Simulations of cell-based growth and maintenance of 3-dimensional trabecular bone structures

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Trabecular bone consists of a complex 3-dimensional structure of struts and plates, which are constantly broken down and rebuild by osteoclasts and osteoblasts respectively. Mechanical forces are thought to play an important role in these processes. Bone mass is thought to correlate with loading magnitude, and trabecular orientation is aligned to the loading direction. The internal tissue architecture can adapt to alternative loading conditions.

In previous work we have proposed a mathematical model of the regulatory mechanism that describes how external mechanical forces could control bone formation and resorption locally [Huiskes et al. (2000), Nature, 405, 704-706]. The model was based on the following set of hypotheses: 1. Osteocytes, which are embedded in the tissue matrix, are the cells responsible for mechanosensation. 2. These cells translate the mechanical stimulus they experience into a bone formation signal. 3. The signal is transducted to the trabecular surface where osteoblasts are recruited to form bone tissue. 4. Microdamage on the trabecular surface initiates osteoclastic resorption. 5. It was assumed that the distribution of microdamage over the trabecular surface is random.

Using a 2-dimensional computer model we were able to show that the regulation mechanism could explain the emergence, maintenance and adaptation of trabecular-like patterns, as an effect of mechanical loading.

In the current work we developed a 3-dimensional computer simulation model so that the behavior of the proposed regulatory mechanism can be quantitatively compared to actual trabecular bone metabolism. Finite Element Analysis was used to evaluate the strain energy density rates in the bone matrix, which we assume to be the mechanical stimulus experienced by the osteocytes. First simulation results show that the regulatory rules proposed earlier can describe the growth and adaptation of complex 3-dimensional structures like trabecular bone. Comparison to experimental data is currently ongoing.