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ORIGINAL ARTICLE

Computational mechanical analysis of AO 44 A1, B1 and C1 fracture with Finite Element:

Evaluation of screw, plate and k-wire fixation

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Background: The aim of this study was to create AO 44 A1, B1 and C1 fractures using finite element analysis (FEA), to determine the stability of k-wire, intramedullary screw (IS) and plate-screw (PS) fixation methods in fracture

Methods: Using FEA the post-reduction behaviour of AO 44 A1, B1 and C1 fractures with k-wire, IS and PS fixation methods was analysed and compared in terms of displacement and stress.

Results: The lowest amount of displacement was provided with the IS method in AO 44 A1 and B1. It was observed in the detection of 4 mm k-wire in AO 44 C1. The total displacement of the IS system used for fixation in AO 44 A1, B1 and C1 fractures was lower

Conclusions: According to FEA results, the lowest amount of displacement was obtained with IS in AO 44 A1 and B1, while 4 mm K-wire fixation was achieved in AO 44 C1 fractures.

[6] With k-wire [7]? If we are going to use K-wire, what thickness should we use? There does
not appear to be a complete consensus. In our study, we tried to present the subject with a
different perspective with finite element analysis in order to clarify this issue.

Commonly used fixation methods in the procedure of distal fibula fractures contain k-
wire, intramedullary screw (IS), and plate-screw (PS) fixation methods [4], [7]–[10]. Generally,
the results of these procedures conclude in restoration of motion and healing of the fracture.
However, various problems like non-union, losing of fixation, and the need for revision surgery
may occur [3], [11].

K-wire fixation, which is an old treatment method in the procedure of distal fibula
fractures, using as a traditional method in our clinic. Studies examining this old method in the
literature are few in number and which is usually seen in the form of case series or case reports.
As far as we know, there is not yet a finite element study using this traditional method.
Finite element analysis (FEA) is utilized for the quantification, simulation of structures and
systems as a numerical facility; it ensures an accurate estimate of a component response to
different loading types. Computed tomography (CT) and other images are configured to support
FEA [12]. The main features of FEA in the practice of orthopaedics and traumatology contain
the examination of selected material models for bone and implant with limit and loading
conditions [13].
The purpose of our study, to analyse and compare k-wire, intramedullary screw (IS) and plate-screw (PS) fixation methods among the commonly used fixation methods in the treatment of isolated distal fibula fractures, by using FEA. In addition, we aimed to compare k-wire, which is a cheap, practical and traditional method, compared with other methods.

Materials and Methods

In this study, a 3-dimensional (3D) model consisting of fibula, tibia and foot was applied to investigate the advantages and disadvantages of fixations used in distal fibula AO 44 A1, B1 and C1 fractures. On this model, using Space claim software and The Finite Element Method, which can simulate real fractures on the distal fibula (fracture types 44-A1, 44-B1, and 44-C1 according to Arbeitsgemeinschaft für Osteosynthesefragen [AO] classification) were created. Later, these fractures were fixed with 2mm, 4 mm k-wire, 4.2 mm intramedullary IS and PS methods in the same program.

Solid models created using Ansys Workbench software were converted to Finite Element Models. The fasteners used to join the fractures are stainless steel and titanium, in addition linear elastic isotropic material models have been applied for these materials and to the bone. The properties for the materials are: Modulus of Elasticity for bone E= 16.8 GPa, Poisson's Ratio ν=0.3; E=200 GPa, ν=0.3 for stainless steel and E=110 GPa, ν=0.33 for Titanium alloy [14].
In order to get the best result in Finite Element analysis, mesh optimization was performed and the best mesh density was determined. With the best mesh density, the Finite Element models of the 3D models were also analysed using the Ansys Workbench 2020R2 Finite Element software under the given loading.

This finite element analysis study was carried out at Yozgat Bozok University, Department of Mechanical Engineering, between the mounts January 2022 and April 2022. In this study, different fixation types to heal distal fibula fracture were analysed in terms of fracture movement in the ankle bone. To this end, a three-dimensional (3D) finite element bone model was used.

