2D and 3D bone modelling for analysis of changes in the bone architecture and for evaluation of structural measures

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Simulation of the bone architecture and its evolution (bone modelling) is a necessary tool in the understanding of physical mechanisms behind the bone reconstruction, prediction of the bone loss, and providing the test objects for newly developed structural measures. In this presentation we suggest several algorithms and methods of bone modelling in 2D and 3D, and use these models for testing of newly developed structural measures of complexity.

In 2D we generate test objects with the architecture similar to the trabecular structure of bone. Interchanging randomly the pixels within 2D images we succeed to change crucially the structure, but keep the mean pixel intensity (analogue to Bone Mineral Density) constant. These objects are used to test structural measures based on complexity. This analysis shows the powerfulness and efficiency of these measures both in the detection of ordering or disordering processes, as well as in the detection of small defects.

Additionally, we applied the model algorithm to 2D CT-images of the human lumbar vertebrae. A small square inside the trabecular bone was selected and the pixels inside the square were randomized up to a specified degree, thus providing us with a sequence of objects with a known type of structural changes. These simulations were used for the evaluation of sensitivity and plausibility of different measures of complexity. The complexity measures have shown their efficiency in the detection of local objects, invisible to the eye. Application of bone resorption models to the vertebral CT-images is a work in progress. The results would lead to a construction of the model of bone architecture from in-vivo resolution CT-images where the border between bone and marrow is difficult to determine.

3D bone datasets provided by modern CT- and micro-CT scanners demand adequate mathematical explanation. In 3D we model the bone resorption using an algorithm based on the activity of basic multicellular units (BMU). The localization and area of activity of BMU are generated in randomly. Using this algorithm, we simulate the bone loss in microgravity conditions or osteoporotic changes in patients on Earth. Starting points for the model are 3D datasets from human tibia bone biopsies acquired by a micro-CT scanner. The osteoporotic evolution of the architecture modelled by the bone resorption is assessed by using 3D structural measures of complexity. The comparison of the simulated results with experimental data shows that the model can reproduce experimental dependencies, confirming in this way the credibility of the proposed 3D resorption algorithm.

The proposed bone modeling can contribute to the development of diagnostic measures for quantification the structural loss and, in future, to the prediction of compositional changes of the bone tissue of patients on Earth as well as of the space-flying personnel.

This study was made possible in part by grants from the Microgravity Application Program/Biotechnology from the Manned Spaceflight Program of the European Space Agency (ESA). The authors would also like to acknowledge Scanco Medical, Roche Pharmaceuticals, and Siemens AG for support of the study.