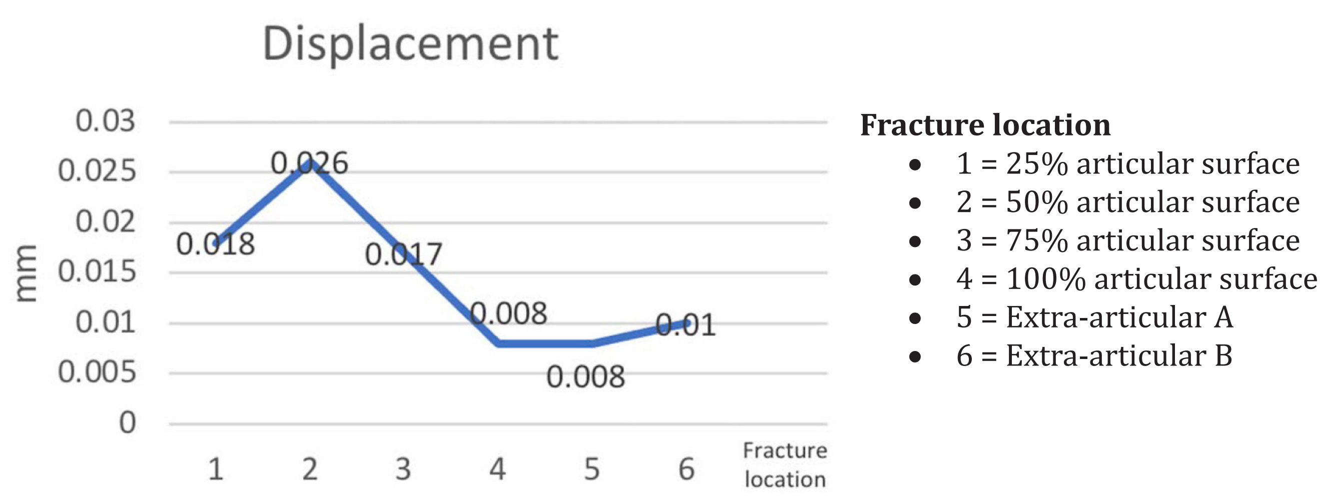


Figure 3. The displacement of the fracture gap after physiologic loading

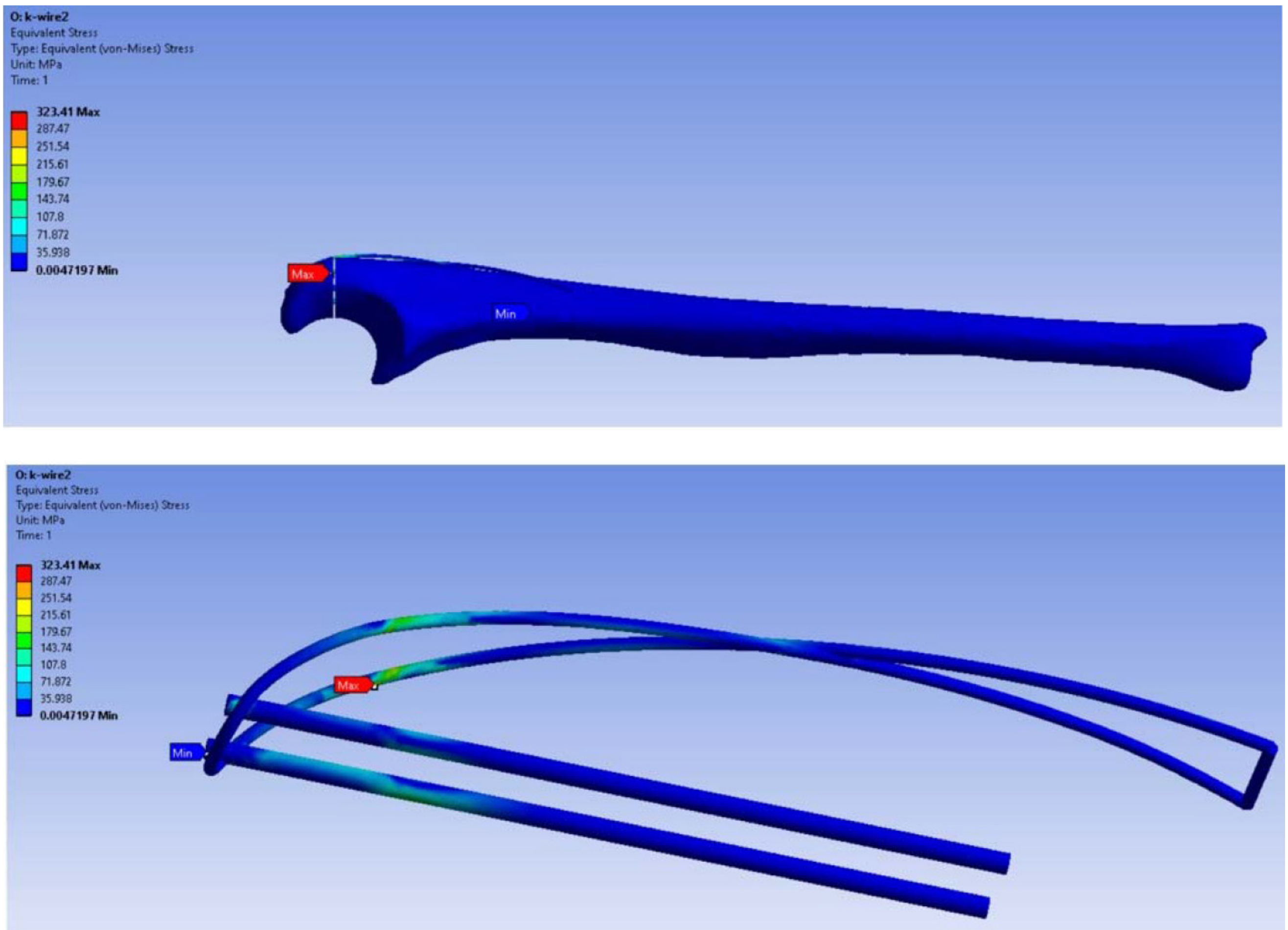