Kirschner wire (k-wire) (Fig. 1,2), one 2 mm, one 4 mm, two 2 mm, 4.2 mm intramedullary screws and plate-3.5 mm screw fixation modelling were used for observing distal fibula AO 44 A1, B1 and C1 fractures.

4.2 mm diameter screw was inserted intramedullary (Fig. 3,4), passing the fracture line from the distal fibula tip to the proximal fibula along the fracture line for the fixation of isolated distal fibula AO 44 A1, B1 and C1 fractures [15].

According to the PS fixation procedure on the patient, the incision is made just distal to the tip of the distal fibula and advanced to the level of the fascia. The medial and lateral flaps are then elevated. The fracture hematoma is drained and the bone bed irrigated [16]. After the fracture line is seen, fracture reduction will be achieved. In the finite element model we

prepared, the plate was placed on the reduced bone bed of the fibula as shown in Figure 3.

Fracture fixation was achieved by placing at least 2 3.5 mm titanium screws from the distal and proximal of the plate fracture line, according to the bone stock (Fig. 5, 6).

Finite element models are fixed in such a way that they cannot make any translations or rotations from the lower boundary of the model. Loads were applied to the upper border of the model, on the tibia, in the form of a downward force of 600 N in the vertical direction [17]. In order to simulate the real state of the fibula and tibia in the tissue, movement in certain directions from the top of the model must be prevented. The elements used for the connection are fixed on the fibula in a similar way to real conditions. The fractured interface is considered as a frictional contact and the friction coefficient is taken as 0.2. The maximum total force originating from the upper extremity was enforced to the fibula along the tibia and fibula anatomical axis. The tibia was fixed in three proximal and distal directions.

Two indication were chosen to yield the FEA results. One of them is the maximum equivalent strain on the metal component of the fixing methods. The maximum equivalent strain specifies which part of the component is most stressed under load and where it will be damaged if damage occurs. The measurement is the displacement and rotation of the fracture gap for comparison with the literature. The displacement and rotation in the fracture area, measured after adding the impact of the physical load, which is described as the movement between the parts. Interfragmentary movement, especially in the axial direction, plays a
significant role and it is widely admitted that this movement stimulates bone healing [18]. Since displacement and rotation are usually evaluated in experiments, these physical parameters are given as an outcome.

When a fracture surface is investigated, marks A and B are located at the minimum and maximum effective marks, respectively. The relative distance measurements of these marks were considered in three axes (X-mediolateral direction, Y-anteroposterior, Z-superoinferior). Later loading, the relative displacements of the fracture marks were defined to evaluate the inter-particle motion as seen in (Fig.7, 8, 9, 10).

Results

In AO 44 A1 and AO 44 B1 fractures, the amount of displacement between the fracture fragments was the least in the IS method, while it was observed in 4 mm K-wire in AO 44 C1 fracture. Therefore, it was defined that the minimum quantity of displacement was in AO 44 A1 fracture IS fixation method, and the highest quantity of displacement was in the single 2 mm k-wire fixation method. It was determined that the minimum quantity of displacement was in the IS detection method in AO 44 B1 fracture, and the highest amount of displacement was in the PS detection method. It was observed that the minimum quantity of displacement was in the 4mm k-wire fixation method in AO 44 C1 fracture, and the highest quantity of displacement was in the single 2mm k-wire fixation process.
IS fixation method produced better stability than other fixations in AO 44 A1 and 44 B1 fractures. In AO 44 C1 fractures, on the other hand, it was observed that 4 mm single k-wire fixation produced better stability than other fixations.

Five different systems, stress evaluation was made in terms of the yield strength of the materials. The stresses were calculated, the maximum stress was seen in a double 2 mm K-wire in AO 44 A1, while it was observed in a single 2 mm K-wire in AO 44 B1 and C1. It was analysed that the least stress was on the screw in AO 44 A1, B1 and C1 fractures. Five methods were compared in terms of X, Y, Z axis and stretch in the isolated distal fibula AO 44 A1, B1 and C1 fractures (Table 1).

