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ORIGINAL ARTICLE

Suture anchor fixation may be an alternative to tension band wiring in olecranon fractures: Finite element analysis

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ABSTRACT

Objectives: This study aims to analyze and compare total deformations with tension band wiring (TBW), intramedullary screw (IS) and novel suture anchor (SA) fixation methods, and to investigate practicality of SA fixation in olecranon fractures using finite element analysis (FEA).

Materials and methods: This finite element analysis study was conducted between May 2019 and October 2019. TBW, IS and SA fixation methods were compared in order to analyze fracture behavior in the ulna and humerus using FEA, which is among the mathematical methods of stress analysis. Boundary conditions were applied to the created model and total deformation amounts were compared among the methods in terms of displacement.

Results: The lowest amount of displacement was obtained with TBW method (1.2095 mm), while IS method (2.7703 mm) showed the highest amount of total displacement. Total displacement was lower with SA system (2.0397 mm) compared to IS fixation. In addition, no problem was observed with SA system in terms of failure occurrence.

Conclusion: According to the results of FEA, although the lowest amount of displacement was obtained with TBW, it is concluded that anchor fixation method may be an alternative with practicality and mechanical properties. However, further studies are needed to obtain more precise data.

Keywords: Cancellous screws, finite element analysis, olecranon fractures, suture anchor, tension band wiring.

The fixation methods commonly used in the treatment of olecranon fractures include tension band wiring (TBW), plate fixation, intramedullary screw (IS) fixation and more recently anchor fixation. Usually, the results of these procedures have been good with the restoration of movement and healing of the fracture. Nevertheless, several problems may occur such as loss of fixation, nonunion and the need for revision surgery.

Today, TBW is the gold standard in fixation of these fractures.[1] However, several complications are encountered with this method including prominence metal work leading to discomfort, wound breakdown, loss of motion and the need for revision surgery for removing the hardware. These complications have been reported as high as 75% with TBW method.[2,3] In IS method, a considerable number of patients undergo reoperation for removal of the implant due to the soft tissue irritation. Therefore, research for alternative methods is continuously conducted to overcome these complications. Numerous devices and implants in the market suggest that currently there is no ideal solution for the treatment of these common fractures.

With the advancements in nonabsorbable suture materials, a novel treatment method, suture anchor (SA) fixation, has been introduced in the treatment of olecranon fractures. This new method is expected to avoid problems of irritation or migration due to metal work and risk of damaging anterior structures.[4] In a study by Bateman et al.,[5] no intraoperative complications were observed in eight patients who underwent anchor fixation due to olecranon fractures and none of the patients had loss of reduction. In addition, none of the patients had removal of hardware and complaints of prominent hardware. These mentioned properties can be clinically considered as advantages of this

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technique, while it has the disadvantages of increased surgical costs due to the increased use of SAs. Studies investigating this novel method in the literature are limited and mostly include case reports or case series. To our knowledge, there is still no finite element study conducted on this method.

Finite element analysis (FEA) is used for quantification and simulation of structures and systems as a numerical tool, providing accurate prediction of a component response to different types of loading. This model is structured based on computed tomography (CT) and other images.[6] Basic features of FEA in orthopedics and traumatology practice include validation of material models chosen for bone and implant with boundary and loading conditions. FEA does not only evaluate pre-, intra-, and postoperative features of materials, but it also reduces operation time, blood loss, penetration rate of the screw, and fracture healing time, and helps in successful fixation and anatomic restoration of fractures.[7] In this study, we aimed to analyze and compare total deformations with TBW, IS and SA fixation methods, and to investigate practicality of SA fixation in olecranon fractures using FEA.

MATERIALS AND METHODS

This finite element analysis study was conducted at Kocaeli University Biomedical Enginering Faculty between May 2019 and October 2019. In this study, different types of fixation performed to heal olecranon fracture were analyzed in terms of fracture behavior at the bony portion of elbow. For this purpose, a three-dimensional (3D) finite element bone model was generated. The nonunion and loss of fixation on the olecranon fractures pose a challenging problem for some fixation appliance.[8,9] Therefore, the humerus and ulna of elbow at left side of body were utilized for this research. The type of the constructs for the fixation was referenced from clinical applications.

