The rational choice of the thickness of the cement mantle in total hip arthroplasty

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Key words: *total hip replacement, bone cement, femur, stress state, finite elements method*

1. Introduction

Since 1959, thanks to the work of Sir John Charnley, numerous researchers working in the field of arthroplasty fixation employed implants with bone cement. This fixation of the prosthesis has advantages in case of wide medullary canal of the femur, osteoporosis, bone dysplasia and the consequences of mechanical injuries of the hip. In addition, this fixation allows to reduce rehabilitation period and to load the prosthetic limb in a shorter period of time. However, the optimal thickness of the cement mantle to the present time is not defined [1]. Typically, the surgeon conducting an operation, selects the thickness of the cement mantle, based on his experience or on the experience of the co-workers. In this regard, the biomechanical rationale of the choice of optimal thickness of the cement mantle at the cement technique of hip replacement surgery is an important and urgent task, which will allow to improve the results of treatment and increase the durability of the prosthesis.

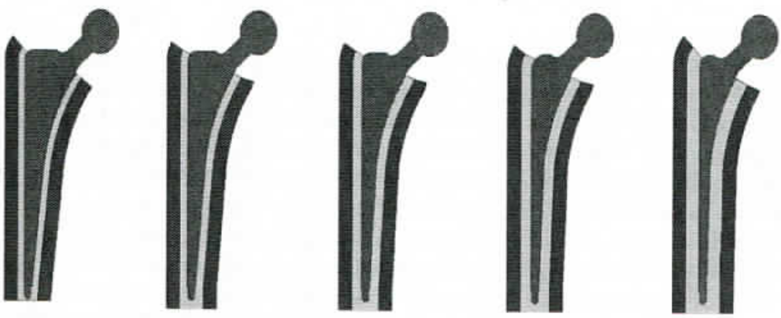

Fig. 1. A geometric model of the endoprosthesis of cement type of fixation with the thickness of cement mantle 1, 2, 3, 4, 5 mm.

2. Materials and methods

Numerical analysis of the stress state of system "bone-cement-implant" have been carried out using FEM (finite element method). Three-dimensional CAD models of the implants have been constructed from their respective manufacturers. Some options of installation stems implants of different sizes in the bone cement that fills the medullary canal of the femur have been considered. Due to the different size of the implant thickness, the cement mantle varied in the range from 5 mm to 1 mm. The stress components acting on the head of the prosthesis are taken as follows: Fx=362 H; Fy=224 H; Fz=1575 H [2], where: X – front axis;Y – axis is sagittal; Z – vertical axis. Stainless steel (316L), having a modulus E = 210 GPA and Poisson ratio 0.3, has been selected as the material for the physical properties of the femoral component of the hip endoprosthesis. Three-dimensional models of the femur using two-dimensional (2D) computed tomography (CT) datasets have been constructed. The heterogeneous material properties of the femur have been calculated based on the bone density values. The following relationship between the Hounsfield units (HU) of the CT scanner and apparent density

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(ρ) have been taken: $\rho = 1 + 7.185\times10^{-4}\times HU$, Young's modulus is: $E = -388.8 + 5925\times\rho$. A total of 20 different bone materials have been assigned for the heterogeneous models.

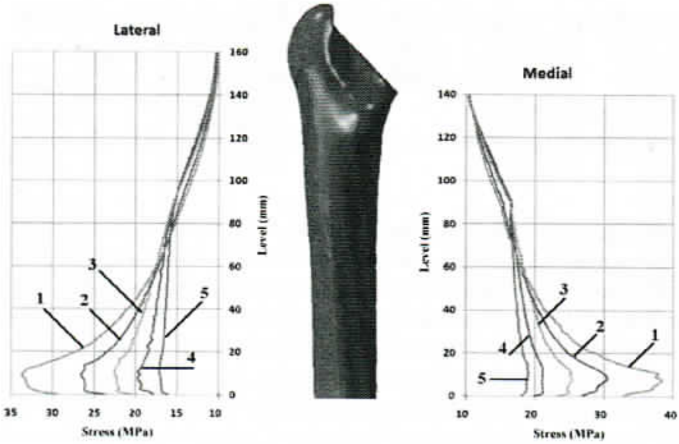

Fig. 2. The distribution of maximum equivalent stress on the medial and the lateral side of the femur in the case of different thicknesses of the cement mantle. (Curve number corresponds to the thickness of cement mantle in mm.).

3. Results and conclusion

The results showed that the maximum stresses in the bone are localized on the medial side in the area of the distal end of the stem prosthesis. In the case of a cement mantle thickness of 1 to 3mm, there is a high concentration of stresses on the medial side in the contact zone of the distal stem with the cortical bone (Fig. 2). This can lead to the development of stress–shielding effect and hypertrophy of the femur. Increasing the thickness of the cement mantle causes a decrease of stresses in the distal part of the bone. In the case, when the thickness of the cement mantle ranges from 3.5 to 5 mm, the stress values (tensile) on the lateral side and stress values (compression) on the medial side of the bone are evenly distributed. In summary it should be noted that finite element analysis is a highly precise numerical method of analysis that allows the study of stress distribution in biological systems. However our study has some limitations within which our findings need to be interpreted carefully. First, we used only the load acting on the head of the endoprosthesis and the force acting from the muscles have not been taken into account. Secondly, it was not considered the effect of bone remodeling in the process of operation of the prosthesis. Thirdly, the connection between the bone cement and cement endoprosthesis has been taken as bonded-bonded, although in reality it has a more complex structure which varies in time. We believe that further investigation and collaboration with orthopedists surgeons will make this work more useful and valuable in the field of arthroplasty.

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