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Finite element analysis of the stability of AO/OTA 43-C1 type distal tibial fractures treated with distal tibia medial anatomic plate versus anterolateral anatomic plate

O. Fuad Oken^{a,*}, A. Ozgur Yildirim^a, Mehmet Asilturk^b^a Ankara Numune Education & Training Hospital, Orthopedics & Traumatology Clinic, Ankara, Turkey^b Ankara Atatürk Education & Training Hospital, Orthopedics & Traumatology Clinic, Ankara, Turkey

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ABSTRACT

Background: The treatment of a pilon fracture type is possible from a medial, an anterolateral approach or both medial and lateral. The aim of study was compare the stability of two different plate fixation of a tibia pilon AO-43C1 type fractures.

Material and methods: In this study, three-dimensional finite element stress analysis was applied using isotropic materials and static linear analysis. Loading of 400 N force was applied to the model of a patient fixed in a standing position. In the model, first the fibula was treated by plating and then in one group the tibia pilon fracture was treated by medial plating, and in the other by anterolateral plating. The displacement and stress values of the fragments of the fracture line were compared of the same points in each model.

Results: The magnitude of the displacement of fragments in the total displacement magnitudes of X, Y, Z axis were measured in the medial plate and anterolateral plate. The anterolateral plate results were similar to those of the medial plate and the displacement values in the Y axis were determined to be lower than in the medial plate.

Conclusion: In AO 43 C1 distal tibia fractures, medial or anterolateral plates can be used, and the results of this study showed similar biomechanical stiffness in the two plates.

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Introduction

The surgical treatment of distal tibial fractures can be difficult, with high rates of infection, wound healing complications, and post-traumatic arthritis.^{1–5} However, the optimal treatment for distal tibial fractures remains controversial. Various treatment modalities have been described, including minimally invasive techniques, open reduction and internal fixation (ORIF), intramedullary nailing (IM), hybrid or ring external fixation, and a two-staged protocol with primarily external transfixation and later conversion to ORIF. The aim of all these different treatment modalities is to provide strong and stable fixation, while reducing complications to a minimum especially wound problems. However, each treatment modality has associated benefits and complications.^{6–16}

* Corresponding author. Zulfu Tigrel Cad. No:18/B ORAN, Cankaya, Ankara 06450, Turkey.

E-mail address: fuadoken@yahoo.com (O.F. Oken).

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Distal tibial fractures can be treated with medial, lateral or anterolateral approaches.^{17,18} The superficial peroneal nerve, which is at risk of injury during the procedure is also better visualized in the anterolateral approach.¹⁹ Despite these advantages, biomechanical stiffness is a significant disadvantage of anterolateral plating compared to medial plating in the treatment of distal tibia fractures. To the best of our knowledge, the relative biomechanical stiffness characteristics of anterolateral versus medial plating in the treatment of distal tibial fractures has not been studied by the finite element method.

The aim of the current study was to test the different fixation alternatives of a tibia pilon AO-43C1 type fracture with two different fixation methods compared to a healthy control model, using a medial anatomic plate and an anterolateral anatomic plate.

Materials and methods

This investigation was undertaken by Ay Tasarim Ltd. Sti. at Ankara University. The investigation was applied using three-

dimensional finite element stress analysis with isotropic materials and static linear analysis.

In these models, 400 N force was applied in a vertical direction to the models which were depicted in a walking condition and the displacements were analyzed using the three-dimensional finite element stress analysis method. A force of 400 N, representing the half of typical person body weight, was loaded on the ankle.²⁰

To create the 3-dimensional mesh models, Intel Xeon® R CPU 3.30 GHz processor, 500 gb Hard disk, 14 GB RAM hardware and Windows 7 Ultimate Version Service Pack 1 operation system computer, Activity 880 optic scanner (smart optics Sinterstrasse 8, D-44795 Bochum, Germany) 3D optical scanner and Rhinoceros 4.0 three-dimensional modeling software (3670 Woodland Park Ave N, Seattle, WA 98103 USA), and VRMesh Studio (Virtual Grid Inc, Bellevue City, WA, USA) and Algor Fempro (ALGOR, Inc. 150 Beta Drive Pittsburgh, PA 15238-2932 USA), to edit and optimize the three-dimensional surface mesh models, and solid meshing to perform the finite element analysis (Fig. 1).

