Numerical simulation of bone remodelling using two-scale FEM

T. Łodygowski¹, M. Wierszycki¹, K. Szajek¹, M. Nowak²

¹ Poznań University of Technology, Institute of Structural Engineering, ul. Piotrowo 5, 61-138 Poznań, Poland
² Poznań University of Technology, Department of Machine Design Methods, ul. Piotrowo 3, 61-138 Poznań, Poland

1. Introduction

The bone tissue is a material that changes in time and which is strongly heterogeneous [2]. These properties are reflected significantly in macroscopic behaviour of bones e.g. maxilla and mandible ones. On the other hand, the macroscopic behaviour of bone determines the internal strain state as a result of external loading which can be caused by ligaments, muscles and implants as well. The effective approach of numerical simulation of bone remodelling is crucial in meaning of biomechanical problems e.g. implants. Real application, e.g. simulation of bone remodelling around an implant, needs huge FE models. The presented two-scale modelling approach enables us to couple bone microstructure remodelling and macroscopic bone behaviour phenomena in order to simulate the evolution of material microstructure in an efficient way. This paper is focused on the FE modelling of bone microstructure remodelling phenomenon.

2. Methods

The proposed approach is based on a first-order computational homogenization technique. The coincidence of macro- and micro-model kinematics is done using uniform displacement and traction boundary conditions [3]. The micro and macro FE models are calculated in Abaqus code [1]. The computational homogenization procedure is driven by self-prepared manager which is coded in Python. This manager supports parallel execution of micromodels.

In the first step, a model of microstructure is divided into a number of substructures. Each substructure is closed within eight plains. The exterior elements of microstructure are tied to these plains. In the points where the plains cross one another, eight reference nodes are defined. For all substructures, stiffness matrices are calculated for elements built from reference nodes. All these matrices are stored in text files. Based on reference points and stiffness matrices of substructures, an FE macro model is created. Next, a linear static analysis is performed to find node displacement of each element/substructure. In the last and most important stage, for all substructures, remodelling of the microstructure is done. At first, reference node displacements are applied to the substructures. Based on strains, microstructure is modified iteratively. Chart-flow of the presented approach is illustrated in Fig. 1.

3. Results

The used remodelling algorithm bases on the trabecular bone surface remodelling which leads to optimization of the trabecular net in the bone ruled by the strain energy density [4]. This approach takes into consideration the real biological process of bone formation and resorption. The rebuilding process is done parallel for all substructures. For optimized substructures, stiffness matrices are calculated again and the procedure is repeated. The procedure is stopped if there are no meaningful changes in the micro structure.
4. Conclusions

In many biomechanical problems the bone remodelling phenomenon is crucial e.g. stress-shielding and bone-loss around implant [5]. The proposed two-scale modelling approach enables us to simulate the evolution of bone microstructure in an efficient way. Therefore, this method can be directly applied to simulate complex change of boundary conditions in case of dental implants as well. However, the proposed approach has several general significant advantages. The macroscopic behaviour of any heterogeneous material, not only bone, can be determined with no assumption of the constitutive relations. Simultaneously, arbitrary non-linear and time dependent material behaviour of microstructure can be taken into consideration. The proposed approach can be used for cases of complex loading paths, large deformations, and large rotations.

Acknowledgements: The results obtained in this work have been supported by the project R13 00 020/06 founded by the Ministry of Science and Higher Education. This help is acknowledged. Computations were partially done in Poznan Supercomputing and Networking Centre.

References