For 3D olecranon fracture model creation, CT images for a right elbow at 105° flexion positions were digitized for solid bone models. These models were segmented as cortical and cancellous bone in humerus and ulna bone models. In order to analyze the condition of the olecranon fracture, a 1.5 mm thick fracture (gap size) (fracture type 21-B1 of Arbeitsgemeinschaft für Osteosynthesefragen [AO] classification) was created in the thinnest part of the cross-section of the olecranon bulge of the ulna bone. The fracture line had a 9° inclination angle with respect to the transverse plane and its direction was parallel to the X axis of the global coordinates. The models were assembled with implants' solid part in the SolidWorks software (Concord, MA, USA) according to the surgical procedure. Three surgical methods called TBW, IS and SA fixation methods were used in the models. TBW and IS techniques were operated according to AO standards.

The TBW model recognized by the figure-of-eight tension-band wire loop contained cerclage (ø 2 mm) and Kirschner wire (K-wire) (ø 1.6 mm) as seen in Figure 1. Two K-wires were placed in intramedullary and transcortical configuration in a parallel position with 5 mm distance. TBW hole was located at 40 mm and 5 mm distance to fracture line and posterior cortex, respectively. Tension band wiring hole was located at four times of the radius of trochlea anterior to the posterior edge of ulna. After the figure-of-eight position, twisting two separate wires as in reality was not processed in digital models. The wire ends were positioned opposite to each other.

In the IS fixation method, a 4.5 mm diameter and 45 mm length cancellous screw was placed from the tip of the olecranon across the fracture site to the distal fragment in the fracture line for repair of olecranon fracture as seen in Figure 2. The geometrical parameters of the bone screw thread were drawn according to the ASTM F-543-02 standards. The screw crossed the fracture site approximately 35 mm.

In the third method, a newer method called SA fixation was used in digital models as described by Bateman et al.[5] According to this surgical procedure,[5] a longitudinal, posterior incision was performed just radial to the tip of the olecranon and advanced down to the level of the fascia with the patient in lateral decubitus position. Medial and lateral flaps were then elevated. Fracture hematoma was evacuated and the bone bed was irrigated. After the fracture line was reduced, two 5.5 mm biocomposite fully threaded SAs were placed in the cancellous healthy bone bed of the ulna. Anchor threads were passed through the olecranon fracture lines and fracture reduction was provided. The finite element model we prepared contained two nonmetallic SAs interconnected with suture strands (ø 0.6 mm). These two ø 5.5 mm biocomposite fully threaded SAs were inserted distally in the cancellous bone bed of the ulna as shown in Figure 3. Two distal ø 3.0 mm PushLock anchors (Parcus Medical, Sarasota, FL, USA) were placed transversely and reciprocal in the medulla canal so as not to exceed 30 mm from the fracture line. Each of the two pairs of suture strands was extended to the screws in the fracture line that were not in its symmetry with respect to the long axis of the bone. In this method, as in the TBW fixation, separate digital solid models were not sewn or combined.

FIGURE 1. Tension band wiring fixation model.

FIGURE 2. Intramedullary screw fixation method.

The materials used in anchor fixation method were ultra-high-molecular-weight polyethylene and polyetheretherketone for suture and anchor screw, respectively.[10-12] SOLID187 tetrahedron element was used for the finite element models. The contact types between each bone and its inner bone, contacting models and separate models were defined as bonded, debonded (frictionless) and non-bonding (no separation) types, respectively. A tensile force of 10 N was applied to the wires in the TBW fixation method as specified by Greenfield et al.[13] Same tensile force was applied to the sutures in the SA fixation. Wire ends were not joined for TBW and SA fixation analysis. The models were applied to static load obtained from the literature for a 500 N.[14] Maximum total force resulting from triceps tendon was applied to the ulna along the anatomical axis of the humerus as seen in Figure 4.[14] The proximal humerus and distal ulna were fixed in three directions.