The models were created geometrically by using VRMesh software and transferred to Algor Fempro software in stl format (which is an universal file format for 3-D modeling software) for analysis. In stl format the coordinates of the nodes are saved so that it is possible to transfer part of an assembly between different software.

Modeling of screws and plates

The plates and screws used in this study were produced by Biomet Inc., Warsaw, IN, USA. The OptiLock® Periarticular Plating System is an implant/instrument set for applying right distal lateral tibial pre-contoured, titanium alloy plates. The system features include:

- The anatomically contoured Anterolateral Distal Tibial Plate is used with 12 holes and 206 mm in length for right distal tibias.
- The anatomically contoured Medial Distal Tibial Plate is used with 15 holes and 244 mm in length for right distal tibias.
- The Locking Fibular Plate is used with 14 holes and 67 mm in length for distal fibulas.
- Non-locking bone screws: 2.7 mm, 3.5 mm and 4.5 mm.
- Locking bone screws: 2.7 mm, 3.5 mm and 4.5 mm.

We used only locking bone screws for the plate fixation. We did not use non-locking screws.

The plates and the screws were 3-D scanned by Smart Optics and saved as stl format. Then, these files were opened in Rhinoceros software and the adaptation of the implants to the other sets was managed.

Modeling of the bone tissues

Our simulation object was taken from “Visible Human Project” (<http://www.nlm.nih.gov/research/visible/visiblehuman.html>) was used for modeling of ankle. It contains muscles and ligaments of the ankle. The axial slice data derived from the visible human project were converted into 3-dimensional models using 3d-Doctor software. The 3d models modeled in 3d-doctor were exported to VrMesh in stl format to be fixed.

Models that were finalized in Rhinoceros software were exported to Fempro. Models were 3d mesh modeled in Fempro to Bricks and Tetrahedra elements. In bricks and tetrahedral modeling, Fempro uses 8 noded elements as much as it can and uses 7,6,5,4 node elements as needed.

All materials are defined as linear, homogenous and isotropic. A homogenous material has the same mechanical properties in each

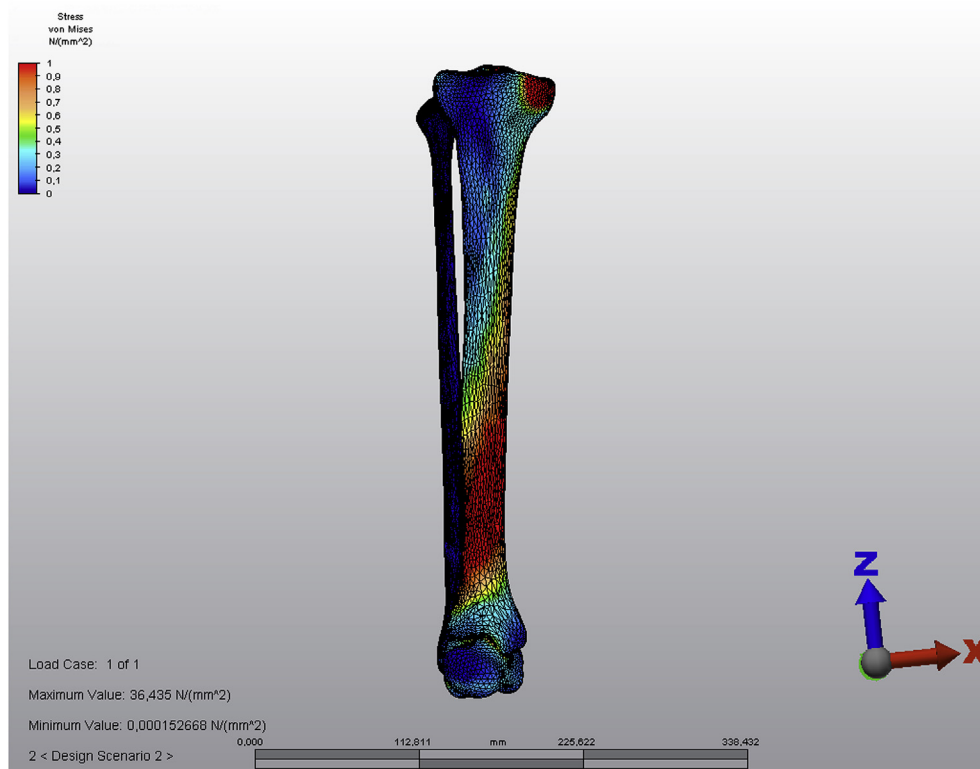


Fig. 1. To create the 3-dimensional mesh models to perform the finite element analysis.

