THE INFLUENCE OF THE CALLUS SHAPE AND LEVEL OF CONSOLIDATION ON STRESS AND STRAIN IN FEMUR WITH DISTRACTION INTRAMEDULLARY NAIL–FE STUDY

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1. Introduction

Leg length discrepancy (LLD) is a common condition that affects up to 70 percent of the population [1]. In most cases, however, the LLD does not require surgical treatment and is treated by shoe lifts or not treated at all [1]. Surgical treatment is usually applied when the LLD is bigger than 40 mm [2].

The most common surgical technique for treating LLD is currently the distraction osteogenesis [2, 3]. The study of the distractor-bone system may provide new information about nail loading during the healing process and consequently improve the treatment strategy.

The aim of this study is to assess biomechanical performance of the distraction intramedullary nail.

2. Materials and Methods

CT images of the human femur in physiological state were obtained from the Visible Human Project datasets [4]. The model of geometry is composed of two solid parts representing the cortical and trabecular bone structure. To model the state after lengthening, i.e. femur with callus, the solid model was cut in accordance to the surgical guides for osteotomy. Different callus shapes were obtained on the basis of case studies which contained the information about the shape of callus or the x-ray images. Shapes were divided into four groups partially reflecting the classification proposed by Li et al.: fusiform, medially fusiform, cylindrical and asymmetric (see Fig. 2).

The geometrical model of distraction intramedullary nail was created based on PRECICE intramedullary nail [5]. The geometrical model of the nail is the antegrade variant with trochanteric entry.

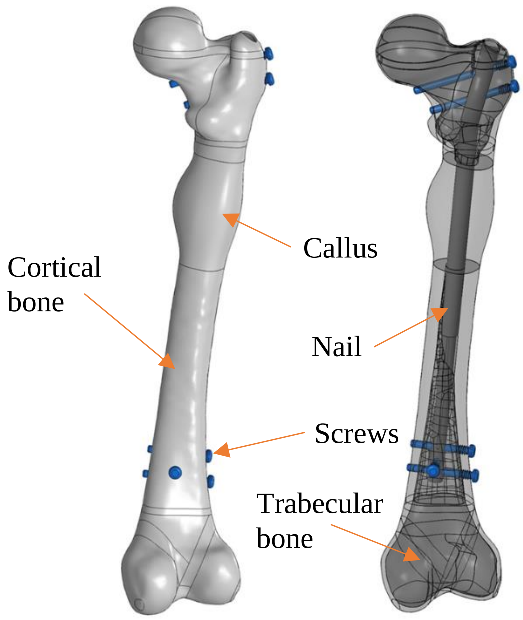

Fig. 1. Geometrical model of femur with intramedullary distraction nail and callus.

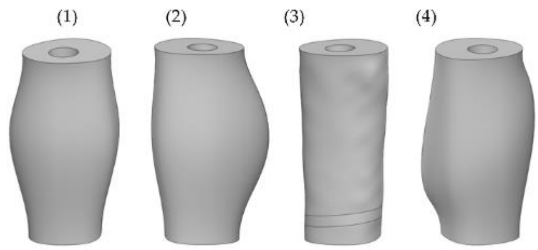

Fig. 2. Four different callus shapes used in this study: (1) Fusiform, (2) Medially fusiform, (3) Cylindrical and (4) Asymmetric.

The isotropic homogenous linear material model was used in this study; material properties of tissues were taken from literature. Material properties of bone tissues were prescribed as follows: cortical bone E = 17 000 MPa and μ = 0.3, trabecular bone E = 800 MPa, μ = 0.3. Material properties of the callus tissues were prescribed as follows: soft tissues E = 10 MPa and μ = 0.167, bone in different stages of consolidation E = 1000, 3000 and 6000 MPa and μ = 0.3. Distraction intramedullary nail and fixation screws are made from titanium alloy Ti6Al4V with material properties E = 113 800 MPa and μ = 0.342.

All DOF on both condyles and intercondylar fossa were set to zero. The model was loaded with two static forces applied on femoral head F_H and trochanter major F_T. Three sets of force values were used to simulate different loading of the limb during the healing process corresponding to 20, 60 and 100 % of body weight (BW).

For the simulations, the ANSYS 18.1 software was used. Model of geometry was discretized using SOLID186 and SOLID187 elements, contact surfaces were created using CONTA174 and TARGE170 elements. Contact behavior between the nail parts and the bone and the nail parts and the screws was prescribed frictional with frictional coefficient 0.01. Connections between the screws and the bone and between the bone parts were defined as bonded.

3. Results and discussion

Von Mises stresses in the nail components were compared. In the nail itself there were significantly higher stresses in model with cylindrical and asymmetric callus shape in comparison to fusiform and medially fusiform callus shape. Also stresses in proximal screws were higher for cylindrical callus shape. Von Mises stresses in distal screws were significantly lower than stresses in other parts and there were small differences between callus shapes.

The influence of the level of the consolidation of the callus was investigated through the von Mises stresses in the nail under loads of partial and full weight-bearing. Maximum von Mises stresses in variant with material properties of callus for soft tissues were 533 MPa for 60 % of BW and 896 MPa for 100 % of BW which exceeds the yield strength of Ti6Al4V (890 MPa [6]). Von Mises stress in nail in variants with bony callus material properties were approximately six times lower both for partial and full weight-bearing.

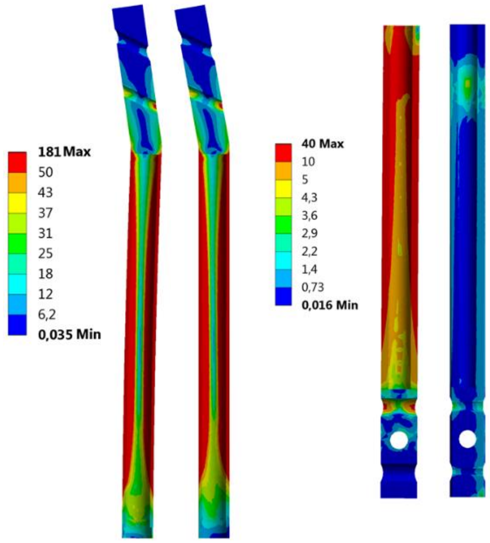

Fig. 3. Results: von Mises stress [MPa] in nail parts.

4. Conclusions

Results show significant influence of callus shape on stresses in the nail components. The variant with cylindrical callus shape shows highest stresses in nail and the variant with fusiform shape shows lowest stresses in nail.

Full weight-bearing in the early stages of consolidation results in high stress in the nail body.

References

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