Two criteria were selected to determine the FEA results. One of them was the von Mises stress on the metal component of fixation methods. The von Mises stress criteria determine if a given material will yield or fracture. The other criterion was the displacement and rotation of fracture gap in order to compare with the literature. The displacement and rotation in the fracture area measured after putting the effect of the physical load are defined as the interfragmentary

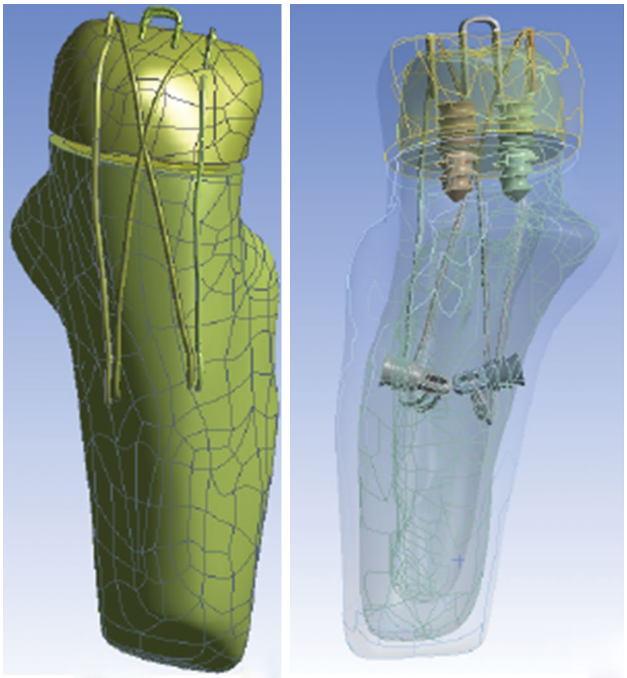


FIGURE 3. Suture anchor fixation method.

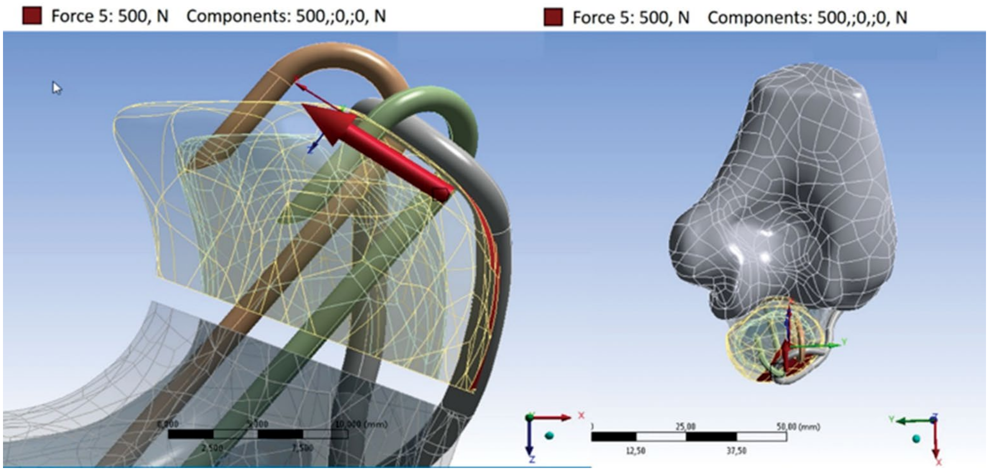


FIGURE 4. Direction of force attached to ulna bone.

movement. The interfragmentary movement particularly in axial direction plays an important role and this movement is widely accepted to stimulate bone healing.[15] Since the displacement and rotation are generally measured in the experiments, these physical parameters were given as a result.

When a fracture surface was examined, as seen in Figure 5, points A and B were placed respectively at the maximum and minimum acting points. Relative distance measurements of these points were calculated across three axes (X-mediolateral direction, Y-anteroposterior, Z-superoinferior). After the loading, the relative displacements of fracture points were determined for the evaluation of the interfragmentary movement as seen in Figure 6. This criterion was used to evaluate the stability between fracture fragments with different fixation designs, which evidence the practicality and powerfulness of the suggested method.

