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FEM SIMULATION OF HEADLESS SCREW

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Abstract: *There are many ways for osteosynthetical treatment of broken bones via fixation. One of them is internal fixation by headless screw, which causes desired compression of bone fragments. In cooperation with medics and industry, FEM simulation (i.e. stress, deformation) was done for prototype of headless screw for 5th metatarsus. Simulations were based on experiment and are followed by other simulation methods too. The aim of this research is to describe basis of issue, define mechanical dependences in headless screws and assessment of headless screws. According to the results, the headless screws can be applied in orthopaedics treatment of fractures.*

Keywords: Biomechanics, Headless Screw, FEM, CT images, Stress deformation states, 5th metatarsus.

1. Introduction

Internal fixation via Headless (Herbert) compression screws is advocated as the main primary treatment for 5th metatarsal fractures. However, the ideal headless screw has not been determined yet. Hence, this article deals with the Finite Element Method (FEM) analysis of headless screw. The FE analysis of headless screw was solved in cooperation with industry (MEDIN a.s., CZ) and medics (University Hospital in Ostrava and University of Ostrava, CZ). The whole problem was solved using Mimics software (CT preparation of bone input data) and FEM (Hypermesh, Optistruct and Hyperview sw). The prototype of headless screw Ti4.0/1.4x30/75 was used for osteosynthetic treatment of broken bone (5th metatarsus). According to surgical procedure of implantation, the headless screw in a broken bone was exposed to tensile loading. Acquired FEM results are in good agreement with prior experiments, analytical and stochastic solutions (Bajtek et al., 2020 and Šimečková et al., 2018). Hence, according to the biomechanical results of modelling, the headless screws can be applied in orthopaedics for treatment of fractures.

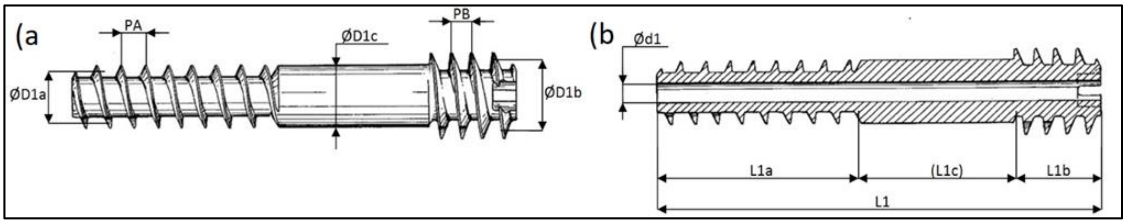

Fig. 1: Dimensions of headless screw (a headless screw; (b cross- section of screw.

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2. Method

Prototype of headless screw Ti 4.0/1.4x30/7 was used for this specific case of fracture of 5th metatarsus (Perry et al., 1992 and Šimečková et al., 2018), see Fig. 1. Basic dimensions are written in Tab. 1.

Tab. 1: Basic dimensions of headless screw Ti 4.0/1.1x30/7.

Dimensions of headless screw Ti: 4.0/1.1x30/7, producer MEDIN a.s.				
Length [mm]	L1	L1a	L1b	L1c
	30	7	4	19
Mean diameter [mm]	D1a	D1b	D1c	D1
	3.3	4.7	2.5	1.4
Thread pitch [mm]	PA		PB	
	1.1		0.9	

Application (implantation) of headless screw is shown in Fig. 2. There is description of osteosynthetic treatment of fracture of 5th metatarsus (Maňák et al., 2012 and Haspl et al., 2018). Firstly, Kirschner wire is drilled into bone. This wire helps to implement cannulated headless screw, which will cause the compression of both bone fragments.

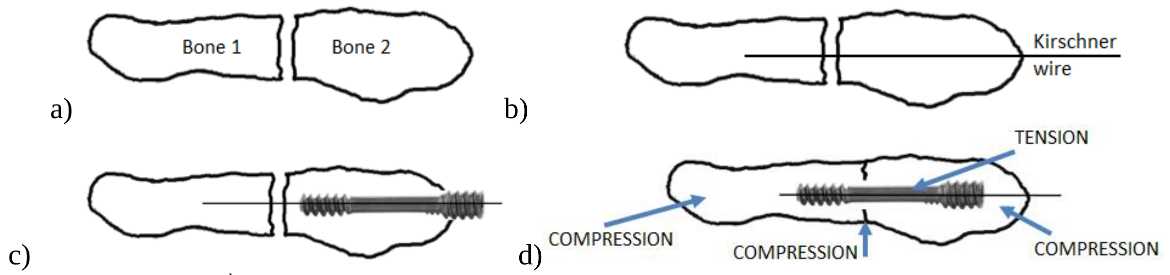

Fig. 2: a) Broken 5th metatarsus; b) Drilling of Kirschner wire into 5th metatarsus; c) Application of cannulated headless screw; d) Tightening of headless screw and compression of bone fragments.

