Original Article

Cannulated compressive screw compared with cortical screw for fixation of simple first tarsometatarsal joint fracture-dislocation: a finite element analysis

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Abstract: Objective: Nowadays, various kinds of screws can be used in orthopedic surgeries; however, in the fixation tarsometatarsal joint injury, which screw should always be used is widely controversial. The aim of this study was to explore the biomechanical characteristics between the cannulated screw and cortical screw for the fixation of simple first tarsometatarsal joint fracture-dislocation. Methods: The finite element analysis was used and after the establishment of the finite element model of simple first tarsometatarsal joint fracture-dislocation, two simulations were designed. In one model, the AO 4.5 mm-cannulated compressive screw was simulated in the fixation of the fracture-dislocation. In the other model, the fracture-dislocation was fixed with the AO 3.5 mm-cortical screw. The two finite element models were simulated under the same loading and the displacement of the first tarsometatarsal articular surface and the stress distribution in screws of the two models were calculated respectively. Results: The maximum principal stress focused on the lower leg in both the models under the same loading. In the model of cannulated compressive screw fixation, the minimum displacement of the articular surface was 0.4834 mm, while it was 0.496 mm in the model of cortical screw fixation. The maximum principal stress in the cannulated compressive screw and cortical screw were 4.124×10² MPa and 6.075×10² MPa respectively, which were mainly concentrated in the middle of screws, especially in the side of the first metatarsal. Conclusion: Both the cannulated compressive screw and cortical screw are suitable for fixing simple first tarsometatarsal joint fracture-dislocation. However, compared with the cortical screw, the cannulated compressive screw has more obvious advantages. Therefore, using the cannulated compressive screw to fix the simple first tarsometatarsal joint fracture-dislocation is recommended.

Keywords: Cannulated compressive screw, cortical screw, tarsometatarsal joint, fracture-dislocation, finite element analysis

Introduction

The first tarsometatarsal joint plays an important role in the foot, which has important significance in the maintenance of foot arch and load transfer. Therefore, the first tarsometatarsal joint injury should be treated actively to recover the alignment of the midfoot and to ensure the load transfer from forefoot to the midfoot [1]. The screw might be the first choice to fix the first tarsometatarsal joint injury. However, there are many kinds of screws and which kind is the most suitable implant is still controversial, for improper implant may cause the changes of the local biomechanical environment of the feet, leading to the complications such as implant breakage, loss of reduction and malunion easily [2]. Therefore, it is necessary to study the biomechanical characteristics of different screws.

Due to the irregular anatomical structure of the first tarsometatarsal joint in midfoot, it is quite difficult to carry out the biomechanical research on the corpse specimens [3]. Therefore, in this study, a three dimensional (3D) finite element model of simple first tarsometatarsal joint fracture-dislocation was established and two kinds of implants, which were the AO 4.5 mm-cannulated compressive screw and the AO-3.5 mm cortical screw were simulated. The aim of this study was to analyze the displacement of the articular surface and the stress distribution in
Finite element analysis for first tarsometatarsal joint injury

Materials and methods

General data

A 35 year-old healthy male Chinese volunteer (height 170 cm and weight 70 kg) was recruited. The appearance and X-ray examination showed there was no deformity and damage in the foot. The volunteer signed the informed consent of the potential radiation hazard and the screws to provide experimental evidence for the choice of screws for the first tarsometatarsal joint injury.

Equipment and software

In this study, the following equipment and software were used: (1) The 4D dual source CT (Siemens Ltd, German); (2) Mimics 12.0 (Materialise Ltd, Belgium); (3) Geomagic Studio (Rainrop Ltd, USA); (4) SolidWorks 2010 (Dassault Systemes Ltd, USA); (5) ANSYS 13.0 (ANSYS Ltd, USA).

Experimental method

Data collection: The 4D dual source CT was used to scan the volunteer from lower segment of the leg to the whole foot in neutral position. The slice thickness was 1 mm and the scan speed is 0.4 s/ring. The original CT image data of 512×512 matrix was obtained (Dicom format).

