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Research paper

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

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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.

1. Introduction

Living bone undergoes a constant renewal process, helping to maintain its mechanical performance over the lifespan and allowing for adaptation to changes in the mechanical requirements. In trabecular bone this remodelling process leads, on the tissue level, to architectural changes of the network-like structure (Currey, 2002; Fratzl and Weinkamer, 2007; Robling et al., 2006). On the material level bone is resorbed locally from the surface of trabeculae and new bone is formed in discrete bone packets at the surface (Parfitt, 1979). Bone packets in trabecular bone have the shape of a half-cylinder, since bone resorption produces a trench on the bone's surface (hemi-osteonal remodelling) rather than a tunnel as in

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