RELATIONSHIP BETWEEN MICROSTRUCTURE AND MECHANICAL PROPERTIES OF TRABECULAR BONE FROM μFEA AND TESTING

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1. Introduction

Predicting the mechanical properties of trabecular bone in individuals with osteo-related diseases is essential for preventing fractures and planning effective treatments. This study aimed to verify voxel-based finite element models of bovine trabecular bone samples using micro-computed tomography (µCT) images to provide a more comprehensive understanding of the complex relationship between trabecular microstructure and mechanical properties.

2. Materials and Methods

Twenty-two bovine bone cores (10 mm high by 10 mm diameter) were obtained from an ex vivo bone core study. Each bone core underwent quasi-static uniaxial compression testing (Biomomentum, Laval, QC, Canada), and the experimental apparent elastic modulus ($E_{app,EXP}$) was computed using Hooke's law (Eq. 1).

$$E_{app,EXP} = \frac{KL}{A} \quad (1)$$

Where K (N/mm) is the slope of last 50% (linear) portion of load-displacement curve; L (mm) is the length of the sample, A (mm^2) is the core cross-sectional area. All bone cores were µCT scanned in air (50 kV, 0.43 mA, 100 ms exposure time, and 0.1-degree rotation step in 360 degrees, 20 µm voxel size) using the Vector4CT pre-clinical scanner (MILABS B.V., Utrecht, Netherlands). The microstructure morphology such as bone volume fraction (BV/TV), degree of anisotropy (DA), connectivity density (Conn.D), trabecular thickness (Tb. Th), and trabecular spacing (Tb. Sp) of each bone core was assessed using Mimics (v24, Materialse, Germany) and BoneJ 1.4.3 (ImageJ version 1.53f, National Institute of Health, MD, USA) [xx]. The segmented µCT data were imported into an open-source FEA model generator and solver (n88modelgenerator, Version 9.0; and Faim Version 8.0, Numerics88 Inc., Alberta, Canada). Mesh sensitivity was done by resampling µCT images of all samples with isotropic voxels ranging from 0.02 to 0.1 mm.

(a) (b)

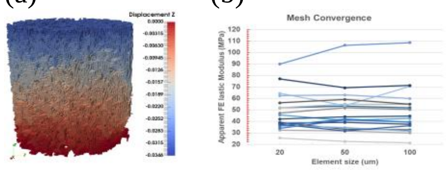

Figure 1. (a) Voxel-based FE model of a representative bone core **(b)** mesh sensitivity analysis with isotropic voxels ranging from 0.02 to 0.1 mm.

Homogeneous initial elastic modulus (E_i) of 1GPa with Poisson's ratio (ν) of 0.3 were assigned to each bone core. The apparent FE elastic modulus ($E_{app,\,FEA}$) was calculated using (Eq. 1). The tissue elastic modulus (E_{tissue}) was calculated using equation (2).

$$E_{tissue} = \frac{E_{app,EXP}}{E_{app,FEA}} \times E_i \quad (2)$$

3. Results and Discussion

There was a strong agreement between the $E_{app,EXP}$ and $E_{app,FEA}$. Samples had an average BV/TV of 0.23, DA of 0.43, Conn.D of 4.07mm^{-3}, Tb.Th of 0.17mm, and Tb.Sp of 0.69 mm. Changes in BV/TV did not consistently correspond to changes in the $E_{app,EXP}$ and $E_{app,FEA}$ as anticipated. This observation emphasizes the complexity of the relationship between bone microstructure and mechanical properties. As a result, we intend to explore the relationship between all trabecular parameters and numerical von-Mises stress, apparent elastic modulus, and strain energy density in our future investigations.

(a) **(b)**

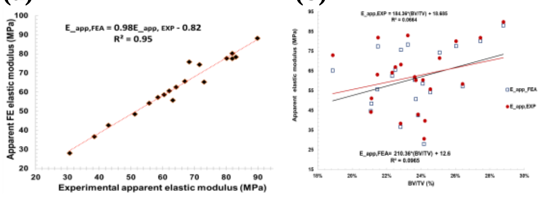

Figure 2: Linear regression plots illustrating the proportional correlations for $E_{app,EXP}$, $E_{app,FEA}$ and BV/TV **(a)** There is a good correlation between $E_{app,EXP}$ and $E_{app,FEA}$ (R^2=0.95, $p<0.05$) **(b)** There is a weak relationship between $E_{app,EXP}$ and $E_{app,FEA}$ and BV/TV(R^2=0.09 p=0.12; and R^2=0.06 p=0.24, respectively).