The study of stress state in the case of different types of fixation of the stem prosthesis in the femoral bone

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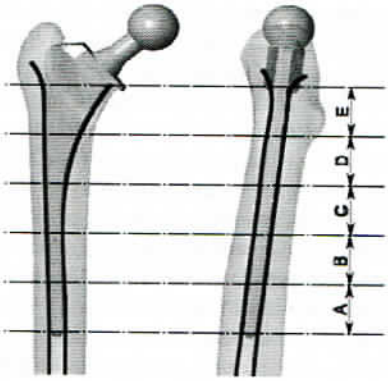
Key words: *arthroplasty, stem of hip endoprosthesis, femur, stress state, finite element method*

1. Introduction

Total hip arthroplasty is now one of the most effective methods of treatment for patients with severe diseases of the hip joint [1]. However, despite the wide range of designs in hip arthroplasty, a major problem is associated with instability of the endoprosthesis, development of stress–shielding syndrome and fracture of the structure due to the mismatch between the shape of the implant and the medullary canal of the femur. These drawbacks are most common in the case of dysplastic coxarthrosis with large anatomical deviations of the femur. Therefore, in the process of designing implants, efforts should be aimed at solving the aforementioned problems. Currently one of the most effective and informative methods of studying problems of biomechanics is the method of mathematical modeling, and in particular the finite element method (FEM).



Area of fixation	Types of fixation
E	by collar
DE	by collar
CDE	metaphyseal
BCDE	metaphyseal– diaphyseal
ABCDE	full
ABCD	diaphyseal–metaphyseal
ABC	diaphyseal
AB	diaphyseal
A	diaphyseal

Fig. 1. Types of fixation of cemented femoral stem of the prosthesis in different zones of the medullary canal of the femur.

2. Materials and methods

One of the most important stages in the development of endoprostheses is biomechanical rationale of performance and reliability of implants. In this case, the carried out fem analysis allowed to estimate the stress state of the "femur – implant" system. The influence of conditions fixation of the implant at various levels of the medullary canal of the femur to the stresses occurring in the bone structures and the implant under the action of functional loads have been illustrated (Fig. 1). Three-dimensional model of the femur has been developed based on the results of computer tomography. Parameters and dimensions of geometric models of the femoral components corresponded to their real size and shape. From the literature data [2], the value of the components of load (in the case of a human body weight of 700 N) was equal to: Fx=520 N; Fy=177H; Fz=1854H, where: X stands for the front axis; Y–axis is sagittal; and Z is the vertical axis. Titanium alloy (Ti6Al4V), having a modulus E = 110 GPA and Poisson ratio 0.3, has been selected as the material for the physical properties of the femoral component

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of the hip endoprosthesis. This choice is based on the fact that the elasticity of titanium is close to that of the femur. Nonhomogeneous material distribution has been modelled based on the linear relation between bone density and the Hounsfield unit (HU) from the CT scan. For the correlation between elastic modulus and density, the relationship $E = -388.8 + 5925\rho$ has been used [3].

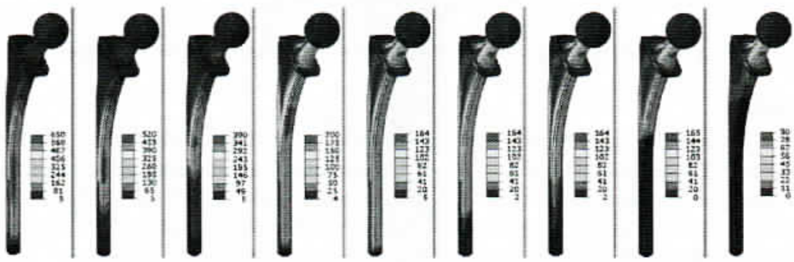

Fig. 2. Distribution of equivalent stress on the medial side of the foot prosthesis in the case of different types of fixation.

3. Results

The carried out calculations showed that the stress state of the stem prosthesis occurs due to the bending moment in the frontal plane and compression forces in the axial direction (Fig. 2). The value of the compressive stresses arising on the medial side in the bone and the endoprosthesis is larger than the value of the tensile stresses arising on the lateral side in the bone and the endoprosthesis. Values of stresses on lateral and medial sides varies by about 8%. Depending on the type of fixation of the implant the maximum equivalent von Mises stress in the implants varies in the range from 650 to 90 MPaDuring calculation, it has been found that for the design of stem endoprosthesis of the hip joint, the most dangerous diaphyseal fixation type are: A, AB, ABC. In the latter case, the stresses vary from 650 MPa to 390 MPa. These type of implants, and fixations are unacceptable, since stresses occurred in the body stem exceed the limit of durability of the metal, and such loads may imply fatigue fracture of the stem. For other types of fixation, our results have shown that the maximum stresses in the elements of the assembly have not exceeded the durability limit of the material, and all elements of the system have been in a state of elastic deformation. Therefore, metaphyseal, metaphyseal-diaphyseal, diaphyseal-metaphyseal types of fixation and fixation using collar guarantee the required safety margin.

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