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MODELLING OF HETEROGENEOUS MATERIAL PROPERTIES DISTRIBUTION ON EXAMPLE OF FEMUR AFTER THA

Antoni John[1] and Mateusz Duda[2]

[1] Institute of Computational Mechanics and Engineering, Silesian University of Technology, ul. Konarskiego 18a,44-100 Gliwice, Poland, e-mail: antoni.john@polsl.pl
[2] Institute of Computational Mechanics and Engineering, Silesian University of Technology, ul. Konarskiego 18a,44-100 Gliwice, Poland, e-mail: mateusz.duda@polsl.pl

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In this paper the volumetric modelling of heterogeneous material properties distribution ensuring the exact assumed Young E modulus is presented. The in-house equations E(ρ) are proposed and the way of adaptation of literature equations ensuring the assumed weighted value of material parameter are shown, too. The application of this approach in biomechanical investigation is described on the example of the femur after cement THA. For this reason, very accurate model of proximal femur was built as well as the anatomic endoprosthesis. The material assignment was conducted and as a result the four different models with different weighted Young E modulus for cancellous and cortical bone were created. The evaluation of compliance of femur-endoprosthesis system was done, as well as the strain and stress state of femur. The results were compared to results obtained from model with homogeneous material parameters distribution due to investigation of influence the character of relation E(ρ) into the strain and stress values and their distribution. The presented method allows to conduct above investigation regardless lack of QCT approach.
The approach to modelling of the materials parameters distribution in biomechanics investigations as the homogeneous is still alive in literature [i.e. 1;2]. The reason of this state is lack of possibility to conducting the quantitative computed tomography (QCT). The disadvantage of mentioned approach is the too high simplification of material model due to the orthotropic character of cancellous and cortical bone which could lead to unreliable results. For this reason the material is very often modelled as isotropic heterogeneous using the equation E[ρ(HU)] according to literature or some previous experiments. However, this solution is also not accurate due to lack of correlation of the apparent density and phantom density used in QCT investigation. The investigator could model the healthy bone but the materials distribution could correspond to the pathological state, i.e. changed by osteoporosis or coxarthrosis. The solution of this obstacle is the proposed way of modelling the materials parameters distribution with volumetric approach providing the exact weighed Young's modulus E. The modified literature equations could be used for this approach. For this reason the way of adaptation of literature equations is presented in this paper, too. The relation E(ρ) is also proposed and the comparison with adapted equations is conducted on the example of the femur after cement THA. The assumption in proposed approach is that the total weighted Young E modulus in investigated structure depends on the volume participation of each

material group in this structure. This is the main reason for which any applied equation from literature delivers different results for average Young E modulus, not assumed by the investigator. In order to avoid such a mistake the function for particular anatomical structure is chosen in such a way, as weighted mean of all modules for particular groups should be equal to assumed weighted mean. The relation ρ(HU) was taken from the literature [3]. The adaptation of the known literature expression E(ρ) is the multiplication by scale number.

The proposed methodology of modelling the heterogeneous material parameters distribution was used in investigation of femur after cement THA. The first step was the creation of the CAD model of intact femur with extracted the cancellous and cortical structure, which was done on the base of CT data. On this basis the FEM model was created using the Mimics Innovation Suite 15.0.1 and MSC.Patran. The total number of 4-node elements of model was 1.5 mln what allowed to obtain the very accurate material distribution. The next step was the division each structure into 30 material groups and the evaluation of their volume. The total volume was equalled 50.42 cm^3 and 45.89 cm^3 for cancellous and cortical bone respectively. On the basis of information of percentage participation of each material group in total volume of each bone structure, some function E(ρ) was proposed using the in-house equation. In addition, the weighted number of Hounsfield units and apparent density was established. The model of femur after cement THA was created using the CAD modelling. The resection of femoral head and implantation of anatomic endoprosthesis was done according to the literature guidelines [4,5]. As the result the four models were obtained where different equations were used.

The investigation shows that in all cases the most exposed to the high values of stresses and strains is the front side of cancellous bone. In opposite to the area of occurrence of the maximal value of stresses (we found them on left side), the average values shows that the right side is more effort. It’s mean that this part will be more globally reinforced, but the left part locally and probably faster. We also found that material parameters distribution in intermediate layer has the influence on stress state but not on strain state as well as the compliance of all system.

The conducted investigation presents the usefulness of volumetric approach to modeling the heterogeneous material parameters distribution ensuring the exact level of weighted Young modulus E, which allows to simulate and study the material parameters distribution of bones.

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