Morphology analysis of vertebral trabecular bone under dynamic loading based on multi-scale theory

Abstract

Trabecular bone has a complicated porous microstructure and consists of interconnected plates and rods known as trabeculae. The microarchitecture of the trabeculae contributes to load distribution capacity and, particularly, the optimal bone strength. Many previous studies have shown that morphological parameters are used to characterize the microarchitecture of trabecular bone, but little is known about the mechanical role of trabecular morphology in the context of load-bearing behavior. Therefore, this study proposes a new segmentation method for examining the morphology of trabecular structure foci of load-bearing capability. A micro-finite element model of trabecular bone was obtained from the fourth lumbar vertebra on the basis of a three-dimensionally reconstructed micro-computed tomography (CT) image. We used an asymptotic homogenization method to determine microscopic stress by applying three unidirectional compressive loads in the vertical, anteroposterior, and right-left axes of two trabecular bone volumes. We then classified the complicated trabecular microstructure into three segments: primary and secondary trabeculae and trabeculae of no contribution. Next, a dynamic analysis was conducted by applying a force impulse load. The result indicated that 1/3 of the trabecular volume functions as primary trabecula. The morphology of the trabecular network could be visualized successfully highlighting the percolation of the stress wave in the primary trabecular segment. Further, we found that the role of the plate-like structures was that of a hub in the trabecular network system.