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PROBABILISTIC ANALYSIS OF SCREWS FOR FEMORAL NECK FRACTURES

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Abstract: *This contribution describes a non-traditional application of the probabilistic approach for the evaluation of implants in biomechanics, trauma surgery, and orthopedics. Particularly, it focuses on the osteosynthesis of the proximal femur (collum femoris). The application of the Winkler elastic foundation as a surrogate for the interaction between the collum femoris and femoral/cancellous screws combined with the Monte Carlo (SBRA) method), seems to be a modern trend in the biomechanical evaluation of implant reliability. Here, we present a biomechanical probabilistic assessment based on mechanical stress and deformation of screws in bone is presented.*

Keywords: Collum femoris fracturae, Winkler elastic foundation, Osteosynthesis, Femoral/cancellous screws, Stochastic approach, Biomechanics, Traumatology, Orthopaedics.

1. Introduction

Femoral neck fractures (FNF) are typical intracapsular fractures posing significant clinical problems; see (Timkovič el al., 2021; Klíma and Madeja et al., 2018) and (Torabi et al., 2022). Application of femoral screws, so-called cancellous lag screws produced by the MEDIN a.s. company (Nové Město na Moravě, Czech Republic), is one of the possible minimally invasive FNF treatment methods. These screws are made up from either stainless steel or Ti6Al4V materials. This report focuses on the biomechanical deformation and strength analyses and a probabilistic reliability assessment of femoral screws using the Simulation-Based Reliability Assessment (SBRA) Method; see (Frydrýšek et al., 2018; Frydrýšek et al., 2022; Klima et al., 2017), and (Marek, et al., 2003). The goals of this article are to use a “fully” probabilistic reliability assessment in the branch of biomechanics and traumatology as a new way of assessment and support of clinical testing of new implants.

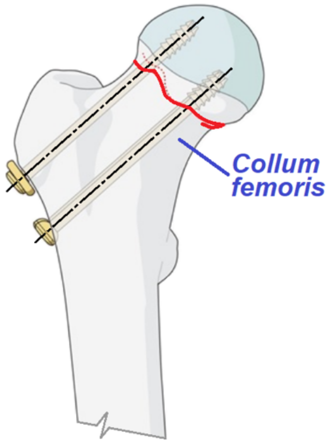

Fig. 1: Application.

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2. Stochastic model

From the biomechanical perspective, the femoral screws in FNF can be described and solved as 2D beams on the Winkler elastic foundation based on the 2nd order theory and described by a set of differential equations $EJ_{\mathrm{ZT}}\dfrac{d^4v_i}{dx_i^4} - N\dfrac{d^2v_i}{dx_i^2} + kv_i = 0$, where $i = 1,2,3$ and v_i are deflections, x_i are coordinates, N is the normal (axial) force, EJ_{ZT} is the bending stiffness and k the elastic foundation stiffness. Forces F_1 and F_2 are loadings with different variabilities on each screw; see (Frydrýšek et al., 2018; Frydrýšek et al., 2022).

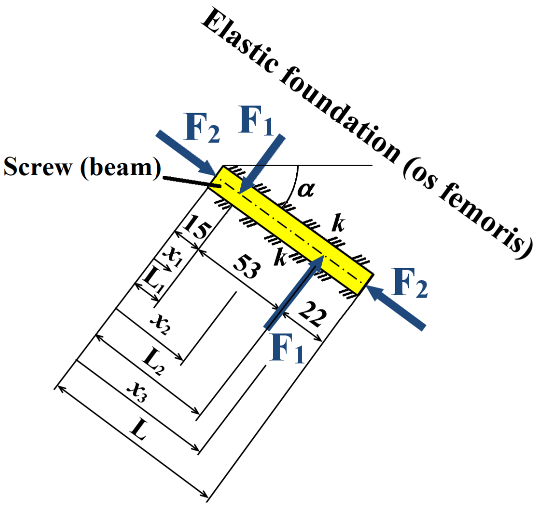

Fig. 2:A single femoral screw as a beam.

