Journal of Achievements in Materials and Manufacturing Engineering
VOLUME 26
ISSUE 2
February
2008

Numerical analysis of femur in living and dead phase

A. Krauze*, M. Kaczmarek, J. Marciniak
Division of Biomedical Engineering,
Institute of Engineering Materials and Biomaterials, Silesian University of Technology,
ul. Konarskiego 18a, 44-100 Gliwice, Poland
* Corresponding author: E-mail address: anita.krauze@polsl.pl

Received 27.12.2007; published in revised form 01.02.2008

Analysis and modelling

ABSTRACT

Purpose: The paper presents numerical analysis results of stresses and displacement in femur in a living and a dead phase. The aim of the work was to present the influence of different mechanical properties of bone tissue on the obtained results. The appropriate selection of the properties ensures correct results, comparable with the results obtained in real conditions.
Design/methodology/approach: The analysis was carried out on the femur of adult. The influence of the selected properties on the results of numerical analyses was analyzed. In order to carry out calculations, 3 models of diverse mechanical properties (Young modulus of bone in a living phase E_I=17260 MPa, Young modulus in order to carry out a comparison analysis $E_{II.}$=18600 MPa and Young modulus of bone in a dead phase E_{III}=20202 MPa) were selected.
Findings: The analyses showed the difference in displacements and reduced stresses depending on the selected mechanical properties. The analyses show that in order to select the appropriate stabilization method, mechanical characteristics of bone structures should be considered as viscoelastic. Quality of bone structures depends on individual features (genetic, hormonal, metabolic and circulatory factors).
Research limitations/implications: The limitations were connected with simplification of numerical model of femur as well as with the selected boundary conditions.
Practical implications: The obtained results can be useful in clinical practice. They can be applied in selection of stabilization methods or rehabilitation as well as in describing the biomechanical conditions connected with type of bone fracture obtained from medical imaging.
Originality/value: Stress – displacement characteristics of femur for different degrees of demineralization, obtained from the numerical analyses were presented in the work.
Keywords: Numerical techniques; Biomechanical analysis

1. Introduction

Numerical analyses of biomaterial – tissue systems are commonly used to select mechanical properties of implants applied in a bone system. Results of these analyses are useful in mechanical properties selection of biomaterials and implants. But it is to be remembered that these results are connected with preselected mechanical properties of bone tissue. Knowledge connected with mechanical and structural properties of tissues, especially hard tissues, is essential in order to carry out correct numerical and experimental analyses. From the biomechanical point of view, determination of hard tissues structure is crucial. Knowledge of the properties is essential, both in diagnosis of bone system illnesses as well as in selection of implants' mechanical properties. Stiffness of a bone – implant system is particularly important.

Young modulus of bone changes with age. It is related with demineralization of bone. Increase of bone porosity is caused by different factors, for example osteoporosis which is characterized by decrease of bone mass, disordered microarchitecture of bone and, as a consequence, decreased mechanical strength. These factors lead to increase of fracture risk.

Literature data indicate that maximum mass of bone tissue is reached in adults (approximately 30 years old). In this age, metabolism of bone is stabilized and osteoblastic and osteoclastic processes are in equilibrium. After the age of 40 intensification of osteoblastic effects is reduced and demineralization processes start to dominate that causes loss of bone mass. In this way, about 0.5-1.0% of minerals pre year are lost. However, in osteoporotic bone the loss is in the range 2-5% per year. That is why the osteoporotic bone is porous and brittle [1].

Table 1.
Mechanical properties of fresh and desiccated cortical bone [2]

Bone	Living phase	Dead phase
Young modulus of bone, MPa		
Femur	17 260	20 202
Tibia	19 040	20 590
Fibula	18 540	21 080

Knowledge of material data and mechanical properties of bone tissue (tensile, bending and torsional strength) allows to evaluate stresses and strains in bones and select mechanical properties of implants [1]. Comparison test results of mechanical properties of fresh and desiccated cortical bone are presented in Table 1 [2].

2. Material and methods

Femur of adult man of length l=455 mm, shaft diameter D=28 mm and diameter of canal d=12 mm was applied in the research. Numerical model of the femur was worked out in Laboratorio di Technologia dei Materiali, Instituti Ortopedici Rizzoli [3]. In order to carry out numerical analyses, the model was modified with the use of Ansys 11.0.

