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NUMERICAL ANALYSIS OF FRACTURED FEMUR WITH INTERNAL OSTEOSYNTHESIS

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Abstract: *The internal osteosynthesis method of the thighbone diaphysis allows use of some different types of devices in dependence on complexity and a type of the diaphysis fracture. The aim of this project is a numerical stress analysis in case of two types osteosynthesis plates applied to two different thighbone diaphysis fractures. We simulated incidents, when a pacient's broken leg was too early however fully treated and his thighbone did not begin to recovery yet. In these extreme incidents the whole stresses are carried by the plates. The modeling and calculations was done using FEM software ANSYS Workbench.*

Keywords: ***Biomechanics, Internal osteosynthesis, Femur, Finite element method, ANSYS Workbench***

1. Introduction

This paper disserts about numerical analyses of two internal osteosynthesis methods used in fractured human thighbone therapy. The aim is a comparison of stress distribution in two types of osteosynthesis plates applied to two types of the thighbone diaphysis fractures, oblique and wedge, ones which represent the most common fractures of the thighbone diaphysis caused by light traffic accidents. In the project we analysed 5 models: a virtual model of unbroken thighbone, virtual model of an oblique fractured thighbone with wave plate implementation, virtual model of wedge fractured thighbone with wave plate implementation, virtual model of oblique fractured thighbone with straight plate implementation and virtual model of wedge fractured thighbone with straight plate implementation.

2. Virtual models

The virtual models used in our analyses were made up by the fractured thighbone, two types of plate with cortical screws and cortical filler in case of the wave plate. All models were imported or created in ANSYS Workbench (fig.1).

2.1. Thighbone

The original `*.x_t` format of 470 mm tall left thighbone virtual model is provided by author (Dr. Marcello Papini, University Ryerson, Toronto, Canada) for noncomercial use. This model was imported to ANSYS Workbench DesignModeler where we modified a volume of the cancellous bone and made diaphysis fractures. A form of the cancellous bones inside both epiphyses of the femur were greatly simplified.

The thighbone diaphysis fractures used in our thesis represent the most common fractures of the thighbone diaphysis which have been caused by light traffic accidents- maximum impact speed was 25km/h (Drábek, 2009).

2.2. Plates and screws

The virtual model of the 230 mm tall wave plate was created in ANSYS Workbench DesignModeler in the base of the original `*.stl` model provided for this project purposes by its producer, ©Litos

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company. Our virtual model represented a little simplified contrary to original geometry especially use of cylindrical screw holes in our model. The real use of the wave plate internal osteosynthesis is related with implementation of the cortical filler between the wave-middle part of the plate and femur diaphysis. We used a simple filler of cuboid design in our analyses.

The straight plate virtual model is based on our wave plate model and has not any real template. This plate was made up by straightening wave plate middle part because of the objective stress distribution comparison between the plate with wave and the same plate without wave.

Analogous to screw holes were created all virtual models of cortical screws. We designed cylindrical screws according to their litos dimension template with the lenght agreed to robustness of the femur diaphysis and the diameter of model cylindrical screws corresponded to outer diameter of the litos original screws.

Fig. 1: Complete four virtual models of fractured femur diaphyses with internal osteosyntheses

2.3. Finite element model

We compromised mesh quality in dependence on sophistication of parts of our model systems between hardware requirements to numerical analysis and precision of results. Our models consisted of 28 000 to 37 000 elements (size of elements: 2.5- 8mm). The finite element model was done in ANSYS Workbench Mesher. The femur, plates and screws were meshed by solid tetrahedron elements. The cortical filler was meshed by cuboid elements.

2.4. Material properties

Our models contained four types of materials. There were a material model of a cortical bone, cancellous bone, *Titanium Grade 1* for plates and $TiAl_6V_4$ for cortical screws. We used the homogeneous linear isotropic mechanical properties for all used virtual models because of simplifying and agility of the analyses. There was need to know two mechanical characteristics: Young's modulus and Poisson's ratio (tab.1).

2.5. Initial conditions and loads

The thighbone was loaded by force of 2500N that occurred on a proximal side of the thighbone head. A vector of the force occurred in axis (Z axis) intersected the center of the femur head on the proximal side and the center of distal epiphysis. We used the support of distal parts of both condyluses that allowed free displacement in ortoghonal plane (represented by X axis and Y axis) to the force vector (represented by Z axis). Similar to the real experiment, we allowed a rotation around Z axis in our analyses.

In our analyses, were used three types of contact types. First contact type (in ANSYS Workbench called *Bounded*) ensuring compagination of joined parts was used in cases of appositions of plates to

Tab. 1: Material properties

Material	Young's modulus [MPa]	Poisson's ratio [-]
Cortical bone	17600	0.25
Cancellous bone	350	0.25
$TiAl_6V_4$	115000	0.34
Titanium Grade 1	103000	0.34

screws, screws to diaphyses parts of the damaged thighbone, for appositions of the wave plate to the cortical filler and for joints of cancellous bone to the cortical bone. The second contact type called *frictional* was used for appositions of proximals to distals faces of the fractured thighbones and for diaphyses to the cortical filler contacts in cases of the wave plate use. This contact type allows frictional sliding of contact faces (cortical bone to cortical bone) with friction coefficient equal to 0.15 (Landor, 2010). The last used contact type, *Frictionless*, allowed sliding of contact faces without friction. For simplification of all analyses, we used this contact type in cases of appositions of plates to the thighbone diaphyses.

