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HOMOGENIZATION OF TRABECULAR BONE MICROSTRUCTURE BASED ON FINITE ELEMENT METHOD AND MICRO COMPUTED TOMOGRAPHY

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The prediction of the mechanical properties of trabecular bone is usually based on in vitro measurements of real samples via Micro Computed Tomography (MicroCT, µCT) combined with Finite Element Method (FEM). The aim of this study was to compare such an approach with the homogenization techniques, well established for composite materials, to determine the full elastic constant tensor of the trabecular bone.

Alternatively, the bone can be treated as a composite material, which consists of the matrix (trabecular part of the bone tissue) and ellipsoidal inclusions (corresponding to the voids) to obtain versatile method of determining the elastic constants. Therefore a complicated geometrical structure of trabecular bone can be substituted by a simpler material with several interacting ellipsoidal inclusions of different shapes, sizes and relative positions. The determination of these geometrical parameters was treated as a following inverse problem.

Based on the real samples of animal origin, three-dimensional parallelepiped models can be automatically meshed with the usage of hexahedral elements. Calculations of the apparent mechanical properties of the trabecular bone structure is next performed attributing any *a priori* selected elastic properties of the trabeculae. The models are virtually tested under traction (compression) and shear loads in three orthogonal directions. From elongations and reactions obtained, the apparent elastic properties of the sample can be deduced. The knowledge of these apparent properties of the bone sample allows finding parameters of the composite material model. The genetic algorithm was used in order to set up the best geometric properties of inclusions. For simplicity, in this work, the mechanical properties of bone trabeculae were assumed to be isotropic.

A series of homogenization techniques for the calculation of the average mechanical properties of composite materials based on the concept of Eshelby's inclusion [1] was implemented and tested, namely: Mori-Tanaka (M-T) [2], Self-Consistent (S-C) [3] and Incremental Scheme (IS) [4]. Ultimately, for determining the elastic properties, the incremental approach of averaging the mechanical properties (IS) was used. This scheme proved to be well suited for the materials of high porosity. In order to set up the proper distribution, sizes and orientations of the ellipsoids that are consistent with the measured or simulated results, the genetic algorithm was used. The results obtained by averaging composite material properties were compared with the FEM-based simulations.

The proposed method is fast and enough accurate in comparison to the FEM calculations. Further validation is planned to be implemented soon, however the presented approach can be used at this stage in several applications, potentially also for other materials. Study of the three-dimensional structures creates possibilities to obtain the results of the mechanical properties of trabecular bone microstructure, taking into account the structural parameters.

REFERENCES

[1] J.D. Eshelby. The determination of the elastic field of an ellipsoidal inclusion, and related problems. *Proceedings of the Royal Society of London*, 376–396, 1957.

[2] T. Mori and K. Tanaka. Average stress in matrix and average elastic energy of materials with misfitting inclusions. *Acta Metallurgica*, Vol. **21**, 571–574, 1973.

[3] O. Fassi-Fehri, A. Hihi and M. Berveiller. Multiple site self consistent scheme. *Int. J. Engng. Sci.*, 495–502, 1989.

[4] P. Vieville, A.S. Bonnet and P. Lipinski, Modeling effective properties of composite materials using the inclusion concept. General considerations. *Arch. Mech.*, Vol. **58**, No. **3**, 207–239, 2001.