Next stage of the analysis was meshing of the geometrical model. The meshing was carried out with the use of the SOLID95 finite element. The obtained numerical model consisted of 45 300 elements – Fig. 1

3 viscoelastic models were applied in the analysis. Calculations were carried out for the femur of different mechanical properties corresponding with the living (fresh bone) and the dead (desiccated bone) phase. In order to obtain more adequate results, a intermediate values were also selected. The following mechanical properties were selected [7]:

- for the living phase (model 1) – E_I=17260 MPa, υ=0.3
- for the intermediate phase (model 2) – E_{II}=18600 MPa, υ=0.3
- for the dead phase (model 3) – E_{III}=20202 MPa, υ=0.3.

In order to carry out the numerical analysis the following boundary conditions were established:

- lower part of the femur was immobilized (all degrees of freedom of nodes on external surfaces of condyles were taken away),
- the models were loaded with the following forces [2, 4, 5]:
  - resultant of reduced body mass (0,81G) and abductor muscle force R (head of femur),
  - Muscle reaction forces M (gluteus band),
  - Muscle reaction forces of iliotibial band T.

Loading scheme of the femur was presented in Fig. 2.

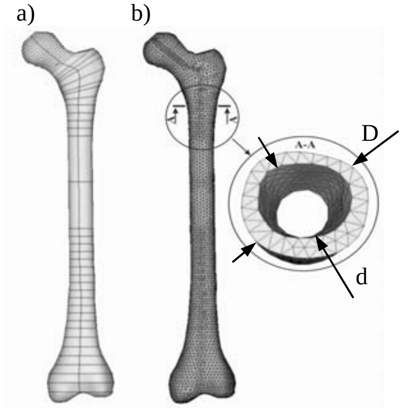

Fig. 1. Model of femur: a – geometrical, b – discrete

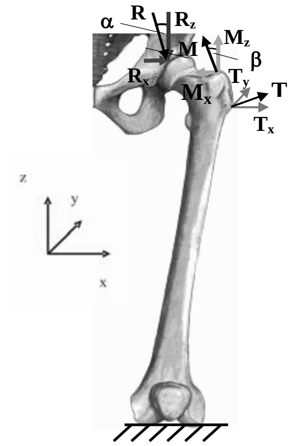

Fig. 2. Loading scheme of model: α=16°, β=21°

Table 2.
Maximum displacements distribution in the plane ux, uy and uz and stress distribution [4]

Model	Displ. ux, mm	Displ. uy, mm	Displ.uz, mm	Stress, MPa
1	-13.14	1.20	-3.99	49.4
2	-12.19	1.11	-3.70	49.4
3	-11.23	1.02	-3.41	49.4

Displ. – displacement

3. Results

Results of the numerical analysis for different mechanical properties were presented in Table 2 and in Figs. 3-7. Obtained displacements and stresses are reduced values according to the Huber-Misses-Henck hypothesis [6-16].

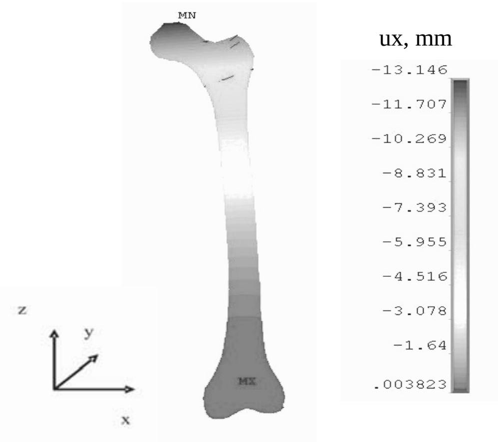

Fig. 3. Displacements distribution in the bone in the frontal plane (ux) - model 1

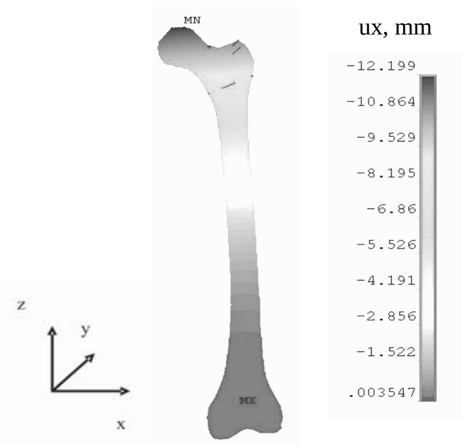

Fig. 4. Displacements distribution in the bone in the frontal plane (ux) - model 2

