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Research paper

Effects of loading frequency on the functional adaptation of trabeculae predicted by bone remodeling simulation

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ABSTRACT

The process of bone remodeling is regulated by metabolic activities of many bone cells. While osteoclasts and osteoblasts are responsible for bone resorption and formation, respectively, activities of these cells are believed to be controlled by a mechanosensory system of osteocytes embedded in the extracellular bone matrix. Several experimental and theoretical studies have suggested that the strain-derived interstitial fluid flow in lacuno-canalicular porosity serves as the prime mover for bone remodeling. Previously, we constructed a mathematical model for trabecular bone remodeling that interconnects the microscopic cellular activities with the macroscopic morphological changes in trabeculae through the mechanical hierarchy. This model assumes that fluid-induced shear stress acting on osteocyte processes is a driving force for bone remodeling. The validity of this model has been demonstrated with a remodeling simulation using a two-dimensional trabecular model. In this study, to investigate the effects of loading frequency, which is thought to be a significant mechanical factor in bone remodeling, we simulated morphological changes of a three-dimensional single trabecula under cyclic uniaxial loading with various frequencies. The results of the simulation show the trabecula reoriented to the loading direction with the progress of bone remodeling. Furthermore, as the imposed loading frequency increased, the diameter of the trabecula in the equilibrium state was enlarged by remodeling. These results indicate that our simulation model can successfully evaluate the relationship between loading frequency and trabecular bone remodeling.

1. Introduction

Bone is a load-bearing tissue that can adapt its internal structure and outer shape by remodeling to a changing mechanical environment. The morphological changes of the trabecular microstructure are realized by the coupling of osteoclastic bone resorption and osteoblastic bone formation (Parfitt, 1994). It is widely believed that the metabolic activities of these executive cells are coupled with osteocytes, which are interconnected within the extracellular bone

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