A mathematical model for predicting the elastic properties of cortical bone using algorithm-generated images

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Abstract

With the increasing elderly population, osteoporosis has become one of the major factors affecting health. In order to provide precise diagnosis and treatment, quickly predicting the mechanical properties of bones in the elderly is crucial. However, traditional methods for evaluating bone strength typically rely on cumbersome mechanical experiments and macroscopic assessment methods, which often fail to consider the impact of microstructural features and cannot provide rapid evaluations. To address these shortcomings, this study proposes a model for rapid prediction of cortical bone mechanical properties based on an algorithm that generates effective bone cross-sections. Specifically, this paper introduces a novel parameter, the planar elliptical eccentricity , to better reveal the geometric characteristics of cortical bone cross-sections. Additionally, a model combining multi-objective optimization and depth-first search algorithms is proposed, which efficiently generates cortical bone-like cross-sections. Through parameters such as the osteons distribution density, the area ratio between osteons and Haversian canals, and eccentricity, the model accurately and comprehensively represents the hierarchical structure of cortical bone. This method overcomes the limitation of scarce cortical bone cross-sectional images, providing rich data support for subsequent mechanical analysis. In terms of mechanical analysis, finite element analysis is performed using ABAQUS, which calculates the dimensions of the representative volume element (RVE) of cortical bone and the macroscopic equivalent Young's modulus, thereby enabling the rapid assessment of cortical bone mechanical properties. This study demonstrates that the microstructural parameters of cortical bone, particularly the distribution density of bone units, the area ratio of bone units to Haversian canals, and the eccentricity , are key factors influencing the elastic modulus of cortical bone. Further analysis reveals a significant quantitative relationship between , and . and a fitting equation is derived within a certain range. The findings of this study provide new insights for predicting the mechanical properties of cortical bone in the elderly, with significant clinical implications. In the future, further optimization and application of this method could provide a scientific basis for the elderly diagnosis of osteoporosis.

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