In silico size effects in cancellous bone

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Abstract

Introduction

Continuum theories are commonly used in the mechanical characterisation and modelling of cancellous bone. However, at the microstructural level, cancellous bone exhibits several important length scales which must be included for cancellous bone to be modelled realistically. Classical elasticity does not take into consideration these length scales; thus, the need for suitable continuum theories which enable consideration of these length scales is essential to understand the mechanical macro-properties of cancellous bone [1,2]. This study tests the hypothesis that cancellous bone will exhibit size effects when loaded in silico, equivalent to regular lattice models. Such data is essential in developing an appropriate continuum model for cancellous bone.

Methods

A single sample of trabecular bone (10x10x40mm) was excised from a bovine distal femur and mCT scanned (Skyscan 1172, Bruker) to obtain a high resolution image (2.09μm pixel size). Morphometric analysis determined the average trabecular length, l_t, and a surface mesh was generated (CTAn by Bruker). Forty virtual bone samples of size dxdx2d, where $d=2l_t$, $3l_t$, $4l_t$ and $5l_t$(n=10 in each group), were extracted from the surface mesh and solid meshes generated (3-Matic by Materialise). Two regular lattice models of equivalent void fraction and trabecular length were also created (rod and cubic array). All samples were tested in silico (ANSYS Mechanical APDL 16.1 by ANSYS) under uni-axial compression and cantilever bending assuming material isotropy (E=12GPa and v=0.3) and normalised compressive and flexural stiffness were calculated.

Results

Normalised compressive and flexural stiffness increased with sample size for bone samples, with a very different relationship obtained for regular lattice models (Figure 1). One-sample t-tests identify significant differences between bone and regular lattices at all length scales ($p<0.001$).

Discussion

Cellular solids exhibit size effects in shear, torsion, bending and compression [2, 3, 4] and theories have been used to predict size effects in these structures [1]. An increase in stiffness with sample size has been experimentally observed in cortical bone [5]. The novelty of this study is that a mCT scanner has been used to construct multiple virtual bone samples to determine average size effects from real tissue. The results put in doubt the application of classical elasticity, non-local elasticity and homogenization methods to accurately characterise cancellous bone at meaningful length scales. Alternative lattice models are being investigated in an attempt to ascertain mechanical equivalence to trabecular bone.

Results

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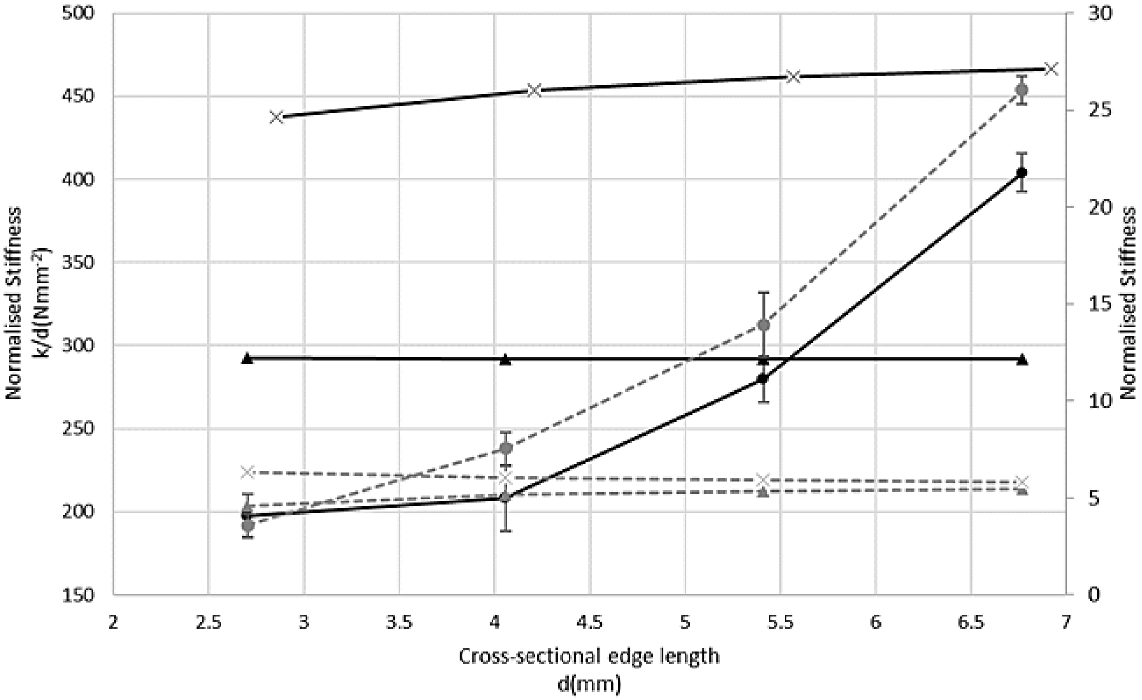

Figure 1: Results from loading the models in unconfined uniaxial compression (black) and cantilever bending (gray) Rod Model Cubic Array Cancellous bone

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