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Numerical and experimental analysis of the intact and implanted femoral bone under different loading scenario

Summary

This doctoral thesis is devoted to both numerical and experimental investigations of the intact and implanted human femoral bone subjected to different loading scenario. And although in the recent years significant progresses have been made in the development of total hip replacement, behavior of the femoral component of an endoprosthesis in relation to the type of its fixation in the bone is still not fully understood. For instance, if in certain areas of the implant the functional load causes stress which exceeds critical value (e.g., tensile strength, fatigue limit, etc.), then a destruction or plastic deformation occurs, which leads to partial or complete loss of functionality of the whole system. Also, after the installation, the implant may greatly influence the transmission of the load to the host tissue, what can cause excessive bone resorption at the bone-tissue interface and lead to the aseptic loosening or even bone fracture. Thus, to avoid the failure of surgery, numerical and experimental study can help in pre-clinical practice. That is why, the main goals of this study are both numerical and experimental study, in which the femoral strain, both before and after implantation was investigated using different methods.

During performed analysis, behavior of the femoral bone and the stem prosthesis is studied taking into account different types of prosthesis fixation in the medullary canal of the femur under the action of different functional loads. To analyse the considered biomechanical system, a three-dimensional model of a femur has been developed based on the computed tomography scans. The mechanical properties (distributions of Young's moduli) of the femur have been also found by using computed tomography data and the Hounsfield scale. The stress–strain state governing behavior of the femoral bone and the stem prosthesis has been estimated with the use of the finite element method in Abaqus software. During performed investigations different variants of femoral bone and implant were tested. Namely, behaviour of the femoral bone and the stem prosthesis has been investigated under the action of functional loads, and taking into account different types of prosthesis fixation in the medullary canal of the femur. To determine the best conditions for long-term functioning of the bone–implant system leading to improvement of treatment of patients, the standard strength analysis have been carried out. In the doctoral thesis, a finite element method coupled with a bone remodelling model has also been used to evaluate how different three-dimensional prosthesis models influence distribution of the density of bone tissue. In this case, the remodelling process began after the density field obtained from a computed tomography scans. Then, an isotropic Stanford model was employed to solve the bone remodelling process and verify bone tissue adaptation in relation to different prosthesis models.

The results obtained in this doctoral thesis can provide guidance and recommendations for selection of the optimal technique for femoral bone replacement, as well as can be useful for constructors for better developing of hip replacements, which will finally lead to increase quality of life of a patient after surgery. For instance, based on the obtained results, recommendations for the optimal thickness of the cement mantle in cemented hip arthroplasty are presented in this thesis.

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