Real material properties of 5th metatarsus were obtained from CT scans (anatomy of an old man) and used as input parameters for FE analysis. Mimics software was used for processing of CT scans.

Hence, there is selected and separated bone with FE mesh in Fig. 3. According to the density of bone (i.e. Hounsfield units nonlinear evaluation), there are chosen 100 different elastic material properties in volume of 5th metatarsus, which are obtained from real bone in CT scans. These material properties are used in FE smulations. Minimal value of modulus of elasticity E_{min} = 93.52 MPa and maximal value E_{max} = 18548.30 MPa, see Fig. 3. Partially isotropic and homogeneous material is considered in 5th metatarsus.

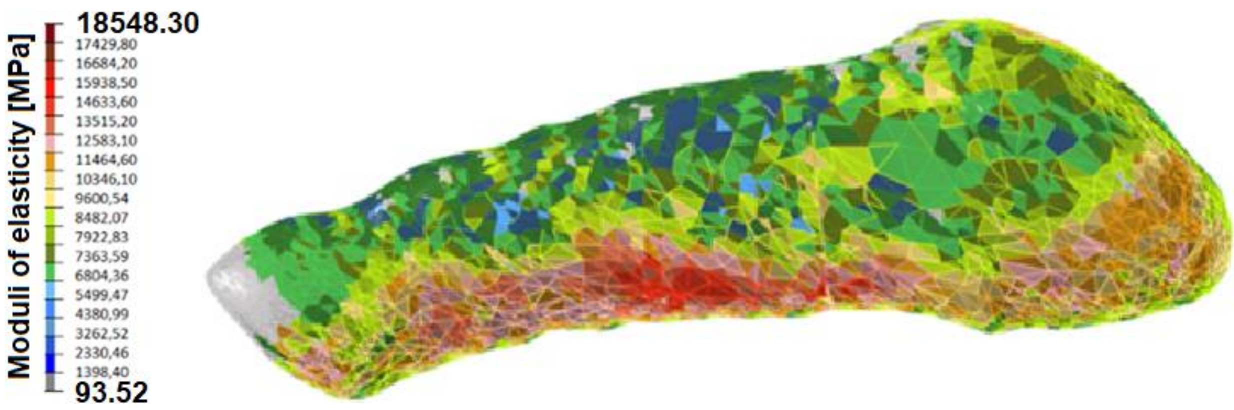

Fig. 3: Generated mesh of finite elements on 5th metatarsus with distribution of modulus of elasticity in volume.

Isotropic and homogeneous material is considered for headless screw, which is made of Ti6Al4V. Material data of headless screw Ti 4.0/1.4x30/7 are written in Tab. 2.

Tab. 2: Material data of simulated headless screw Ti 4.0/1.4x30/7.

Modulus of Elasticity E [MPa]	Poisson's Ratio [1]	Yield Stress Re [MPa]
110000	0.31	920

Preprocessing of FE simulation was performed in Hypermesh software. For this case, simplified headless screw was used (basic geometry without threads). Total of 464 500 volume elements were created on headless screw geometry (mostly hexa elements). There is 0.2 mm average size of elements. According to (Bajtek et al.,2020 and Šimečková et al.,2018), the goal was not to study the thread of screw but the screw-bone interaction. However, the simplified screw-bone interaction is sufficient and it is in good agreement with analytical approach and experiments (i.e. influence of thread can be neglected).

The prerequisite for tightening bone fragments to each other is based on the different thread pitch of the headless screw (Čada et al., 2017 and Šimečková et al., 2018). It means thread pitch PA [mm] must be greater than thread pitch PB [mm], see Fig. 1. When bones are in close proximity and headless screw is implemented, then displacement Δs [mm] of bone fragments comes from rotation of screw by turn value n [1]. The displacement Δs causes compression in bone and tension in headless screw and is used as one of boundary conditions in FE simulation. Hence, $\Delta s = n \cdot (PA - PB)$. There is turn value $n = 2.5$ turns, which is verified value from experiment (headless screw in porcine bones). Tightening delay λ [1] and slipping turn value n_0 [1] must be also considered. Ideal value from experiment is $\lambda = 0.3$ turns. Final Δs counts with $n = n_0 \cdot (1 - \lambda)$. According to the mentioned measurements and analytical approach, $\Delta s = 0.35$ mm, which is applied on 5th metatarsus fragments as boundary condition.

