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Biomechanical analysis of tibia – double threaded screw fixation

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ABSTRACT

Purpose: The aim of the work was determination of biomechanical characteristics of a tibia – double threaded screw system with the use of finite element method.

Design/methodology/approach: Geometrical model of the tibia was worked out on the basis of data from computer tomography of real bone. Geometrical model of the double threaded screw was prepared in ANSYS v. 11. Meshing was realized with the use of SOLID95 elements, applied in analyses of volumes. The model was loaded with forces in the range F = 100-2000 N.

Findings: Initial biomechanical analysis, carried out with the use of finite element method, showed usefulness of the analyzed form of the double threaded screw made of Ti6Al4V alloy in fractured tibia treatment.

Research limitations/implications: Due to applied simplifications of the tibia – double threaded screw fixation model, the analysis results should be experimentally verified in laboratory conditions.

Originality/value: The obtained biomechanical characteristics of the tibia – double threaded screw system ($u = f(F)$, $\sigma_{max} = f(F)$) are the basis for selection of degree of strain hardening of the applied metallic biomaterial and optimization of geometrical features of the analyzed form of implant. Appropriate selection of mechanical properties and geometrical features of the implant is the main factor determining a stability of the fixation.

Keywords: Numerical techniques; Finite Elements Methods; Biomaterials; Mechanical properties

METHODOLOGY OF RESEARCH, ANALYSIS AND MODELLING

1. Introduction

Double threaded screws are new solution of tissue reconstructions in orthopaedics (stabilization of metaphysis fractures of long bones and spinal fractures) and dentistry. The most often the screws are applied in stabilizations of metacarpus and metatarsus fractures. The matter of these solutions is application of two threads of diverse diameter, assuring stabilization of bone fragments with the use of physiological effects [1-7].

Clinical experiences show that double threaded screws applied in orthopaedics and traumatology indicate many favorable features connected with both biomechanical quality of fixations and clinical results, especially with reference to minimization of tissue traumas.

The presented work is continuation of authors' research in the field of numerical analysis of diverse implants with the use of finite element method [8-14]. The main aim of the work was determination of biomechanical characteristics of a tibia – double threaded screw fixation.

2. Methods

Stabilization of an oblique tibia fracture with the use of the double threaded screw, mainly applied in phalangeal fixations, was analyzed in the work. On the basis of anthropometric data, modification of screw's geometry was proposed – Fig. 1.

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2.1. Numerical model

Geometrical model of the tibia was worked out on the basis of data from computer tomography of the real bone. In order to carry out calculations the following Young modulus of the bone equal to E = 18600 MPa and Poisson ratio υ = 0.4 were applied [15]. Geometrical model of the double threaded screw was prepared in ANSYS v. 11. The following material properties, corresponding with the Ti-6Al-4V alloy were established: E = $1.06 \cdot 10^5$ MPa, Poisson ration υ = 0.33 [15]. Geometrical model of the tibia – double threaded screw system was presented in Fig. 2.

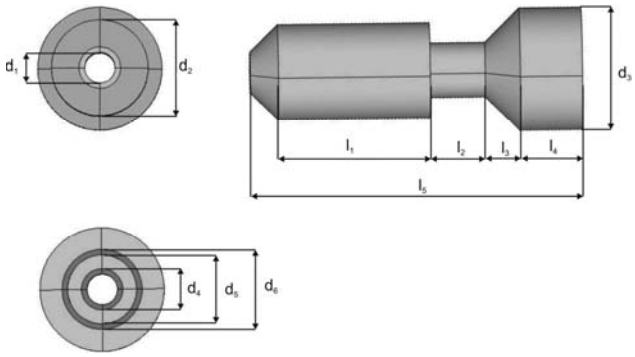

Fig. 1. Geometrical model of the double threaded screw

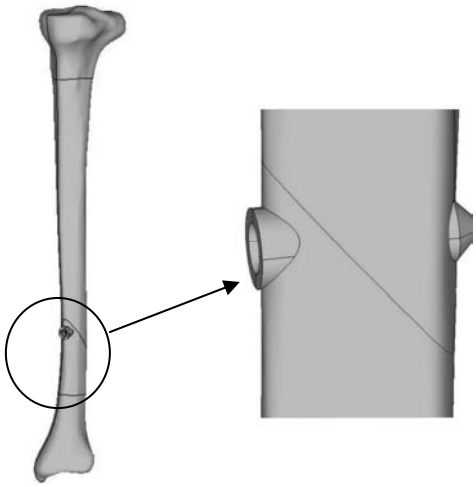

Fig. 2. Geometrical model of the tibia – double threaded screw system

On the basis of the geometrical models, finite element meshes were generated – Fig. 3. Meshing was realized with the use of SOLID95 elements applied in analyses of volumes. The scope of the analysis included determination of displacements, strains and stresses in:

- healthy tibia,
- elements of the tibia – double threaded screw (made of Ti-6Al-4V alloy) system.

