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Real time simulations of bone remodeling predictions: an improvement of actual numerical analyses

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ABSTRACT

Bone modeling and remodeling have been extensively studied in many fields of research. The process of adaptive bone remodeling can be described mathematically and simulated in a computer model, integrated with the finite element method (FEM). A bone remodeling model implemented in a FE code can determine the long-term behavior of bone and the impact on bone biomechanics produced by the incorporation of prosthesis. Bone remodeling simulation normally starts assuming a uniform bone density distribution. As a consequence of the sequentially loads application, bone material properties changed, till a stable bone density distribution is predicted. As a consequence, we should run the FE solver for a large number of time increments to find out the final density distribution using a bone remodeling algorithm.

Therefore, the aim of this work is to combine FE analyses with numerical extrapolation techniques to run real-time simulations of bone remodeling predictions [1]. Two vector extrapolation methods, reduce ranked extrapolation (RRE) and minimal polynomial extrapolation (MPE), are used to reduce the simulation time. These extrapolation techniques have been applied to predict the bone density distribution of several 3D FE models (femur, femur with a hip prosthesis and mandible). The procedure is extremely fast and substantially reduces the computational cost. For example, the simulation time of a 3D femur model in order to obtain its bone density distribution has been reduced by a factor of 10.

In this work, we have demonstrated that real-time bone remodeling predictions can be computed using two different vector extrapolation techniques, reduced rank extrapolation (RRE) and minimal polynomial extrapolation (MPE). RRE and MPE are very cheap to implement in terms of the computational cost and storage savings. Both methods are based on basic vector multiplications in linear algebra, so they are able to calculate the extrapolation vector much faster than the FE simulation combined with the bone remodeling algorithm. The most important advantage of the proposed methodology is its compatibility with any bone remodeling theory and the reduction in the computing time will be very useful in the clinical practice.

REFERENCE

[1] M.A. Perez, P. Fornells M. Doblaré, J. M. García-Aznar. Comparative analysis of bone remodelling models with respect to computerised tomography-based finite element models of bone. Comput Methods Biomech Biomed Engin. 2010;13(1):71-80

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