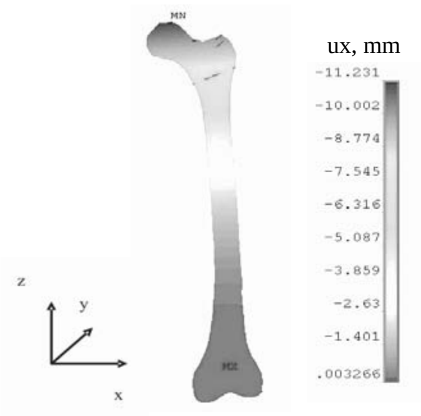

Fig. 5. Displacements distribution in the bone in the frontal plane (ux) - model 3

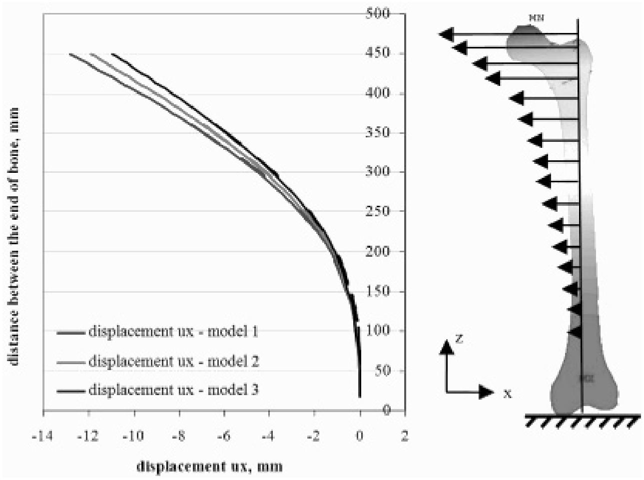

Fig. 6. Diagram of displacement distribution in the frontal plane (ux)

The obtained results indicate differences in displacement and stresses depending on mechanical properties of the analyzed bone models.

The results indicate that the displacements appear mainly in the frontal plane (ux). The highest values (for all the models) are observed in femur head region. It was also observed that increase of the Young modulus caused the decrease of displacements in the transversal plane. It is caused by higher stiffness of the bone. The highest value of displacements was observed in region of the femur head, which for the model 1 was equal to ux=-13.14 whereas the lowest value was observed in the model 3 (dead phase) - ux=-11.23. The lowest values of displacements were observed in the sagittal plane (uy) and along the bone axis (uz). For the model 1 the values were equal to uy=-0.01 mm and uz=1.54 mm (condyles region) and uy=1.20 mm and uz=-3.99 mm (femur head region). For the model 2 the displacements were in the range 0.01-1.11 mm and uz=-3.70-1.43 mm. For the model 3 the displacement values were the lowest and were in the range uy=-0.01-1.02 mm i uz=-3.40-1.32 mm.

a) b)

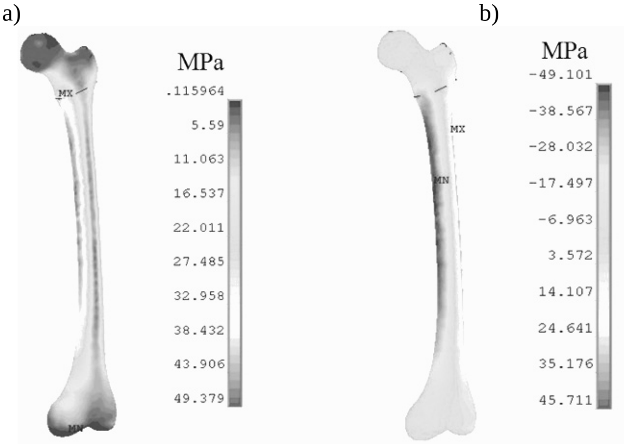

Fig. 7. Stress distribution in the bone – a, compression and tensile stresses – b

Stress analysis of the femur (for different mechanical properties) showed that stresses, for the all analyzed bone models, are similar and did not exceed the value of 50 MPa. The applied loading generated tensile stresses in the external region of the bone and compression stresses in the medial region.