Establishment of 3D model: The original data was loaded in the software of Mimics 12.0 to obtain a three-dimensional model of the foot. After the optimization of the model, it was loaded to the software of Ansys 13.0 and a three dimensional finite element of foot with 66540 nodes and 349475 units could be obtained. The materials in the model were simplified as homogeneous elastic materials. The thickness of the cortical bone was set in 2 mm. The ligaments and plantar fascia were established by 2 node TRUSS unit (Figure 1). The model of the foot was then loaded into the Solidworks 2010 to simulate cutting off the dorsal and plantar ligaments between the medial cuneiform and the first metatarsal and osteotomy along the articular surface of the first tarsometatarsal joint.
The geometric parameters of the screws were loaded into the Solidworks 2010 and two implant models were established according to the experiment. The AO 4.5 mm-cannulated compressive screw was fixed trans-articular from the base to the first metatarsal to the media cuneiform, which was perpendicular to the fracture line. The AO 3.5 mm-cortical screw was also fixed trans-articular from the base to the first metatarsal to the media cuneiform, which was perpendicular to the fracture line (Figure 3). The elastic constants of the different materials were set as shown in Table 1 [5].

**Loading of the external force:**
According to the mechanism of tarsometatarsal joint injury, in this study, the ankle was fixed at 30° of plantar flexion (Figure 1). We set the lowest contact point of the tibia and fibula and the head of the first metatarsal with the ground as the constraint point. The loading was 700 N in accordance with the body weight and direction was set from the lower leg perpendicular to the ground, while the reverse direction was set in the head of the first metatarsal. The tensile force caused by the traction of the muscles and ligaments around the joint could be offset according to the principle of the synthesis and decomposition of the force [5].

**Results**

**Displacement of the articular surface**
After the loading of 700 N, both of the screws provided the firm fixation to the models without breakage of the screws and destroy of the models. However, the articular surface still had a tendency of dorsal dislocation in both models. The maximum displacement in the model of

![Image](image_url)

**Figure 3.** Two implant models were established. A. The AO 4.5 mm-cannulated compressive screw was fixed trans-articular from the base to the first metatarsal to the media cuneiform, which was perpendicular to the fracture line. B. The AO 3.5 mm-cortical screw was also fixed trans-articular from the base to the first metatarsal to the media cuneiform, which was perpendicular to the fracture line.

**Table 1.** Elastic constants of the different materials

<table>
<thead>
<tr>
<th>Materials</th>
<th>Modulus of elasticity (MPa)</th>
<th>Poisson ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cortical bone</td>
<td>7300</td>
<td>0.3</td>
</tr>
<tr>
<td>Cancellous bone</td>
<td>100</td>
<td>0.3</td>
</tr>
<tr>
<td>Titanium screw</td>
<td>110000</td>
<td>0.28</td>
</tr>
<tr>
<td>Fracture line</td>
<td>5</td>
<td>0.4</td>
</tr>
<tr>
<td>Ligaments and plantar fascia</td>
<td>500</td>
<td>0.3</td>
</tr>
</tbody>
</table>

the fracture line was replaced by the soft material.
The minimum displacement in the model of cannulated compressive screw fixation was 0.4834 mm, which appeared in the first tarsometatarsal articular surface. However, the maximum displacement in this model was 5.952 mm, which appeared in the first metatarsal head (Figure 4).

