Ideal plate screw configuration in femoral shaft fractures: 3D finite element analysis

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Abstract

Background/Aim: Plate screw fixation is an important method in femoral shaft fractures. Although there are many studies on plate screw fixation, the ideal plate screw configuration has not yet been determined. In our study, we investigated the optimal plate-screw configuration in femoral shaft fractures using the 3D finite element analysis method.

Methods: A fracture model was created by removing the segment from the femur model obtained from 3D computed tomography scanning. Five different fixation models were designed using a 4.5 mm diameter steel locked femoral shaft plate and different screw configurations. Screws with double cortex locks of 4.5 mm in width were used in different configurations. To evaluate the effect of screw diameter, a 5.5 mm diameter screw with a double cortex lock was used in one model. Static linear analyses of these prepared Finite Element models were performed using Ansys Workbench 2020 R2 Finite Elements software.

Results: The maximum stresses on the plate at the fracture sites were 156 MPa at 200 N, and 546 MPa at 700 N in model 1, 274 MPa at 200 N, and 784 MPa at 700 N in Model 2, 274 MPa at 200 N, and 959 MPa at 700 N in Model 3, 389 MPa at 200 N, and 1118 MPa at 700 N in Model 4, and 200 N is 274 MPa, and 961 MPa at 700 N in Model 5.

Conclusion: The stress on the plate in the fracture area increases in parallel with the increase in screw diameter, plate length and plate working distance. Filling all screw holes does not alter the stress on the plate at the fracture line level.

Keywords: Femoral fractures, Plate fixation, Screw configuration, Finite element study
**Introduction**

Femoral shaft fractures are one of the most common fractures treated by orthopedists [1]. Its incidence is 0.01% [2]. It often occurs because of high-energy traumas, and is associated with polytrauma, open fractures, and multiple fractures [3]. In young patients, it is frequently caused by traffic accidents, falling from a height, gunshot injuries, and in elderly osteoporotic patients due to falling from same heights [1, 2]. Skeletal traction, plate and screw, intramedullary nail and external fixator are used in the treatment of femoral shaft fractures [4-6]. Intramedullary nailing is the gold standard in treatment [2, 3]. Plate fixation is recommended for fractures where intramedullary fixation is not suitable [7, 8].

In the follow-ups performed after fixation with the plate, the plate was broken at a rate of approximately 3.5% - 13.3% [9, 10]. It has been stated that most of the causes of failure of internal fixation materials are related to material fatigue [11]. There are many studies about the plate screw configuration [12-14]. However, there is still no consensus on the optimal plate screw configuration.

In this study, we aimed to investigate the best plate screw configuration in femoral shaft fractures using 3D finite element analysis method and contribute to the literature.

**Materials and methods**

Finite Element Method (FEM) is a mathematics-based calculation technique used in solving complex analytical structural problems. When creating a model resembling the human body, solid modeling programs such as Solid Works is utilized. This model is obtained from real CT scans using real computed tomography (CT) images. Modified solid models are produced in a problem-based solid modeling program, then transferred to a Finite Element Analysis software such as Ansys Workbench, a useful tool specifically for engineers [15].

In this study, 3-dimensional (3D) plates of different sizes, thicknesses and holes were created in Space Claim to be used in analysis. The femur model was obtained from 3D computed tomography scans used in previous studies in the literature [16,17]. In the 3D femur model, a fracture was created by removing the segment in the transverse plan from the femur diaphysis area. Plates were placed on the models and prepared for Finite Element Analysis under real loading conditions.

Five different fixation models were designed using a 4.5 mm diameter femoral shaft plate with steel lock and different screw configurations. Screws with double cortex locks of 4.5 mm in width were used in different configurations. To evaluate the effect of the screw diameter, a 5.5 mm diameter screw with double cortex lock was used in one model. In the first model, a 6-hole plate was used, and 3 screws of 4.5 mm diameter were placed the proximal and distal to the fracture. In the second model, a 6-hole plate and three screws with 5.5 mm diameter were placed proximal and distal to the fracture. In the third model, an 8-hole plate and 3 screws with locks placed with 4.5 mm between them were used. In the fourth model, an 8-hole plate and 3 screws were used. In this model, the working length was increased by leaving the screw holes closest to the fracture empty. In the fifth model, 8-hole plates and 4 screws were used (Figure 1).

