Biomechanical Evaluation of Reconstruction Plates with Locking and Nonlocking screws configurations in Calcaneal Fracture: A Finite Element Model Study

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INTRODUCTION

Calcaneal fractures are the most common of the tarsal bone fractures and constitute 2% of all fractures. They are usually due to axial loading trauma, as from a fall or a motor vehicle accident. Currently, the standard treatment used mostly for displaced intraarticular fractures is open reduction and internal fixation (ORIF).

Recent studies on ORIF surgery have focused on comparing plate fixations that use whole locking screws (WLS) and whole nonlocking screws (WNS), and controversy still exists. The difference in the biomechanical effect between locking screws (LS) and nonlocking screws (NS) used for calcaneal fractures remains uncertain.

Computer-modeling approaches, such as finite element (FE) analysis, are commonly used by engineers and other investigators to predict the internal stress, and can incorporate the biomechanical influence of plantar fascia.

The primary aim of this study was to develop a 3D FE foot model, and then a joint depression type of Sanders type IIB calcaneal fracture was created. The secondary aim was to evaluate the biomechanical influence of plate fixation with WLS and WNS for calcaneal fractures during early weight bearing.

METHODS

This study established a 3D FE foot model using ANSYS Workbench 14.5 (ANSYS Inc., Swanson, Houston, USA), which comprised bones, cartilages, plantar fascia, and soft tissue. (Fig. 1).

Foot geometry was obtained from computed tomography imaging with 0.625-mm increments from the right foot of a 32-year-old male participant (height 177 cm, weight 70 kg), in the neutral unloaded position.

Balanced and symmetric standing was used to simulate early weight bearing. The participant weighed 70 kg; half of the weight, approximately 350 N, was considered the reaction force on a single foot. In addition to the ground reaction force, the tensile force acting through the Achilles tendon was applied on the posterior superior calcaneal tuberosity. The force generated by the Achilles tendon during balanced standing is approximately 50% of the foot reaction force (i.e. 175 N), according to a study by Simkin[1]. The superior surfaces of the tibia, fibula, and soft tissue were fixed, whereas the ground was allowed to move only in the vertical direction. The mechanical interaction between the ground and foot was assumed to be frictionless contact behavior

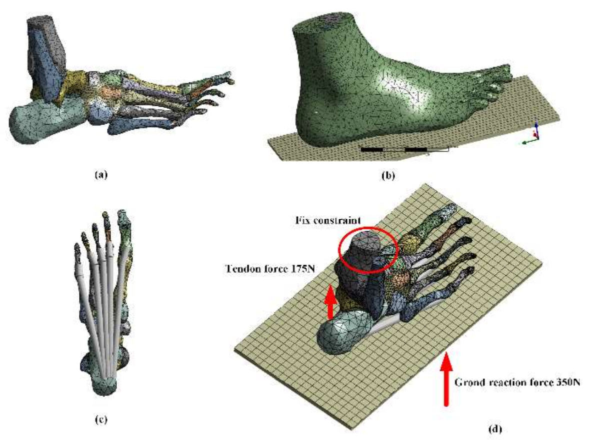

Figure 1: Finite element foot model (a) Bony structure with cartilage (b) Foot shape and ground (c) Plantar fascia (d) Loading condition for early weight-bearing standing.

After validating the foot FE model with Pedar measurements, it was modified as a joint depression type of Sanders type IIB calcaneal fracture and applied the plate and screws. (Fig. 2)
The contact behavior of the plate-screw interface was defined as bonded for LS, and frictional for NS with a frictional coefficient of 0.2 [2]. The bone-screw interface was defined as bonded contact behavior.

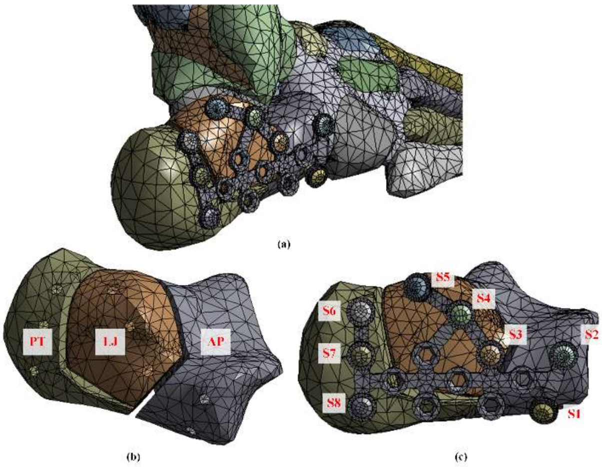

Figure 2: (a) The calcaneal fracture foot model with implant (b) Sanders type IIB was divided into three fragments: anterior process (AP), lateral joint (LJ), and posterior tuberosity (PT) fragments (c) The calcaneal plate and screws numbered.

Bohler angle in this study is used to assess the reduction of the calcaneal fractures. This angle is formed at the intersection of two lines, one of which is drawn from the apex of anterior process to apex of posterior facet, and the second of which is drawn from the apex of the posterior facet to the apex of the calcaneal tuberosity.

RESULTS AND DISCUSSION

The Bohler angle of the WNS (18.9 degree) are lower than that of the WLS (21.1 degree) and intact model (25 degree). In addition, the NS poorly resists bending and torque forces due to its small core diameter and large pitch[3, 4]. Therefore, this study demonstrated that the WLS has greater stability than WNS for Sanders type IIB calcaneal fractures.

Clinically, it is necessary to use some NS to fit the plate closely onto the calcaneus before the insertion of LS. The hybrid screw configurations combining of nonlocking and locking screws remains to be further research.

The stress distributions of calcaneal fracture showed how the screws stabilized the fragments. In the WLS model, the stability was mainly dependent on four screws. S3 and S4 were on the lateral joint fragment; S7 and S8 were on the posterior tuberosity fragment (Fig. 3a). In the WNS, the greater stress occurred on the AP fragment near the subtalar joint around the primary fracture line. The higher stress also appeared in lateral joint and posterior tuberosity fragments (Fig. 3b).

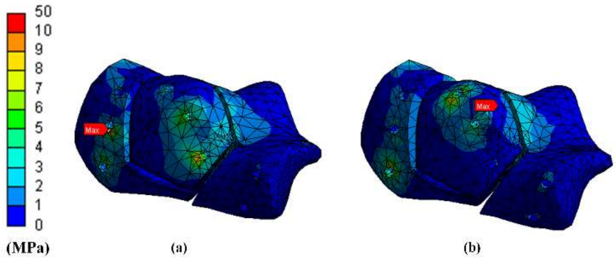

Figure 3: Stress distribution of the calcaneal fracture (a) WLS (b) WNS

CONCLUSIONS

To the best our knowledge, this study established the first whole foot calcaneal fracture FE model to analyze the biomechanical influence between WNS and WLS for the reconstruction of calcaneal fractures. This study demonstrated that the WLS has greater stability than WNS for Sanders type IIB calcaneal fractures. The FE results both showed that the fragments at the posterior facet and the posterior tuberosity sustained more stress during early weight-bearing. The results of this study may provide surgeons some useful information to choose appropriate screws for the fixation of calcaneal fractures.

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