For more information about boundary conditions and FE (mechanical contacts, prescribed displacements, tightening etc., type of FE elements), see reference (Čada, 2017; Bajtek et al., 2020 and Šimečková et al., 2018).

3. Results

For FEM simulation, Optistruct solver was used. Displacement of bone fragments Δs causes extension of headless screw 0.27 mm, see Fig. 4. All results are displayed via Hyperview software.

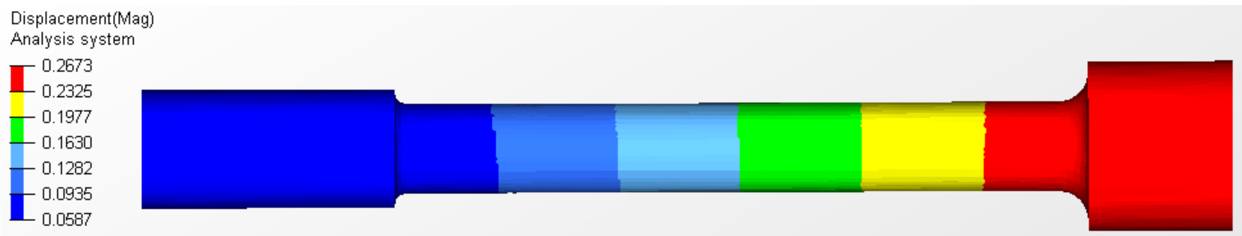

Fig. 4: Displacement (extension) of headless screw [mm].

Fig. 5: Axial normal force NF [N] in headless screw.

Axial normal force in headless screw is caused by its extension. This normal force $NF = 1520.5$ N, see Fig. 5. Acquired NF is in good agreement with analytical and stochastic approach and experiments, see (Bajtek et al., 2020 and Šimečková et al., 2018).

The maximum values of equivalent von Mises stress in headless screw are located in screw shank, see Fig. 6. Maximum values of stresses are lesser than yield limit of screw.

The goal was to study headless screw and therefore, the analyses of stresses in bones are not exposed in this article. However, stresses in bones were small.

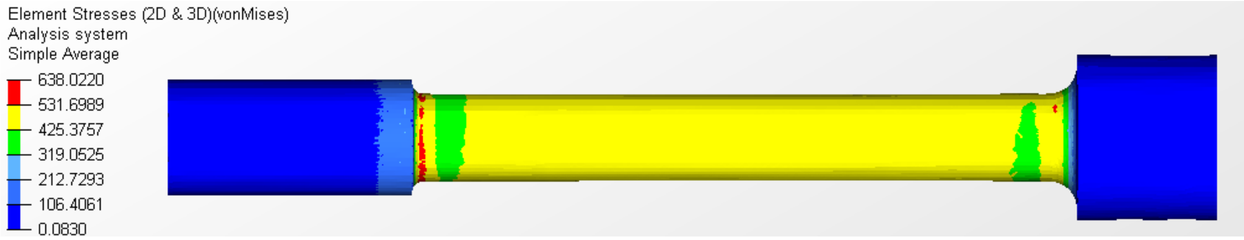

Fig. 6: Headless screw - von Mises stress distribution [MPa].

4. Conclusion

Stress-deformation states, in the prototype of headless (Herbert) screw implanted in a human broken 5th metatarsus, were made using FE analysis. FE analyses were performed in cooperation of VSB - Technical University of Ostrava, University of Ostrava, Medin, a.s. and University Hospital of Ostrava.

The acquired dependencies of displacements, internal axial forces and stresses in headless screw and 5th metatarsus fragments are in good agreement with analytical, stochastic and experimental approaches, see (Bajtek et al., 2020 and Šimečková et al., 2018, Wandrol et al., 2013). According to the results, the prototype of headless screw Ti 4.0/1.1x30/7 can be applied for medical treatment of bone fractures.

All simulations were done as a part of the PhD. study at the Department of Applied Mechanics at the VSB – Technical University of Ostrava (Bajtek et al., 2020). The results of the simulations will be published in the doctoral thesis of the main author.

Another possible biomechanical approaches, for treatment and investigation of human fractures, are presented in (Kalová et al., 2019 and Maršálek et al., 2017).

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