**Stress distribution in the implants**

After the loading of 700 N, it showed a concentrated distribution of the stress both in the cannulated compressive screw and cortical screw. The maximum stress in the cannulated compressive screw was $4.124 \times 10^2$ MPa, which was mainly concentrated in the middle of the screw but it supported equal stress both the in the sides of the first metatarsal and medial cuneiform. However, the maximum stress in the cortical screw was $6.075 \times 10^2$ MPa, which was also mainly concentrated in middle of the screw, especially in the side of the first metatarsal, which supported more stress than that in the side of the first tarsometatarsal joint. Therefore, the finite element analysis (FEA) is always used for the biomechanical research with its special advantage of high accuracy simulation of complex shapes and material properties [6, 7]. In the study, the original data from CT scan of the foot was loaded in Mimics12.0 to obtain the initial 3D model of the foot, and then the Solidworks 2010 could be used to cleave the model according to the Myerson classification type B1 to achieve the model of simple first tarsometatarsal joint fracture-dislocation. The Ansys 13.0 can be used to simulate the operations and assign the physical properties to the implants. After loading, the calculation could be carried on to work out the displacement of the articular surface, the stress distribution in the implants. However, as the limitation of the finite element analysis, the mechanical properties of materials are defined as continuous and homoge-
Finite element analysis for first tarsometatarsal joint injury

According to the mechanism of tarsometatarsal joint injury, the model was axially loaded in 30° plantar flexion of the ankle rather than neutral position with the maximum load of 700 N (body weight of the volunteer). In order to reflect the displacement of the articular surface and the stress distribution of the implants more veritably, the fracture line and articular surface was replaced and bonded by the soft material with the Modulus of elasticity 5 MPa and Poisson ratio 0.4 and the titanium screws with the Modulus of elasticity 110 Gpa and Poisson ratio 0.28. After loading, the results showed that the displacements of the articular surface of two models were less than 2 mm, which meant that both of the implants could provide firm fixation [10]. However, the articular surface still had a tendency of dorsal dislocation in both models. In the model of cannulated compressive screw fixation, the minimum displacement of the articular surface was 0.4834 mm, while in the model of cortical screw fixation, the minimum displacement was 0.496 mm. The results revealed that the firm fixation by cannulated compressive screw or cortical screw could restore the normal anatomy and slight mobility of the first tarsometatarsal joint. According to the FEA, the maximum displacements were located in the head of the first metatarsal in both models. Therefore, when the first tarsometatarsal joint is injured, it is advisable to stop the weight bearing of the foot whether or not the implants are fixed. Otherwise, it may cause the instability of the first ray, leading to complications such as the metatarsalgia, plantar fasciitis and pressure ulcer and so on [11].

As for the stress distribution in the implants, after the loading of 700 N, it showed a concentrated distribution of the stress both in the cannulated compressive screw and cortical screw. The maximum stress in the cannulated compressive screw was 4.124×10² MPa, which was mainly concentrated in the middle of the screw but it supported equal stress both the in the sides of the first metatarsal and medial cuneiform. The maximum stress in the cortical screw was 6.075×10² MPa, which was also mainly concentrated in middle of the screw, especially in the side of the first metatarsal, which supported more stress than that in the side of medial cuneiform.

Figure 5. The stress distribution in the implants. A. The maximum stress in the cannulated compressive screw was 4.124×10² MPa, which was mainly concentrated in the middle of the screw but it supported equal stress both the in the sides of the first metatarsal and medial cuneiform. B. The maximum stress in the cortical screw was 6.075×10² MPa, which was also mainly concentrated in middle of the screw, especially in the side of the first metatarsal, which supported more stress than that in the side of medial cuneiform.

neous, isotropic, this assumption is slightly different from the real situation of the first tarsometatarsal joint in midfoot itself [8, 9].
Finite element analysis for first tarsometatarsal joint injury

It had more obvious advantages in fixing simple fracture-dislocation. Furthermore, the cannulated compressive screw will lead less iatrogenic traumatic arthritis than the cortical screw because the cannulated design will make the area of the necrosis in the articular surface smaller [16].

In conclusion, in this finite element analysis we found that both the cannulated compressive screw and cortical screw are suitable for fixing simple first tarsometatarsal joint fracture-dislocation. However, compared with the cortical screw, the cannulated compressive screw had more obvious advantages in biomechanics. Therefore, it is recommended to use the cannulated compressive screw to fix simple first tarsometatarsal joint fracture-dislocation.

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Disclosure of conflict of interest

None.

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