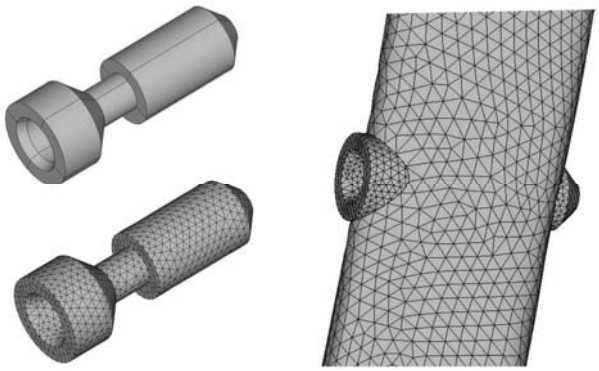

Fig. 3. Meshed model

2.2. Boundary conditions

In order to carry out calculations it was necessary to evaluate and establish initial and boundary conditions which imitate phenomena in real system with appropriate accuracy. The following assumptions were established:

- distal fragment of tibia was immobilized (all degrees of freedom of surface nodes were taken away). It enabled displacements of the proximal fragment, blocking possible rotation,
- proximal fragment of the tibia was loaded with forces in the range F = 100-2000 N with increment of 100 N,
- in the distal part of the tibia the oblique fractures was simulated (45°), enabling implantation of the double threaded screw according to the operating technique.

Stresses and strains obtained in the analysis are reduced values according to the Huber – Misses hypothesis.

3. Results

3.1. Tibia

The aim of this analysis was determination of influence of bone loading on stress distribution in the individual areas of the bone. Maximal stresses are localized in the distal, metaphysic part of the bone and for the maximal loading F = 2000 N are equal to σ_{max} = 66 MPa. The obtained stresses did not exceed the strength of a bone (≈ 160 MPa) [15]. Example stress distribution in elements of the healthy bone, caused by the loading from the range F = 100-2000 N was presented in Fig. 4. The analysis of the healthy bone allowed to asses the area of maximum effort.

3.2. Tibia – double threaded screw system

Results of the analysis carried out for the tibia – double threaded screw system are presented in Figs. 5-9. On the basis of the analysis it was affirmed that maximum displacements of in screw's elements, calculated for different loadings were in the range u = 0.16-1.54 mm – Fig. 5.

Fig. 4. Stresses in the healthy tibia loaded with the force: a) 100N, b) 1000N, c) 2000N

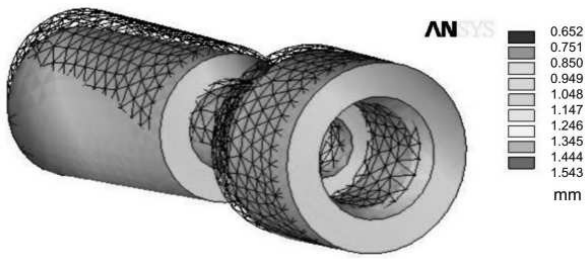

Fig. 5. Displacements in the double threaded screw loaded with the force F = 2000 N

Analysis of stresses caused by the axial loading of the bone with the implanted screw showed that maximum reduced stresses were localized in the transition area between threads (change of external diameter) as well as in areas of direct contact between the screw and the bone fragments. Values of the reduced stresses, for the applied loading from the range F = 100-2000 N, were in the range σ = 1-1321 MPa – Fig. 6. In the areas of maximum stresses also maximum strains were observed. The maximum strain did not exceed the value ε_{max} = 1.4 %.

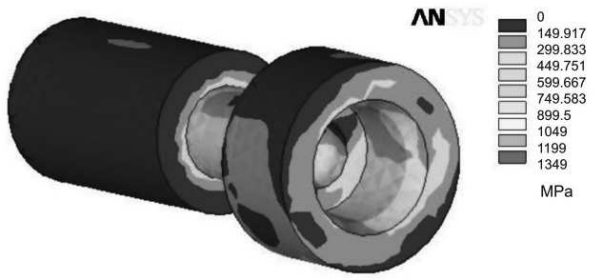

Fig. 6. Reduced stresses in the double threaded screw loaded with the force F = 2000 N