structural element. An isotropic material has uniformly the same material properties in all directions. Linear elasticity is the proportional variability of deformation of the structure.

Boundary conditions

The models were fixed from the talus with 0 DOF (Degree of freedom). The model was fixed from the upper part of the tibia with 5 DOF excluding Z axis motion to depict tibia movement.

Loading and stress analysis

In this study, loading was applied to the model fixed in a standing position. 400 N force was applied in a negative Z axis direction.

The displacement values of the superior and inferior fragments at the anterior and posterior of the fracture line were compared by selecting the same points in each model.

As the values obtained from finite element stress analysis are derived from mathematical calculations without any variance, a statistical analysis is not possible. The critical issues are the precise assessment of the scans, and the amount and distribution of the stress.

Fempro software is able to give 25 different stress values. It is important to know which stress value should be assessed.

Shear stress can be shown as $\tau_{xy} = \tau_{yx}$, $\tau_{yz} = \tau_{zy}$, $\tau_{xz} = \tau_{zx}$. Any 3-D stress element has one normal stress (tension and compression) component and two shear stress components on the x, y and z axes. Therefore, any stress elements are defined as 3 normal and 3 shear stress components.

Positive values show distraction stresses and negative values show compression stresses. Any stress element is under the effect of the stress type which has the largest absolute value. Therefore, that stress type should be considered.

We could not evaluate torsional results in this modal.

Results

The magnitudes of the displacement of the fragments in total displacement magnitudes of the X, Y, Z axis in the medial plate and anterolateral plate are given in Table 1.

In the finite element analysis, average stress distributions on the normal human distal tibia model were 0.650900, 0.741023, 0.472321 and 0.811504 at the medial, anterior, lateral, posterior cortices, respectively. When the implants were applied, the stress on the fracture lines decreased, with the decrease at the same value with both materials (Table 2).

The displacements of the fracture line with the medial plate were 0.001376 mm in X axis, 0.001092 mm in Y axis, and 0.001156 mm in Z axis (Fig. 2). The total displacement magnitude was 0.005890 mm in all axes. The displacements of the fracture line with the anterolateral plate were 0.001577 mm in X axis, 0.000232 mm in Y axis, and 0.0004336 mm in Z axis (Fig. 3). The total displacement magnitude was 0.004620 mm in all axes. The anterolateral plate results were similar to those of the medial plate. Moreover, the displacement values in Y axis were less than in the medial plate.

Table 1
Total displacement magnitudes of X, Y, Z axis.

	X axis	Y axis	Z axis	Magnitude
Medial anatomic plate	-0.001376	-0.001092	-0.001156	0.005890
Anterolateral plate	-0.001577	-0.000232	-0.0004336	0.004620

Table 2
Average stress distributions (Von Mises Stress N/mm²).

	Medial	Anterior	Lateral	Posterior
Medial anatomic plate	0.190576	0.489690	0.144652	0.106060
Anterolateral anatomic plate	0.206839	0.395411	0.280077	0.395411
Control (N0 fractures)	0.650900	0.741023	0.472321	0.811504

Discussion

Intraarticular fractures of the distal tibia are commonly caused by axial loading forces, so in this model, the fracture was created by axial loading^{21,22} and the models were depicted in a walking condition. The same trademark plates and screws were used in all the fractures, and the displacement values of the superior and inferior fragments at the anterior and posterior of the fracture line were compared by selecting the same points in each model. All the variables were the same and it was aimed to show only the biomechanical stiffness in the two plates.