Discussion

In this study, we compared the fixation methods, which are missing in the literature, in the isolated distal fibula AO 44 A1, B1 and C1 fractures using finite elements. We also emphasized the importance of applying k-wires, which are less studied in the literature, that are old, practical and, inexpensive. According to our results, it was observed that single 2 mm k-wire fixation provided insufficient fixation in all three fracture types compared to other fixation methods. We concluded that intramedullary 4.2 mm compression screw in AO 44 A1 and B1 fracture fixation and 4 mm-k-wire fixation in AO 44 C1 fracture fixation are the most suitable methods in X, Y and Z axis for reduction. This showed us the superiority of intramedullary closed fixation methods over
plate-screw fixation methods. When we look at the recent studies, we have seen that intramedullary closed methods are compatible with our findings [9].

In a study on the fixation of fibular fractures with early-stage intramedullary implants, it is stated that proper data on intramedullary fixation of the fibula are limited and the results contain important early-stage data [15]. With this study, we concluded that an intramedullary titanium 4.2 mm screw for isolated distal fibula AO 44 A1, B1 fractures and a steel 4 mm k-wire for isolated distal fibula AO 44 C1 fracture are sufficient for bone fixation.

Loukachov et al. focused on the soft tissue protective effect of intramedullary fixations compared intramedullary fixation with plate-screw fixation method in ankle fractures [6]. Intramedullary fixation methods are recommended especially in cases where the ankle is oedematous and swollen, and in conditions where the operation time should be short [6]. In our study, we also demonstrated the stabilization superiority of intramedullary 4.2 mm compression screw or 4 mm k-wire fixation, which is an intramedullary closed fixation method, over plate-screw fixation in AO 44 A1, B1 and C1 fractures with the help of a finite element study.

A previous study evaluated the postoperative consequences of postponing surgery for plate-screw application in oedematous ankle injuries. It was emphasized that every effort should be made to operate closed ankle fractures as soon as possible. In this study, more than one week delay in fracture reduction and fixation was shown to cause a significant increase in infectious wound complications. As a result, it is suggested that fractures should be treated

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preferably within the first day, supporting the view that this approach provides a significant reduction in wound complications and a better functional outcome [3]. This study helps us to reach a conclusion that early intramedullary fixation can be advantageous in oedematous distal fibula fractures.

It was recently reported that the use of intramedullary fixation in lower fibula fractures is a good alternative for plate-screw fixation. Although plate-screw fixation provides optimal anatomical reconstruction of fractures, intramedullary fixation has a lower risk of complications, it has been concluded [19]. In our study, according to the finite element results of fibula AO 44 A1, B1 fracture modelling, it is observed that intramedullary 4.2 mm compression screw is better than plate-screw fixation in both fracture patterns according to both the X, Y and Z axis displacements and the stress value.

In a study by Wan et al., the clinical effects of Kirschner wire (k-wire) intramedullary fixation in the treatment of distal fibular fractures, k-wire fixation is presented as an easily applicable method with the advantages of less pain and soft tissue safety. It has been stated that k-wire fixation in distal fibula fractures effectively reduces the financial burden of the patients. Thus, it is said that it is worth making it popular in clinical and basic level hospitals [7]. K-wire fixation method is a practical, inexpensive, soft tissue protective method, can be performed in the early period in oedematous ankles, and which is easy to remove after union. On the other hand, it has disadvantages such as pin site infection and skin irritation. In our
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finite element study, 4 mm k-wire and 2 mm double k-wire are the fixation method that can be used in fibula AO 44 A1, B1 and C1 fractures, considering both the displacements in the X, Y, Z axes and the tension values. On the other hand, 2 mm single k-wire fixation is not considered a suitable fixation method for distal fibula fractures, since the amount of displacement in the axes in AO 44 A1 and C1 fractures and the stress value in AO 44 B1 fractures are high.