Figure 1: Schematic representation of the loads applied to the models. A: 200 N loading. B: 700 N loading

In this study, the following materials and properties were taken for the parts used in the model. Bone properties for femur: Modulus of Elasticity (E): 16.8 GPa, Poisson's Ratio (u): 0.47. Steel material was used for the plate, and the Modulus of Elasticity (E) was calculated as 200 GPa and Poisson's Ratio (u) as 0.3.

In the analyses, 200 N partial loading and 700 N full loading cases were used to test different loading cases, which were applied vertically to the proximal surface [12] (Figure 2).


The connections between the plate, screws and femur were designed in the most realistic way, and the screws and femur connection were realized at the screw thread level. Thus, the distributions in the screw threads could also be obtained. In addition, the femur was fixed from the lowest part so that it could not displace in any direction. Static linear analyses were performed by importing these Finite Element models into Ansys Workbench 2020 R2 Finite Elements software.

**Results**

As a result of the evaluation, we found that when the working length increased (the length between the two screws closest to the fracture), the load on the plate was higher in the fracture area. The maximum stress on the plate at the fracture site was 274 MPa at 200 N, and 961 MPa at 700 N in Model 5, and 389 MPa at 200 N, and 1118 MPa at 700 N in Model 4.

Comparing the filling of all screw holes in the 8-hole plate with spaced screws, we found that the stress on the plate was similar in both models. The maximum stress on the plate at 200 N was 274 MPa, and 959 MPa at 700 N in Model 3.

When the use of screws with a diameter of 5.5 and 4.5 mm was compared, it was observed that the stress on the plate at the fracture site was higher in the screws with 5.5 mm width.
We found that the stress on the plate at the fracture site increased with the plate length. The maximum stress on the plate at the fracture site was 156 MPa at 200 N, and 546 MPa at 700 N in Model 1, and 274 MPa at 200 N, and 784 MPa at 700 N in Model 2. (Figure 3) (Table 1).

### Table 1: Stress distribution in models at different loads

<table>
<thead>
<tr>
<th>Load (N)</th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
<th>Model 4</th>
<th>Model 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>156</td>
<td>274</td>
<td>274</td>
<td>389</td>
<td>274</td>
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<tr>
<td>700</td>
<td>546</td>
<td>784</td>
<td>959</td>
<td>1118</td>
<td>961</td>
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</tbody>
</table>

**Discussion**

Plate selection and screw configuration are important in solving implant failure and reducing complications in plate and screw osteosynthesis.

Plate working length is one of the most important mechanical parameters of plate systems and has a major impact on the mechanical environment and structural stability of the fracture site [18, 19]. Studies on plate systems with locks have revealed conflicting results. While some studies suggest increasing the length of the plate, there are opposing views in some others [20–25]. In our study, we found that increasing the working length increased the stress on the plate in the fracture site. Ellis T. et al. [25] found that increasing the working length in case of a gap in the fracture area correspondingly increased the stress on the plate, but if there was no gap in the fracture area, increasing the working length decreased the stress on the plate. In our study, we found a positive correlation between working length and stress on the plate.

Another important mechanical parameter in plate screw systems is plate length. Jianzhao Wang et al. [12] found that the increase in the length of the plate increased the stress on the plate but reduced the stress on the bone. In our study, we found that the increase in the length of the plate increased the stress load on the plate in the fracture area.

The location and configuration of the screws in the plate is another important parameter in plate and screw osteosynthesis. In a study they conducted, Wei Sheng et al. [13] found that the stress loads on the plate in nine different plate screw configurations of the same length were similar. They also found that the stress on the plate and femur increased significantly in the first and second screw holes near the fracture. In previous studies, it was stated that the use of screw holes near the fracture site had a great effect on the stress distribution in the plate fixation system [26, 27]. In our study, we observed that when we compared the filling of all screw holes and spaced screw placement in an 8-hole plate, the stress on the plate in the fracture line was similar in both groups.

Screw diameter also plays an important role in the mechanics of internal fixation [28, 29]. In their study comparing the screw diameters of 4 mm, 4.5 mm, 5 mm, Wei Sheng et al. [13] revealed that the highest stress on the plate was on the 4 mm screws. They showed that the most suitable screws were those with 5mm diameter. In our study, when the use of a 5.5 mm diameter screw was compared with the use of 4.5 mm, we found that the stress on the plate in the fracture line was higher in the model using 5.5 mm screws. This result was not in line with the study of Wei Sheng et al.

**Conclusion**

As the plate’s working length, screw diameter, and plate length are increased, the stress on the plate in the fracture area also increases. The reduction of the screws, provided that the screws were placed in the closest and furthest holes to the fracture, did not change the stress on the plate at the level of the fracture line.

**References**


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