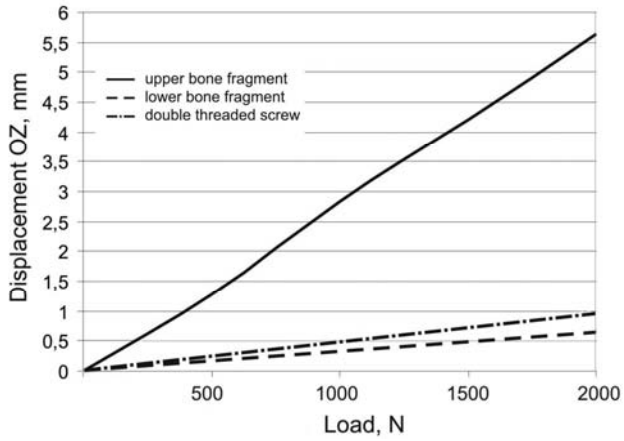

Fig. 7. Displacements in the OZ axis as a function of the applied loading

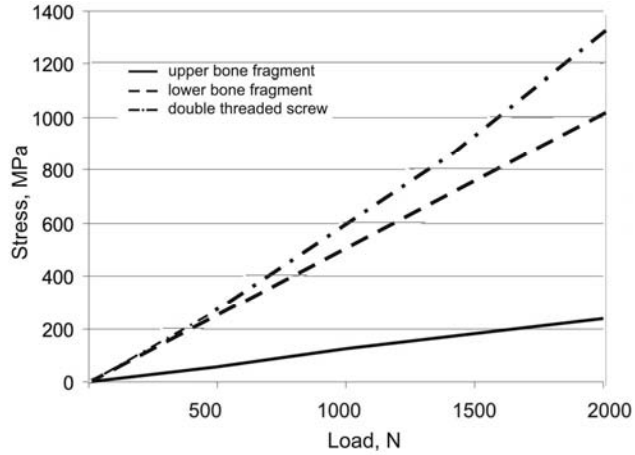

Fig. 8. Maximum reduced stresses as a function of the applied loading

The analysis allowed to determine biomechanical characteristics of the tibia – double threaded screw system. The characteristics show relations between displacements in the OZ axis (bone's long axis) and maximum reduced stresses as a function of the applied loading – Fig. 7 and 8. Displacements of the analyzed system in the fracture gap calculated along the OZ axis, for the applied force F = 2000 N, were presented in Fig. 9.

4. Conclusions

The work presents results of biomechanical analysis of the tibia – double threaded Ti-6Al-4V screw system. The analysis was carried out with the use of finite element method. Displacements, strains and stresses in the system's elements were calculated. The oblique fracture of the tibia was localized in the distal part of the bone. This area was selected on the basis of the initial analysis of the health tibia. The aim of the initial analysis was determination of the maximum strain (effort) region – Fig. 4. The obtained results confirm clinical data about the most frequent fracture localizations.

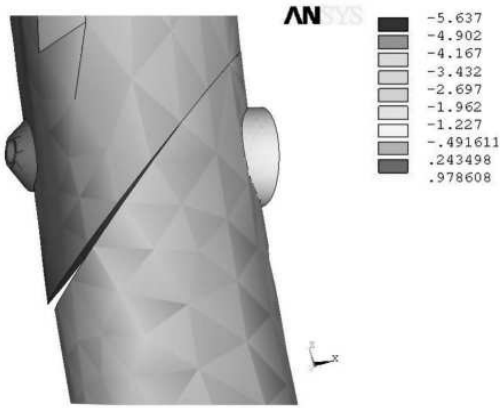

Fig. 9. Displacements in the fracture gap in the OZ axis for the loading equal to 2000N

In order to carry out calculations it was necessary to evaluate and establish initial and boundary conditions which imitate phenomena in real system with appropriate accuracy. The analyzed model was loaded with forces from the range F = 100-2000 N. In fact, during stabilization of the fracture in time of rehabilitation such high loadings do not appear. The established range of forces purposed determination of the biomechanical characteristics in the widest possible range (from so called "biomechanical silence" – directly after the operation, to a physiological, dynamic loading).

The obtained results allowed to determine biomechanical characteristics of the analyzed system (u = f (F), σ_{max} = f(F)) – Fig. 7 and 8. The results are the basis for selection of degree of strain hardening of the applied metallic biomaterial and optimization of geometrical features of the double threaded screw. Appropriate selection of mechanical properties and geometrical features of the implant is the main factor determining a stability of the fixation. Due to applied simplifications of the tibia – double threaded screw fixation model, the analysis results should be experimentally verified in laboratory conditions.

Acknowledgements

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