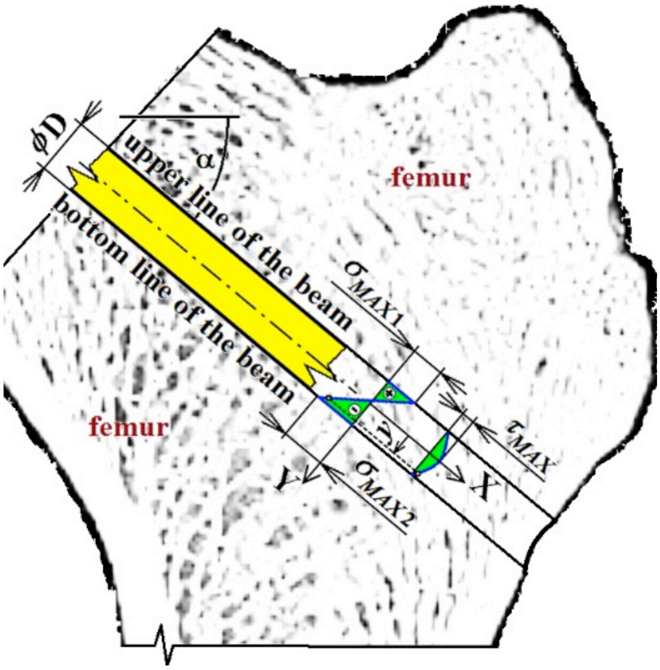

Fig. 3: Stress evaluation.

The maximal normal stress values σ_{MAX} and maximal shear stress τ_{MAX} are calculated for bending & compression loadings; see Fig. 3.

A typical bending moment distribution M_{Oi} is presented in Fig. 4; see (Frydrýšek et al., 2018; Frydrýšek et al., 2022).

For the stochastic simulations (direct Monte Carlo Method, Anthill sw), six stochastic inputs and eight deterministic inputs were used; see, for example, Fig. 5.

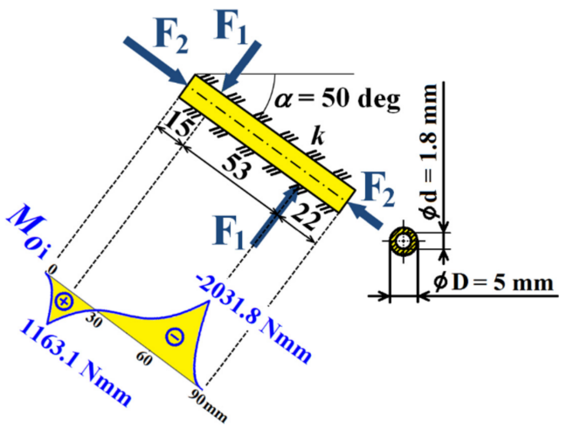

Fig. 4: Example of stress evaluation.

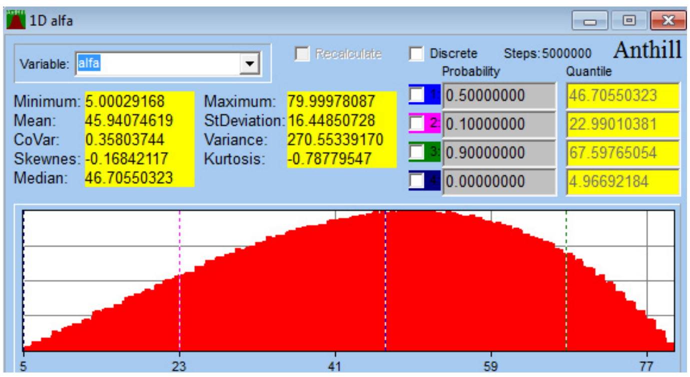

Fig. 5: Example of probabilistic input - histogram of cancellous screw angle $\alpha \in 5$ to 80 deg.

Materials, dimensions, loading, and other information are presented in (Frydrýšek et al., 2018; Frydrýšek et al., 2022).

3. Results

The probabilistic (stochastic) solution was performed for 5×10^6 pseudo-random Monte Carlo simulations. One example of the calculated output histograms, i.e., calculated maximal global compression stress σ_{MAX2} in a femoral screw, is presented in Fig. 6.