4. Conclusions

The numerical analysis was carried out in order to evaluate displacements and stresses in femur models of different mechanical properties. Knowledge of the problems is essential, both in diagnosis of bone system illnesses as well as in appropriate selection of fixation system. It is known that these conditions must be correlated with geometry and mechanical properties of bone (dependent on a bone structure).

On the basis of the established, appropriate boundary conditions and obtained results, it can be stated that:

- displacements of femur depend on its mechanical properties,
- value of Young modulus significantly influences the displacements,
- higher value of displacements for all axes (x, y, z) was observed for the bone in the living phase, because of the higher elasticity in comparison with the bone in the dead phase,
- mechanical properties of bone (Young modulus) do not exert an significant influence on stresses,
- the obtained results can be used in further biomechanical analysis of femur – implant fixation.

References

[1] M. Nałęcz, Biocybernetics and biomedical engineering. 2000, Biomechanics and rehabilitation engineering, Academic Publishing House EXIT, Warsaw, 5 (2004) 1-42, 291-304 (in Polish).

[2] R. Będziński, Engineering biomechanics. Selected issues. Publishing House of Wroclaw Technical University, Wroclaw 1997, 13-45 (in Polish).

[3] http://www.tecno.ior.it/VRLAB/researchers/repository/BEL_repository.html#std2_3

[4] M. Krykant, The correlation of the structure and mechanical properties of the bone tissue in it's animated and lifeless phase, Master thesis, Silesian University of Technology, 2006 (in Polish).

[5] J. Marciniak, W. Chrzanowski, A. Krauze, Intramedullary nailing in osteosynthesis. Printing House of the Silesian University of Technology, Gliwice, 2006.

[6] W. Walke, Z. Paszenda, J. Filipiak, Experimental and numerical biomechanical analysis of vascular stent. Proceedings of the 13th International Scientific Conference on "Achievements in Materials and Mechanical Engineering AMME'2005', Gliwice-Wisła, 2005, 699-702.

[7] W. Walke, Z. Paszenda, J. Filipiak, Experimental and numerical biomechanical analysis of vascular stent. Journal of Materials Processing Technology 164-165 (2005) 1263-1268.

[8] F. Jaroszyk, Biophysics – students textbook Medical Publishing House PZWL, Warszawa, 2001, 413-429.

[9] W. Chrzanowski, J. Marciniak, Biomechanical analysis of the femoral bone-interlocking intramedullary nail system. Proceedings of the 18th European Conference on Biomaterials, Stuttgart, 2003, 154-160.

[10] J. Marciniak, W. Chrzanowski, M. Kaczmarek, Biomechanical analysis of femur-intramedullar nail system with the use of finite element method. Biomaterials Engineering 30-33 (2003) 53-55.

[11] W. Chrzanowski, J. Marciniak, Biomechanical and biomaterial conditions in intramedullar osteosynthesis. Proceedings of the 13th Scientific Conference on "Materials, Mechanical and Manufacturing Engineering", Gliwice-Wisła, 2005, 319-324.

[12] A. Krauze, J. Marciniak, Numerical method in biomechanical analysis of intramedullary osteosynthesis in children. Proceedings of the 11th International Scientific Conference CAM3S'2005 "Contemporary Achievements in Mechanics, Manufacturing and Materials Science". Gliwice-Zakopane, 2005, (CD-ROM).

[13] M. Kaczmarek, J. Marciniak, Issues of plate stabilizers for osteosynthesis Proceedings of the 13th Scientific Conference on "Materials, Mechanical and Manufacturing Engineering", Gliwice-Wisła, 2005, 325-334.

[14] M. Kaczmarek, J. Marciniak, J. Szewczenko, A. Ziębowicz, Plate stabilizers in elastic osteosynthesis. Proceedings of the 11th International Scientific Conference CAM3S'2005 "Contemporary Achievements in Mechanics, Manufacturing and Materials Science". Gliwice-Zakopane, 2005, (CD-ROM).

[15] A. Krauze, J. Marciniak, Numerical method in biomechanical analysis of intramedullary osteosynthesis in children. Journal of Achievements in Material and Manufacturing Engineering 15 (2006) 120-126.

[16] J. Okrajni, M. Plaza, S. Ziemba, Validation of computer models of an artificial hip joint. Archives of Materials Science and Engineering 28/5 (2007) 305-308.