Modeling of interactions between bone tissue and bone-substitute bioresorbable material

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1. Introduction
An application of bone-substitute materials becomes a common practice in orthopaedic surgery [1]. In the present paper we focus on a problem of integration of bioresorbable grafts with bone tissue. This is the final stage of bone healing after orthopaedic surgery and implantation and determines a quality of a graft. An important question that still waits for an answer is what are the optimal conditions and optimal graft micro-structure to assure its good integration with a bone and future effective replacement of bioresorbable material by a natural tissue[2-5].

2. Methods
A theoretical model proposed in this paper is based on several basic assumptions. We consider a mixture of a porous bone tissue and a porous artificial bioresorbable material. According to the next assumption sensor cells – osteocytes can be only located in a tissue. According to a local density of a strain energy and a density of osteocytes in a specific location an appropriate signal is created and transmitted to the surrounding actor cells – osteoblasts and osteoclasts. Their activities are proportional to the received signal from the neighbor sensor cells. The next important assumption states that an artificial material can not be synthesized by cells, it can be only resorbed in contrast to the tissue which can be both - resorbed and synthesized. The production or resorption of a material is dependent on a number of actor cells present in a given location. There exists an optimal porosity guaranteeing the largest density of cells. For low porosity there is no enough space available for cells and for a large porosity the available surface to which the cells are attached is very limited. These fundamental assumptions have been implemented in a computer program for numerical analysis of remodeling of a mixture bone-bioresorbable material. An analysis is done using finite element method and a set of remodeling equations. However before sophisticated analysis a simple one-dimensional case was examined. It is reported in a next section. More dimensional examples will be discussed in a full version of our paper.

3. Results
Simple numerical one dimensional example was considered in order to examine basic mechanisms responsible for changes in the vicinity of the interface between bone and graft material. We consider a bar composed of two porous materials – one half is a bone tissue (red) the other half is made of bioresorbable artificial material (blue), see Fig. 1. One end of a bar is immobilized and to the other a force is applied. In Fig. 1 following steps of remodeling are displayed. Two thin bars at the top of each stage represent distribution of biomaterial and bone respectively. The third thick bar represents a mixture of both materials and an amount of red and blue colors is proportional to the densities of each material. Light color represents large density and dark color – low density of a material. In this way we can follow the changes and see how does each fraction change the density. It should be noted that the synthesis of the tissue decreases porosity and this results in a smaller number of actor cells in this region. Another important observation is that the signal from sensor cells decreases with the distance and can be sensed only in the neighborhood of the osteocytes located in a tissue. The effect of bone remodeling and possible resorption of biomaterial depends significantly on the initial densities of both materials and a distance to which the signals from sensor cells can be distributed.
4. Discussion

In this paper a simplified model of remodelling of a system composed of natural bone tissue and bioresorbable bone-substitute material was proposed. This model describes a fundamental process present after initial post-surgery stage when the primary healing finished and bone cells start their normal activities leading to adaptation of bone to mechanical loadings. It follows from our preliminary investigations that such or extended models can be considered as a useful tool to examine the process of integration of bone graft and its possible replacement by a natural tissue. Presented numerical example illustrating general theory is formulated in one dimensional space and has no practical value. However examination of the model using one dimensional example brings many valuable information useful in explanation of basic mechanisms governing considered problem. In forthcoming paper we intend to present more complex numerical example as well as the results of animal tests to validate proposed model.

References