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Cortical Bone Remodelling: A Mechanostatistical Approach

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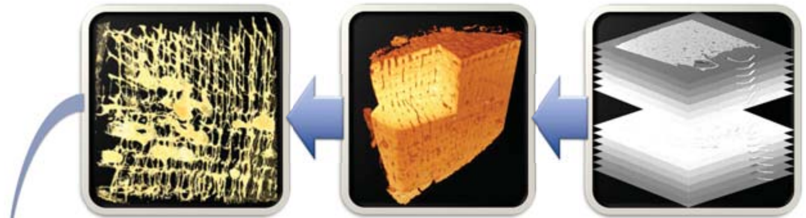
Introduction

Cortical bone bears about 65% of compressive load in people above 40 years of age, and its weakening and failure frequently leads to the fatal condition known as osteoporotic fracture. This study is motivated by the lack of bone remodelling computational research with realistic microstructure in three dimensions. Here we present a description of cortical bone microstructural change and use simulations of cortical bone evolution to build a partial least squared regression (PLSR) surrogate model to cut computation costs for further simulations.

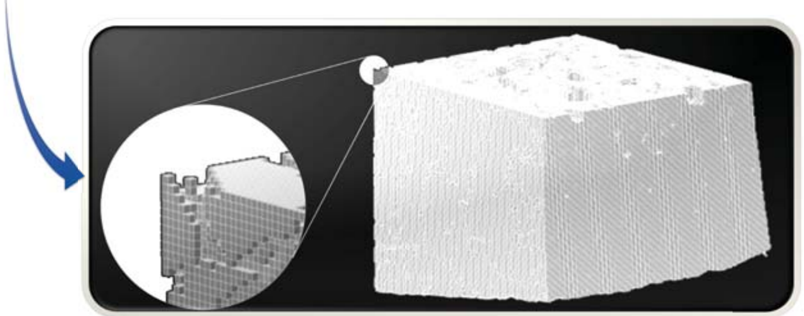
Methods



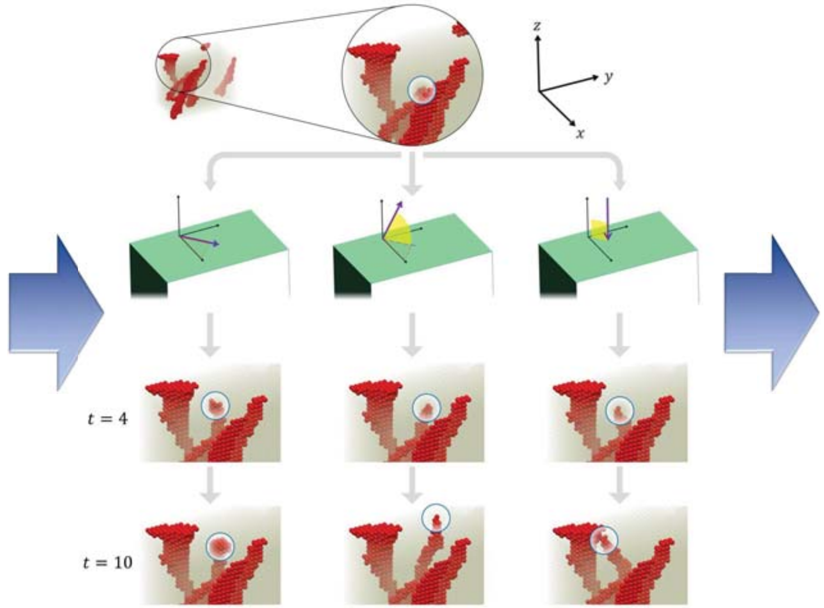
Detailed microstructural features were captured

A 3D geometry was constructed from the images

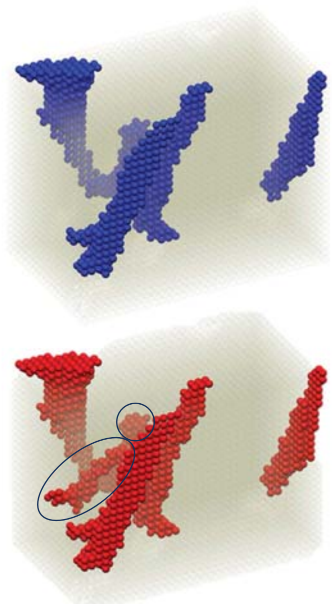
CT images were taken from a cortical bone sample



A voxel (hexahedral) mesh was built at a resolution which is able to retain the important microstructural features



Finite element simulations for different loading conditions, coupled with bone evolution algorithms, simulated change in bone microstructure and stiffness



Simulation results were used to build a database for use in a statistical model

Results

- Cortical bone homogenised material properties evolved according to the load magnitude applied, with loads larger than the default physiological load range causing an increase in stiffness, and loads smaller than this range causing a decrease in stiffness
- Different loading conditions caused a change in the haversian canal 'cutting cone' behaviour, and thus a change in bone microstructural evolution
- Predictions from the PLSR model for microstructure and stiffness resulted in maximum errors of 2.2% and 0.6%, respectively

Conclusions

- Material stiffness evolution agrees with current models of bone adaptation based on Wolff's law and the mechanostat
- The algorithm developed for cortical bone microstructural evolution allowed simulation of haversian canal shape changes seen in naturally occurring bone specimens
- The PLSR model built allowed for rapid calculation of microstructure and material stiffness with minimal error