The optimal treatment for distal tibial fractures remains controversial with high rates of infection, wound healing complications and post-traumatic arthritis. Reports from various institutions have suggested treatment modalities ranging from minimally invasive techniques, to open reduction and internal fixation, intramedullary nailing, and hybrid or ring external fixation.^{6–9}

There have been numerous studies on the orthopedic use of finite element methods and it is accepted as a reliable method for structural analyses. Finite element analysis was used in this study to compare the anterolateral and medial plating.

The results of this study indicate that medial anatomic plate or anterolateral anatomic plate can be used for AO/OTA 43 C1 type distal tibia fractures. Both medial and anterolateral anatomic plates are commonly used on AO/OTA 43 C1 type distal tibia fractures.

Yenna et al²³ compared the biomechanical stiffness of anterolateral and medial plates in a distal tibial fracture model using composite sawbones with AO 43 A2 fractures. No significant difference in stiffness was found between anterolateral and medial locking plate constructs in compression and torsion testing. Thus, even for fracture patterns prone to varus collapse, locked anterolateral plating was seen to be mechanically equivalent to locked medial plating.

We found that the displacement values in Y axis were less than in the medial plate. We believe that, the anterolateral plate's screw directions more anteroposterior direction than medial plate. These anteroposterior screws could make the unit more stable than the medial plate in Y axis.

As the subcutaneous tissue on the medial distal tibia is thin, medial anatomic plates on the distal medial side of the tibia endanger the soft tissue envelope, with problems ranging from skin irritation to necrosis.²⁴ Lee et al²⁵ compared medial and lateral plating of distal tibia fractures with ORIF. Both groups were similar in respect of injury mechanism, union rate, malunion rate, operative time, functional score, and range of ankle motion and both medial and lateral plating treatment of distal tibial fractures achieved good functional outcomes with a low malunion rate. However, the lateral plating group had a lower complication rate ($p = 0.047$) and fewer hardware problems.

In AO 43 C1 distal tibia fractures, medial or anterolateral plates can be used, and the results of this study showed similar biomechanical stiffness in the two plates. In literature, lower rates of complications have been reported from treatment with an anterolateral plate with an anterolateral approach compared to a medial plate with a medial approach. Therefore, the anterolateral plating system can be recommended for these types of fractures. If there is

