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Research paper

Multiscale FE method for analysis of bone micro-structures

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ABSTRACT

Bones are composed of hierarchical bio-composite materials characterized by complex multiscale structural geometry and behavior. The architecture and the mechanical properties of bone tissue differ at each level of hierarchy. Thus, a multiscale approach for mechanical analysis of bone is imperative.

This paper proposes a new approach for 3D multiscale finite element analysis of trabecular bone that can offer physicians a "digital magnifying glass" to facilitate continuous transition between macro- and micro-scales. The approach imitates the human ability to perceive details. That is, zooming-out from an object causes fewer details to be visible. As a result, the material appears to be smoother and more homogeneous. Zooming-in, in contrast, reveals additional details and material heterogeneity.

Realization of the proposed approach requires synergy between a hierarchical geometric model for representing intermediate scales and a mechanical model for local material properties of bone tissue for each scale. The geometric model facilitates seamless and continuous bi-directional transition between macro- and micro-scales, while the mechanical model preserves the effective material properties.

A 2D model of a simplified trabecular structure was implemented and analyzed in order to assess the feasibility of the proposed multiscale approach. The successful results of this model led to extending the method into 3D and analyzing real trabecular structures.

1. Introduction

Bone is a hierarchical material whose architecture differs at each level of hierarchy and whose mechanical properties can vary considerably, even on the same specimen, due to bone heterogeneity. Thus, a multiscale approach seems to be a natural methodology for geometric modeling and mechanical analysis of bone (Knothe Tate, 2007).

Currently, Bone Mineral Density (BMD) testing is used for diagnosing osteoporosis (Kanis et al., 2008; Qaseem et al., 2008), but it accounts for only 70% of bone strength (Draper et al., 2005; Lane, 2006). Because of the difficulty in accurate measurement and in standardization of instruments and sites, experts are in dispute over the continued use of this diagnostic criterion, which occasionally fails to diagnose patients with increased risk of osteoporotic fractures (Schuit et al., 2004). These facts have led to the need to develop 3D micro-scale scanning methods from which 3D models can be constructed and then used for bone micro-structural analysis.

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