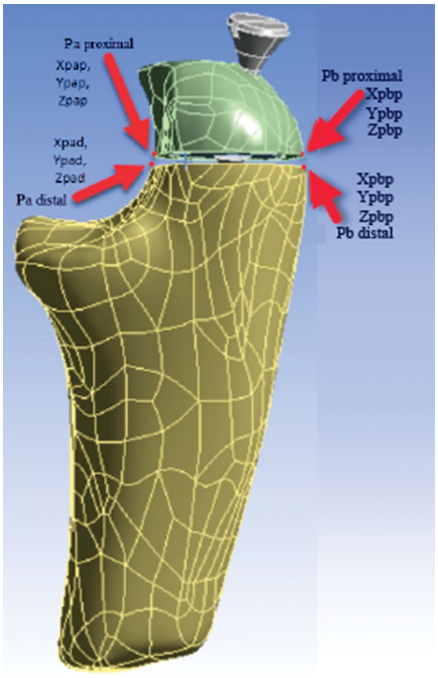
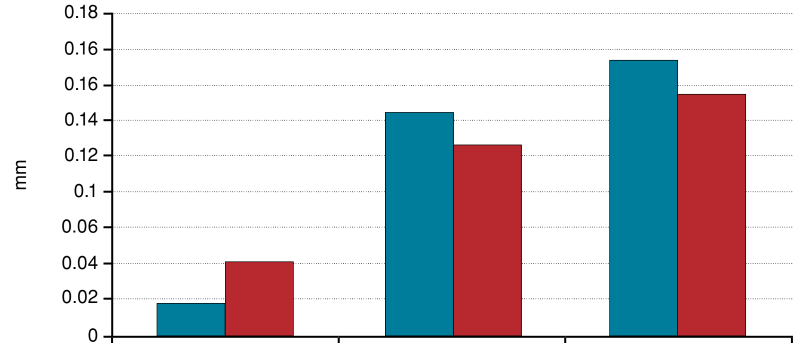


FIGURE 5. Determination of interfragmentary movement using relative displacement of two points (A and B points).

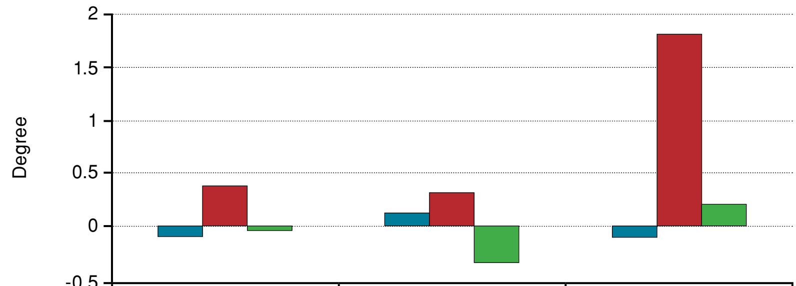
RESULTS

Figure 6 show that the interfregmentary displacement amounts calculated for points A and B were nearly equal. Accordingly, it was determined that the minimum amount of displacement was in TBW fixation method and the highest amount of displacement was in SA fixation method. By comparing IS fixation and TBW fixation, TBW fixation method produced better stability than IS fixation. This means that TBW fixation gave satisfactory results.

For three different systems, the stress assessment can be performed in terms of yield strength of the materials. The residual stresses were calculated, but the stress distribution was found to be around 750 MPa. Considering that the yield strength of the titanium alloy is about 900 MPa,[16] it is understood that there will be no problem for the system. Similarly, in the TBW fixation method, considering that the yield strength of the steel material is about 200 MPa,[17] it is likewise not to be a problem for the system. When the stress distributions on suture and screw were examined in SA fixation, less von Mises stress was obtained compared to the other two



	TBW fixation	IS fixation	SA fixation
Interfragmentary movement (displacement distance-mm) A	0.017	0.124	0.153
Interfragmentary movement (displacement distance-mm) B	0.041	0.107	0.134



	TBW fixation	IS fixation	SA fixation
Interfragmentary movement (displacement rotation-°) x	-0.1	0.15	-0.09
Interfragmentary movement (displacement rotation-°) y	0.38	0.33	1.82
Interfragmentary movement (displacement rotation-°) z	-0.05	-0.36	0.23

FIGURE 6. Maximum and minimum displacements of fracture line and osteotomy gaps.
TBW: Tension band wiring; IS: Intramedullary screw; SA: Suture anchor.

methods. Considering that the yield strength of the material is 550 MPa,[18] it is understood that there is no problem in the SA fixation method in terms of failure occurrence.