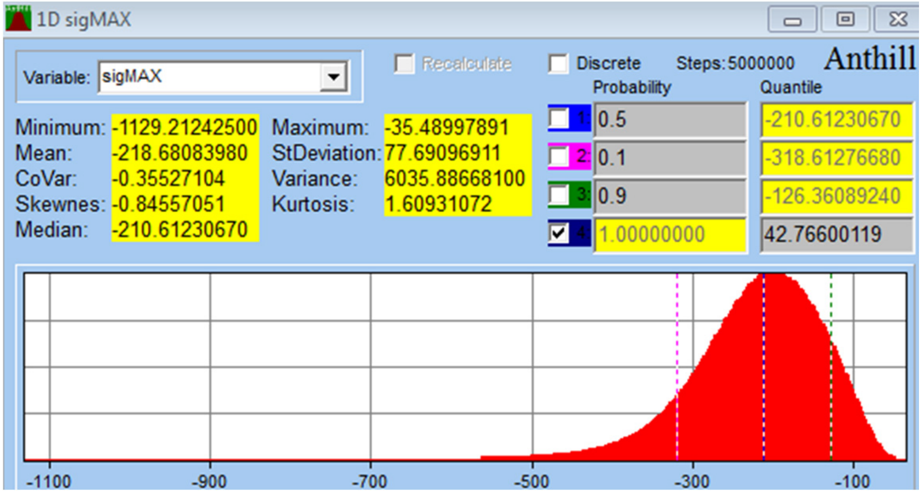

Fig. 6: Histogram of the calculated maximal stress $\sigma_{MAX2} \in \langle -1129.2;\ -35.5\rangle$ MPa.

By SBRA Method, the reliability function RF is defined as $RF = \mathrm{Re} - |\sigma_{MAX2}|$, where Re is yield stress of a femoral screw material, see Fig. 7.

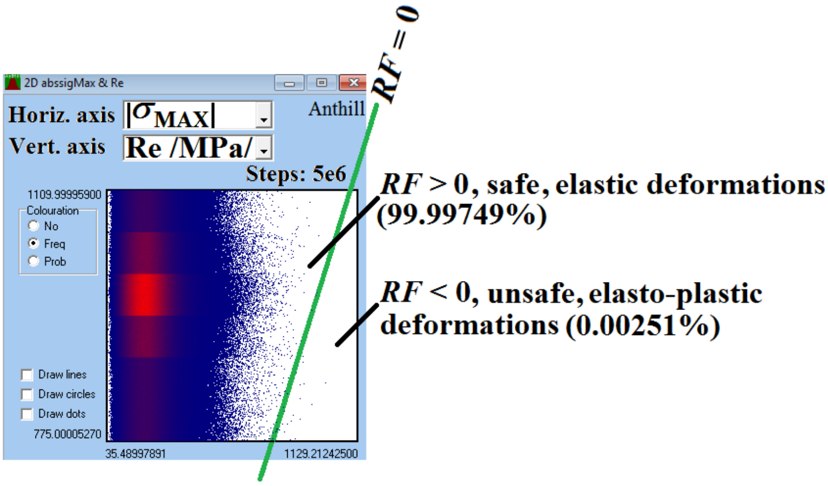

Fig. 7: Dependence of $|\sigma_{MAX2}|$ on Re – 2D histogram of the calculated reliability function RF and probability evaluation for a cancellous screw (Anthill software, cannulated screw, Ti6Al4V material).

The presented results for a cannulated cancellous screw inserted in the collum femoris give the biomechanical failure probability of $2.51\times10^{-5} = 0.00251\%$. The calculated probability is caused mainly by the overloading of the collum femoris including events such as falls etc. (i.e., it accounts for mechanical/biomechanical problems as well, not only for medical problems of unsuccessful treatment). In the future, the 3D beam model, additive dynamic effects, new bone material description, other types of elastic or inelastic foundations, femur as a composite, or optimizations in femoral screws and other medical treatments can be applied too; see (Kompiš et al., 2011; Losertová et al., 2020; Kubíček et al., 2019; Šotola et al., 2020; Tvrdá, 2014) and (Klíma and Novobilsky et al., 2018).

4. Conclusions

Here, a new simple probabilistic (stochastic) 2D model focused on femoral screws for FNF treatment was developed in accordance with methods presented by Frydrýšek et al. (2018) and Frydrýšek et al. (2022). This method is an application of a beam on an elastic Winkler foundation theory, along with the 2nd order theory of small deformations in which bending and compression loadings were applied. Compared to the Finite Element Method, the presented model is characterized by a quick and easy solution and high variability of possible screw insertion positions. Using the Monte Carlo Method (Anthill sw), the biomechanical probabilistic reliability assessment of the undesirable situation (i.e. the probability of plastic deformations in femoral screws) was established, yielding the probability of 2.51×10^{-5}. The undesirable situation is caused mainly by a combination of pathological changes in *os femoris* and "unexpected" overloadings, such as falls. This article is just a report about our work. Hence, detailed information are presented in references (Frydrýšek et al., 2018) and (Frydrýšek et al., 2022).

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