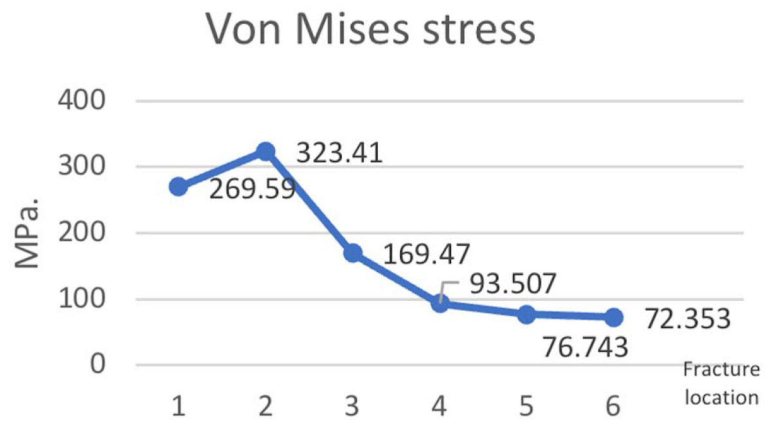


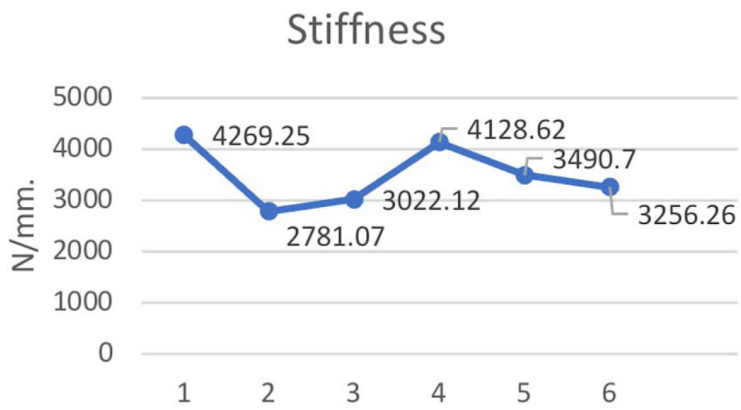
Figure 4. The distribution of the von Mises stress of 50% articular surface fracture pattern