Conclusions

distal fibula fracture should be evaluated together with bone and soft tissue. Soft tissue oedema is an effective factor in the selection of the surgery to be performed. Recent studies suggest that intramedullary fixation options can be used as a surgical technique in oedematous ankle fracture [6, 19]. In the literature, many factors such as fixation strength [20], patient's osteoporosis [1], ankle ligament injury and instability [11] are effective in the surgeon's approach to this fracture type. In our study, we concluded that fixation of screw, 4 mm k-wire and 2-2 mm k-wire can be preferred over plate-screw and 2 mm k-wire fixation. Intramedullary these techniques can be used in order to ensure fracture stability and for preventing wound complications.

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References


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**Figure 1.** K-wire fixation model. AO 44 B1 model has a single 2 mm K-wire
Figure 2. K-wire fixation model. AO 44 C1 model has a single 2 mm K-wire
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Figure 3. Intramedullary screw fixation method. 4.2 mm screw in AO 44 B1 model
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Figure 4. Intramedullary screw fixation method. 4.2 mm screw fixation in AO 44 C1 model
Figure 5. Plate-screw fixation method. Plate-3.5 mm screw in AO 44 A1 model
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Figure 6. Plate-screw fixation method. Plate- 3.5 mm screw in AO 44 B1 model
Figure 7. Determination of motion between parts using the displacement of two marks with respect to the X, Y, and Z axes. The displacement of a single 2 mm K-wire, 4 mm K-wire, Plate screw, intramedullary screw, two 2 mm K-wire fixations according to the X, Y, and Z axes in AO 44 A1 model.
Figure 8. Determination of motion between parts using the displacement of two marks with respect to the X, Y and Z axes. Displacement of a single 2 mm K-wire, 4 mm K-wire, plate-screw, intramedullary screw, two 2 mm K-wire fixations according to the X, Y and Z axes in AO 44 B1 model.
Figure 9. Determination of motion between parts using the displacement of two marks with respect to the X, Y and Z axes. Displacement of single 2 mm K-wire, 4 mm K-wire, Plate screw, intramedullary screw, two 2 mm K-wire fixations in mm according to X, Y and Z axes in AO 44 C1 model.
Figure 10. Tensile strengths of single 2 mm k-wire, 4 mm k-wire, plate-screw, intramedullary screw, double 2 mm k-wire fixation methods in AO 44 A1, B1 and C1 fracture modelling.
Table 1. Comparison of five methods in terms of X, Y, Z axis and stretch in distal fibula AO 44 A1, B1 and C1

<table>
<thead>
<tr>
<th>Method</th>
<th>AO 44 A1</th>
<th>AO 44 B1</th>
<th>AO 44 C1</th>
<th>Stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>X,Y,Z axis</td>
<td>0.0001-0.001</td>
<td>0.0016-0.003</td>
<td>0.0002-0.004</td>
<td>AO44 A1,B1,C1</td>
</tr>
<tr>
<td>4mm single K-wire</td>
<td>min.-max.</td>
<td>min.-max.</td>
<td>min.-max.</td>
<td>min.-max.</td>
</tr>
<tr>
<td>2mm single K-wire</td>
<td>0.0002-0.0012</td>
<td>0.003-0.0064</td>
<td>0.018-0.089</td>
<td>6.8-88.06</td>
</tr>
<tr>
<td>2mm double K-wire</td>
<td>0.000-0.0004</td>
<td>0.0018-0.004</td>
<td>0.0003-0.013</td>
<td>11.2-16.9</td>
</tr>
<tr>
<td>screw</td>
<td>0.000-0.000</td>
<td>0.00124-0.002</td>
<td>0.0003-0.0103</td>
<td>0.0057-8.64</td>
</tr>
<tr>
<td>plate</td>
<td>0.00006-0.013</td>
<td>0.015-0.018</td>
<td>0.0045-0.011</td>
<td>6.18-54.212</td>
</tr>
</tbody>
</table>

min: min; Max: Maximum.