3. Validation of virtual thighbone

There was required to validate our virtual model of the thighbone before the main numerical analyses of fractured thighbones with internal osteosynthesis. This task proceeded per experiments (Jírová et al.,1989) which contained stress values at medial and lateral side of a loaded real human thighbone. We used identic initial conditions and loads for this publication for unbroken thighbone validation and for next other analyses.

During the validation (fig.2), we analysed and compared stress values in 13 points at lateral diaphysis side and stress values in 13 points at medial diaphysis side of our virtual model and the most corresponding human 470 mm tall thighbone (Jírová et al.,1989).

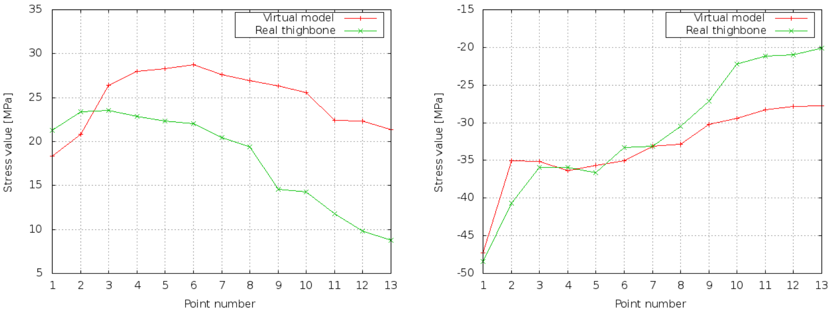

Fig. 2: Graphically compared stress results: lateral side- tensile stress (left graph), medial side- compression stress (right graph)

The stress results in graphs (fig.2) pointed at some diferences between a real human thighbone and our virtual model. These differences were at first caused by different geometry structure of a real thighbone and our virtual model especially by lenght of thighbone neck, at second by different robustness of the cortical bone of diaphyses parts, at third by different conception of a cancellous bone and finally the results could be different due to the finite element quality of our virtual models.

4. Results

Results of stress values on the undamaged thighbone were sufficiently comparable with each other for us to continue in numerical analyses of damaged thighbones with internal osteosyntheses. This project's aim was focused on numerical comparison of marked tensile stress values at screws and the wave plate contrary to the straight plate implemented to the fractured thighbone (by oblique and wedge fractures). We observed the stress results at plates, screws and contact faces of fragmented thighbones, safety factor of the cortical bone and relative deformations of both fragmented parts of the fractured thighbone.

Firstly analysed magnitude represented the screws and plates tensile stress distribution. The specific type and form of the oblique fracture influenced the stress distribution more than in the case of wedge fracture because the oblique faces of fracture allowed a sliding of proximal part in distal part of the fractured thighbobe. This fact caused redundant straining of the last screw in proximal part and especially first screw in distal part of the fractured thighbone. The results with use of the wave plate showed lower stress values (almost half) than with the straight plate. The stress results in the case of the wedge fractured thighbone diaphysis showed almost equal stress distribution along all screws and screw holes in both cases of the used plates.

Secondly a high value of the loading force caused mutual contacts of the proximal to distal parts of the fractured thighbones and mutual contacts of the fractured thighbones to plates. Therefore there was necessary to analyse the compression stress on these faces. In all analyses, we registered the higher compression stress values on the contact faces of the proximal parts of the fractured thighbone. The stress results in case of the wave plate, oblique fractured thighbone combination showed more than half stress result values contrary to use of the straight plate again.

The last analysed magnitude was the safety factor of the cortical bone. Safety factor had been bearing to compression stress on the contact faces of the model described in the last paragraph. This magnitude is characterised by ratio of ultimate compression strenght to the Equivalent (von-Mises) stress of the cortical bone, used 124 MPa (Valenta et al., 1985). The results in cases of the fractured thighbones with both types of plates were not positive. We registered the vaules of safety factor less than limit value 1 in cases of all analysed samples of the fractured thighbone with internal osteosyntheses. The most affected areas in cases of models with the wedge fractures were located at the contact faces of proximal parts of the fractured thighbones. In case of samples with oblique fracture the most damaged areas were located on lateral sides of proximal parts of the thighbone under central parts of the plates. These presented areas of the cortical bone had been probably more destructed.

5. Conclusions

The aim of this project was to compare the stress results at loaded virtual models of fractured thighbones with internal osteosyntheses. We focused mostly on the tensile stress on plates and screws, compressive stress on contact faces of fractured parts of the thighbones (proximal and distal part) and finally on the safety factor of the cortical bone. We registered better ability of the wave plate to stress distribution in all our analyses. Evidently lower values of the tensile stress in case of the analysed loaded oblique fractured thighbone with the wave plate implementation contrary to straight plate. Also the compression stress analyses showed more favorable results for wave plate osteosynthesis than use of the straight plate. Finaly, the wave plate allowed less destruction of the cortical bone than the straight plate.

Acknowledgments

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