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A BIOMECHANICAL MODEL BASED ON A FE^2 APPROACH USING DATA FROM COMPUTER TOMOGRAPHY

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Summary. *The complex remodeling, growth, atrophy and adaptation process in living hard tissues with inherent microstructure like cancellous bones etc. is investigated in the present contribution. To keep the model as simple as possible size effects appearing in such materials are neglected allowing for the usage of standard commercial FE codes (e. g. LS-Dyna, ABAQUS), which have included a user interface for the material subroutine. To circumvent the formulation of complex phenomenological constitutive equations on the macroscale, which require the determination of a large number of material parameters by several independent and complex experiments, we adopt a numerical homogenization scheme connecting the micro- and macroscopical level. Thus, simple and efficient boundary value problems (BVPs) are solved on the microscale whereas the resulting stress on the macroscale is calculated by volumetrical averaging. Microscopic material parameters are accessible by inhomogeneous data derived from computer tomography (CT). Due to the applied homogenization procedure, initial and developing anisotropy is included in a natural way.*

1 MOTIVATION

With respect to the large amount of implants (in 1993 about 750 000 endoprothesis of the hip have been necessary worldwide, c. f. [1]) it becomes more and more important to understand and predict the remodeling process in bones. This process is caused by stiffness changes affecting the load case. Thus, it is the goal to develop a numerical model which predicts the states of interest (e. g. the density and stress distribution) during lifetime. These informations can be used to find an optimal shape of an artificial implant, to make decisions about an optimal fixation of the implant or to get hints, why some implants fail after a certain time, especially as osteoporosis is a frequent comorbidity in patients requiring joint replacement surgery. in case of ostheoporethic patients. The model includes patient specific data by considering CT data, which gives us information about the density distribution before surgery.

The basic idea of mechanically stimulated bone adaptation processes can already be found in works of Wolff [13] and Roux [12] in the 19th century. Most classical density-driven growth models, see e. g. Cowin & Hegedus [3], Beaupre & Carter [2], Nackenhorst [11], Kuhl [10], only consider the influence on the density distribution but effects concerning reorientation (bone fabric) are neglected.

2 NUMERICAL MODEL

From a mechanical point of view, the cancellous part of a bone is a cellular material. Thus, the microstructure is approximated by a Testing Volume Element (TVE) [9] consisting of 8 beam elements, cf. Figure (1). Anisotropic effects are included by allowing for each beam direction an independent beam thickness, resulting in an individual tension, shear and bending stiffness. It is assumed that the major deformation characteristics are reflected by this element.

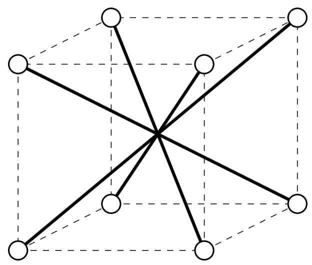

Figure 1: Testing Volume Element

For a BVP of practical relevance numerical simulations directly based on the microstructure are numerically very expensive due to the large amount of degrees of freedom (DOF) and therefore are not suited for clinical applications. Thus, in the present contribution we follow the so-called FE^2 concept [4, 5, 6, 7], which means that the BVP is formulated on the macroscale but microscopic information is included by attaching a TVE to each integration point of the macroscopic FE model. Thereby microscopic quantities of the TVE are transfered to the macroscale by a first order homogenization procedure and vice versa, i. e. a projection based on an inverse homogenization procedure. The approach has the advantage that the orientation of the TVE is still free. Formulating appropriate evolution equations for this orientation it becomes possible to capture the effects of reorientation. Furthermore, evolution equations for the thickness change of the single beam elements are formulated depending on an equivalent stress or strain measure assumed to be the stimulus for growth/atrophy [2]. Due to the applied first order homogenization procedure the model is not able to capture size effects observed in such kind of materials, see e. g. [8]. On the other hand the model has the advantage that a standard FE code with user-defined material subroutines can be used. The initial density of the TVE is calcluated with respect to the grey-scale distribution of relevant CT data. The initial density of the individual beam elements as well as the initial orientation of the TVE are derived by an equilibrium calculation for the intact femur.

3 CONCLUSION

We have investigated a FE^2 model with application to anisotropic growth and reorientation of the microstructure, which can be included into a standard FE code like LS-Dyna. Compared to pure microscopical problems, the proposed model is quite efficient with respect to the numerical effort. Furthermore, the model passes on macroscopical constitutive equations and macroscopical evolution equations. Numerical results for two-dimensional boundary value problems using second order homogenization can be found in [4, 8].

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