Fracture location

- 1 = 25% articular surface
- 2 = 50% articular surface
- 3 = 75% articular surface
- 4 = 100% articular surface
- 5 = Extra-articular A
- 6 = Extra-articular B

Figure 5. The von Mises stress of each model after physiologic loading



Fracture location

- 1 = 25% articular surface
- 2 = 50% articular surface
- 3 = 75% articular surface
- 4 = 100% articular surface
- 5 = Extra-articular A
- 6 = Extra-articular B

Figure 6. Stiffness of each model after physiologic loading

Results

Displacement

All fracture models, either intra- or extra-articular locations, were able to tolerate the load with insignificant displacement **(Figure 3).**

Von-Mises stress

The maximum stress was found in the model with a fracture located in the middle of the olecranon **(Figures 4 and 5).** The mean von Mises stress of intra-articular fracture fixation was 213.99 MPa, while that of extra-articular fixation was 74.55 MPa **(Figure 5).**

Stiffness

The mean stiffness of the intra-articular and extra-articular fracture fixation was 1144.89 N/mm and 1231.45 N/mm, respectively **(Figure 6).**

Discussion

In proximal (extra-articular) ulnar fractures, plate and screw fixation is the mainstay for operative treatment.[25] It provides stability that can withstand the force of daily life activities and allows early motion. However, some drawbacks result, including high implant costs and implant prominence. TBW is the most commonly performed procedure for simple olecranon fracture fixation, being reproducible, cost-effective, exhibiting a low implant prominence, and good clinical outcomes. Currently, the only known drawback is that a second operation is frequently required.[10-12] However, this statement might be questionable because a multicenter study indicated that the implant removal rate in proximal ulnar fractures did not differ between plate fixation and TBW (64.5% vs. 63.6%).[26] TBW was originally thought to rely on dynamic compression from active movement of the elbow, but a biomechanical study proved that TBW only possesses static properties and can be used for simple olecranon fractures as distal as the coronoid tip with the same stability. (13) To our knowledge, no related study has evaluated the use of TBW in simple proximal ulnar fractures distal from the tip of the coronoid.

This study was designed using finite element analysis to evaluate the biomechanical responses of TBW fixation of intra-articular to extra-articular proximal ulnar fractures from the force of daily activities; finite element analysis is commonly used as an analytic tool to study biomechanical responses. Its cost effective and variable parameters can be adjusted in a more controllable manner. [27, 28]

Our results showed that the fracture displacement and von Mises stress had the maximum value in the 50% articular model. This result was similar to that of the study by Hammond et al.13) This could be explained by the position of the fracture that was directly aligned under the humerus, which acted as a wedge when the force from the triceps was applied. Nevertheless, the maximum displacement was 0.026 mm indicated that the TBW system was able to withstand the load of daily life activities immediately after the surgery. Thus, encouraging patients to start early range of motion to prevent stiffness is reasonable, especially in extra-articular fractures where the acceptable alignment is much greater than in intra-articular fractures. [29] The current results showed that the more distal the location of the fracture, created less stress of the implant. This could be explained by the increase in the working distance between the fixation point and the fracture site, decreasing construct stiffness and stress and allowing more motion at the fracture gap.[30-33]

The results of this study suggest that TBW is not only useful in treating simple olecranon fractures regardless of location, but also feasible in treating simple isolated extra-articular proximal ulnar fractures without any associated injuries such as radial head or ligamentous injuries. Results also suggest that patients with fractures managed by TBW should be encouraged to perform early motion because TBW has sufficient strength to withstand the immediate load of daily motion.

This study encountered several limitations. Although finite element analysis is considered one of the most widely used methods in biomechanical studies, it still lacks a physiological environment and body reaction. We did not perform endurance tests, which may cause problems such as pin loosening during clinical use. Further studies are needed to validate and extend our results for practical and clinical use.

Conclusion

TBW is a reproducible procedure. This agrees with the use of TBW for simple olecranon fractures at any fracture location. Our finite element study's results suggest that TBW is able to withstand the immediate force required for daily life activities, even distal to the coronoid level. In addition, results suggest that caution must be taken when the fracture is located in the middle of the olecranon. Further studies are needed to evaluate the clinical use of TBW.

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Data Availability Statement: No new data were created or analyzed in this study. Data sharing is not applicable to this article.

Conflicts of interest: The authors declare they have no conflict of interest.

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