FINITE ELEMENT ANALYSIS OF μ-CT TRABECULAR BONE MODEL: A NUMERICAL METHODOLOGY TO EVALUATE THE INFLUENCE OF STRUCTURAL ADAPTATION ON BIOMECHANICAL RESPONSE

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Introduction

Mechanical behaviour of trabecular bone models (TBM), obtained from micro computed tomography (μCT) of *ex-vivo* bone culture, are evaluated using Finite Element Analysis (FEA) in order to predict trabecular bone adaptation (TBA).
Ex-vivo bone culture models quantify TBA in response to mechanical stimuli by measuring, among others: metabolic markers, bulk bone core stiffness, histological measures, and morphological 3D parameters with μCT.
The objective of this study was to demonstrate a methodology to conduct FEA of TBM and evaluate the changes in biomechanical response due to TBA.

Methods

In a first stage, twenty-two STL geometries (cylinders with 8mm in diameter and 4 mm height) were generated from the center of twenty-two bone core scanners (Siemens MicroCAT II 34 μm, 80 kVp, 50 μA) which were previously segmented (Mimics v18, Materialise) [1]. In a second stage, original models (i.e. Control group) were copied and uniformly scaled, to obtain new geometries with a small mass increase of 2% [2], forming a second set of TBM (i.e. Treatment group). This mass increase represents an TBA as a response to mechanical loading.
Specimens from both groups were analysed with FEA software Ansys v2022R2 to obtain the numerical linear-elastic stress and strain fields. The apparent axial Young's Modulus of each TBSM specimen was computed by means of multi-scale homogenization techniques [3].
Mesh independence analysis was carried out by gradually increasing mesh refinement and the number of elements (SOLID72) to verify convergence of numerical solution in terms of local stresses. Some examples of meshed TBM used in this analysis are shows in fig.1. The number of nodes ranged from 161,412 to 242,726 while the number of elements (10 node tetrahedral) from 569,414 to 909,461.

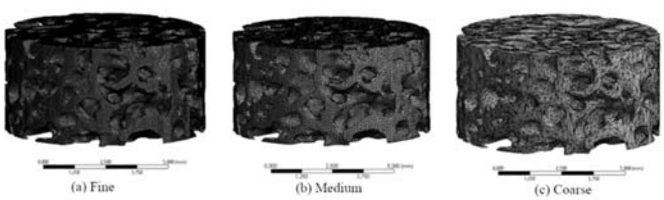

Figure 1: Examples of meshed TBM used in convergence analysis.

Results and Discussion

Preliminary results show that the 2% increase in mass has an appreciable effect in the overall apparent Young's modulus. This effect is thought to be consistent with the corresponding decrease in relative density, ρ/ρ_s, according to Gibson's quadratic model [4],

$$\frac{E^*}{E_s} = C_1\left(\frac{\rho}{\rho_s}\right)^2, \quad (1)$$

where E^* and E_s correspond to the porous apparent and solid (i.e: completely dense material) Young's modulus, respectively. Prior work of the authors for computationally generated metallic foams with non-structured distribution of pores suggests the corresponding constant, C_1, may take the value of 1 [5].
Statistical analysis for differences in Young's modulus of TBM geometries were carried using traditional two-sample paired comparison t-test and significant differences were detected for a level of confidence of 95% ($\alpha = 0.05$). Additionally, a post-hoc power analysis is yet to be carried, to provide the corresponding statistical power exhibited by the tests.

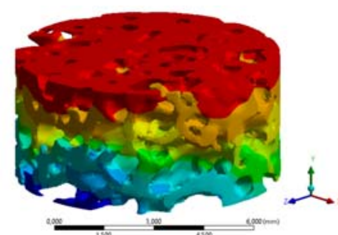

Figure 2: Directional displacement in axial-axis under compression for a TBM sample.

Significance

The present methodology allows to evaluate the changes on mechanical behaviour due to bone adaptation process on TBM.
This analysis can provide information regarding possible problems that may occur when orthopaedic implants are used, possibly altering the contact surface between the implant and human trabecular bone.

References

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