Trabecular bone remodelling simulated by a stochastic exchange of discrete bone packets from the surface

Abstract

Human bone is constantly renewed through life via the process of bone remodelling, in which individual packets of bone are removed by osteoclasts and replaced by osteoblasts. Remodelling is mechanically controlled, where osteocytes embedded within the bone matrix are thought to act as mechanical sensors. In this computational work, a stochastic model for bone remodelling is used in which the renewal of bone material occurs by exchange of discrete bone packets. We tested different hypotheses of how the mechanical stimulus for bone remodelling is integrated by osteocytes and sent to actor cells on the bone's surface. A collective (summed) signal from multiple osteocytes as opposed to an individual (maximal) signal from a single osteocyte was found to lead to lower inner porosity and surface roughness of the simulated bone structure. This observation can be interpreted in that collective osteocyte signalling provides an effective surface tension to the remodelling process. Furthermore, the material heterogeneity due to remodelling was studied on a network of trabeculae. As the model is discrete, the age of individual bone packets can be monitored with time. The simulation results were compared with experimental data coming from quantitative back scattered electron imaging by transforming the information about the age of the bone packet into a mineral content. Discrepancies with experiments indicate that osteoclasts preferentially resorb low mineralized, i.e. young, bone at the bone's surface.

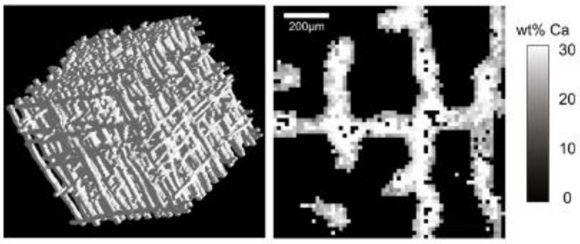

Fig. 7 – Left, snapshot of the whole simulated bone after about 40 years of evolution with a step-like remodelling rule. The simulations were started with a homogeneous and isotropic configuration of high bone volume fraction. Right, a representative two-dimensional portion of a cross-section through the same structure. Black pixels represent the marrow space. The grey scale of the bone pixels give information about the age of the bone elements. Using the mineralisation law from (Ruffoni et al., 2007) to transform bone age into mineral content, the image can be compared to measurements in the electron microscope performed in the back scattered electron mode (Roschger et al., 2008).