Computer modelling of the microstructure of the trabecular bone fragments for the study of stress-strain state

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Abstract: The paper presents the computer models of the structure of the trabecular bone tissue. The approach to the construction of computer models of fragments of cancellous bone tissues was offered. The model fragment of the trabecular bone tissue was built based on the data of structure of the real bone fragments, taking into account the orientation of the trabeculae of bones, their length and thickness.

1. Introduction

The problems of mechanics arising during production of the bone implants are resolved on the basis of the investigation of the mechanics of bone tissue and comprise the development of the approaches and modelling techniques of their complex hierarchy structure, the estimation of the effective mechanical characteristics, the development of the basic requirements to the alternate materials of the implants regarding mechanics.

The bone is the bio composite material of the complex structural arrangement of components that determines the anisotropy of it mechanical properties [1-4]. “On each structural level a biological tissue may be considered as a composite material”, “The heterogeneity of the mechanical properties of bone tissue over the zones of tibia cross-section is caused by both the differences in structure and the heterogeneity of the biochemical composition.” [1]. “Mechanical properties of bones are largely determined by their microstructure.” [2]. “At the micron scale and above, bone tissue is a hierarchical composite.” “Reflecting the anisotropy of its microstructure, the elastic and strength properties of human cortical bone are anisotropic.” [3]. “This microstructural directionality gives trabecular bone anisotropy of mechanical properties.” “Thus, trabecular bone is classified from an engineering materials perspective as a composite, anisotropic, open porous cellular solid.” [4].

Any skeletal bone (macro level) is composed of the compact (cortical) and spongy (trabecular) bone tissue. The nanolevel of the bone tissue is the fibers consisting of a great number of collagenous fibrilllas and the associated hydroxyapatite crystals. The microstructure of the cortical bone tissue is a bunch of the structural elements, i.e. the osteons formed by concentrically interleaved bone layers with the different location focus of the collagen-mineral fibers [3]. The microstructure of the spongy bone is formed by the directed location of the trabeculae [3]. The direction of location of the collagen-mineral fibers of the osteons and trabeculae of the bone tissue varies depending on the anatomical location of the bone fragments while being determined by the effected load [1, 4, 5].

The purpose of the present research is the computer modelling of the spongy bone tissue fragments in view of their structural features determined by the anatomical location.
2. Computer modeling of the microstructure of the trabecular bone tissue

The model fragments of trabecular bone tissue are built on the basis of data of ellipses of structure of the real fragments of bone (Fig. 1), taken from literature [6, 7]. $H_1$ and $H_2$ are semiaxis of the ellipse of structure corresponding to the halves of lengths of main and secondary trabeculae; $\theta_H$ is the angle showing the direction of the ellipse of structure, i.e. the direction of location of the main trabeculae of the spongy bone tissue.

Figure 1. Images of the ellipses of structure corresponding to three different portions of the spongy bone tissue [7].
The trabecular node including the trabeculae, orthogonally located relative to each other, is considered as the structural unit of the geometric model (Fig. 2).

The trabecular node is built based on the parameters $H_1$, $H_2$, $H_3 = H_2$ and the values of the average thickness of the trabeculae [8].

![Figure 2. Trabecular node.](image)

The geometric model is built with use the trabecular nodes copying in three directions, given the angle $\theta_H$, in compliance with the ellipses of structure of natural bone fragments (Fig. 1).

Figure 3 shows the geometric models of the spongy bone tissue fragments with the different anisotropy of the structure corresponding to the ellipses of structure presented in Figure 1.

The developed approach allows building the computer models of trabecular bone fragments, in which the length and thickness of the main and secondary trabeculae may vary. These facts, and the consideration of the bone trabeculae direction by means of turn through $\theta_H$, distinguishes the presented models from the model [8] and allows to more closely replicate the microstructure of natural fragment.

In future it is planned to conduct the calculations of the stress-strained state of fragments of the spongy bone tissue. Similar calculations are needed to develop recommendations for the selection and establishment of mechanically compatible implants intended to replace the fragments of spongy bone in orthopedics.

3. Conclusions
The approach to the construction of computer models of fragments of cancellous bone tissues was offered. The model fragment of the trabecular bone tissue was built based on the data of structure of the real bone fragments, taking into account the orientation of the trabeculae of bones, their length and thickness.

The computer models of the fragments of structure of the spongy bone tissue are required to perform calculations of the stress-strain state, which analysis will allow development of the recommendations for creation of the mechanically compatible implants, ensuring the retention of the stress-strain state existing in the bone macrovolume during implantation.
Figure 3. The geometric models of the spongy bone tissue fragments.

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