Minimum-maximum points, deformation on the healthy and fracture side surfaces and total deformation for anchor fixation method are given in Figure 7. Comparison of the results with the three methods is given in Table I.

DISCUSSION

In our study, we simulated TBW, IS and SA fixation models that are used in the treatment of olecranon fractures on computer using FEA technique, and performed loading to compare total deformations among these methods. To our knowledge, this study is the first to compare treatment methods used in olecranon fractures with 3D FEA.[19] According to our results, TBW technique yielded the lowest amount of total displacement, although total displacement was also lower with novel SA method compared to cancellous screw method.

In our study, displacement and rotation range predicted by FEA was similar with that was reported in a study by Hammond et al.[20] In the biomechanical analysis by Hammond et al.[20] on fresh frozen upper extremities with induced transverse olecranon fractures, a displacement range of 0-2 mm was used. In that study, the mean force applied to reach a displacement of 2 mm was 490 N. In our study, a force of 500 N was applied from the triceps tendon to the ulna along the anatomic axis of the humerus. In a FEA study by Goel et al.,[21] the force applied on the ulna was reported as 500 N. Similarly, in another

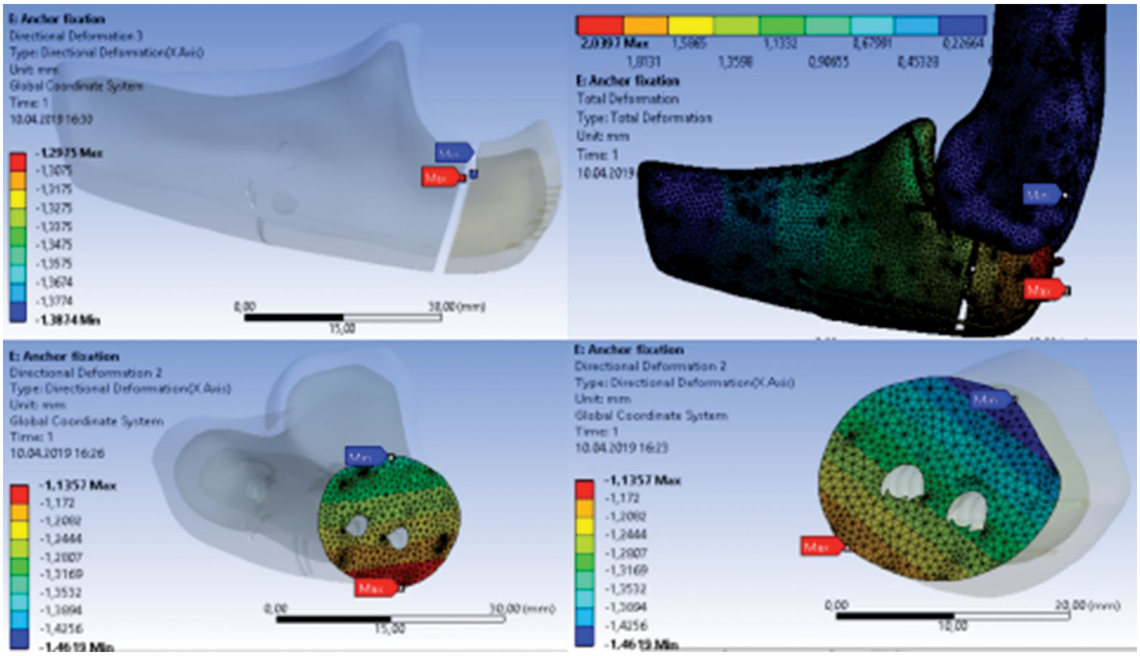


FIGURE 7. Maximum and minimum points (left upper), total deformation (right upper), deformation on healthy surface (left lower), and deformation of fracture side surface (right lower) with anchor fixation method.