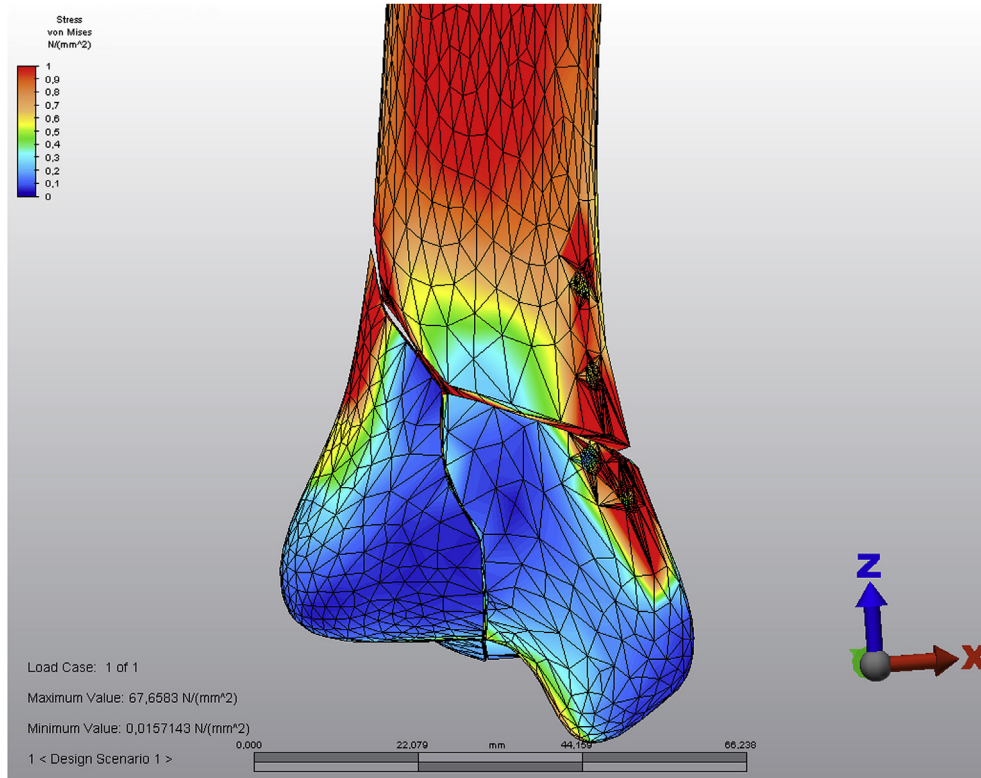


Fig. 2. The displacements of the fracture line with the medial plate were 0.001376 mm in X axis, 0.001092 mm in Y axis, and 0.001156 mm in Z axis.

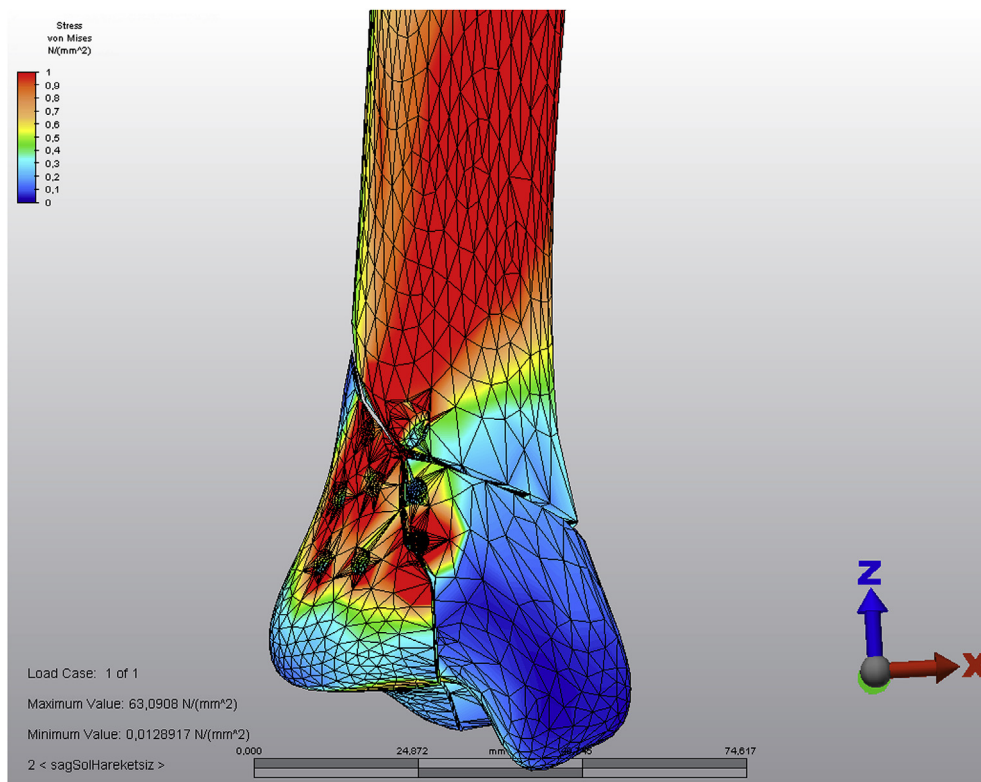


Fig. 3. The displacements of the fracture line with the anterolateral plate were 0.001577 mm in X axis, 0.000232 mm in Y axis, and 0.0004336 mm in Z axis.

a fracture type with varus or valgus deformation the implant can be chosen by different conditions. It has been known that the anterolateral plate can be used in valgus deformation and anterior plate in varus deformation.

The limitation of this study is that only the one fracture type of AO 43 C1 was evaluated. Further studies should examine all fracture types. Another limitation was the finite element modeling. Although finite element modeling is known to be a good choice for fracture modeling, fresh frozen cadaver studies would provide stronger conclusions.

Conclusion

Distal tibia fractures remain challenging for orthopedic surgeons with several potential problems during treatment. Both medial and anterolateral anatomic plates are commonly used on AO/OTA 43 C1 type distal tibia fractures.

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