FEA study by Lysen et al.,[22] a force of 520 N was applied on the ulna. This result indicated that the von Mises stress of FEA ulna model was similar with the natural ulna under the same force in human body. In a biomechanical cadaveric study on forearm specimen, Tan et al.[23] applied a force of 100 N to the tip of the olecranon along the Y axis. This study focused on the displacement of the ligament. The force applied on ulna varies between studies according to several factors including intended displacement speed of the bone, the axis on which the force is applied and measurement parameters. In order to simulate human body, other factors such as varying porosity in some part of the bone should be considered.

Interfragmentary movement is always complex and combined, which also depends on the anatomical location of the fixation device.[24] Interfragmentary movement is measured as the relative displacement of minimum and maximum points. In our study, the lowest interfragmentary movement was obtained with TBW method. In addition, interfragmentary movement was also lower in SA fixation method compared to IS method. In this study, after loading, the amount of total deformation was found as 1.21 mm with TBW, 2.04 mm with SA fixation and 2.77 mm with IS method.

It is important to conduct studies on the materials used in TBW to develop new methods and to compare outcomes of different treatment techniques. In in vivo studies, complications developing in olecranon fractures in short-, middle- and long-term can be evaluated. On the other hand, *in vitro* studies can test

TABLE I
Comparison of deformations with the three methods

	Osteotomy gap Total deformation	Total Deformation	Osteotomy gap Directional deformation	Healthy surface Directional deformation
Method	Min-Max	Min-Max	Min-Max	Min-Max
Tension band wiring	1.1922-0.84378	1.2095-0	1.13 - -0.20	-0.35066 - -0.80555
Cortical screw	2.2499-0.57832	2.7703-0	2.4315-0	2.4315-0.1296
Anchor fixation	-1.2975 - -1.3874	2.0397-0.22664	-1.1357 - -1.4619	-1.1357 - -1.4619

Min: Minimum; Max: Maximum.

the strength of methods under boundary conditions. Cadaver and animal model studies for this purpose have been followed by computed simulation methods with advancements in computer technologies.

In 2014, Lysen et al.[22] analyzed the effects of different materials on the strength of tension band with FEA using various materials. The result of this study revealed that the currently used materials in TBW should be modified. Lee et al.[25] evaluated TBW technique from another angle using FEA. This study evaluated the effects of varying positions in which K-wires can exit the ulna. On the other hand, intermedullary screw method also has some disadvantages. The screw used must be strong and flexible while not exceeding the strength of the bone itself for a good outcome. In addition, screw diameter also affects the amount of deformity.[26]

Our study focused on the comparison of three different methods used in the treatment of olecranon fractures with 3D FEA for the first time in the literature. Among these methods, SA fixation is a novel method compared to other methods. Although good outcomes have been achieved with the use of SAs, studies on this technique are limited.[27] In a case series by Bateman et al.,[5] SA fixation method was used to treat displaced olecranon fractures. In this study, reduction and fixation were safely and efficiently obtained, and patients had excellent long-term functional outcomes that were measured with clinical evaluation. Again, in a study by Bava et al.,[27] SA fixation method provided excellent elbow function in five patients based on validated clinical outcome measures. In a case series by Ravenscroft et al.,[4] SA fixation method was reported to be a safe and easy technique that prevents the risks associated with other fixation methods.

As a limitation, in our model, we assumed that the bone was homogenous. Therefore, we did not include different properties because of porosity in some parts of the bone. Another limitation is that we could not find any study in the literature comparing these techniques in the treatment of olecranon fractures; therefore, we could not compare our results exactly.

In conclusion, the lowest amount of displacement was obtained with TBW method, while IS method showed the highest amount of total displacement in our study. On the other hand, total displacement was lower with SA system compared to IS fixation. Due to the high rate of complications with other techniques, we may conclude that the anchor fixation method may be a safe and efficient alternative with practicality and mechanical properties in olecranon fractures. Further comprehensive studies simulating human body are needed to evaluate the practicality of novel SA fixation.

Declaration of conflicting interests

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