INFLUENCE OF MICROSTRUCTURE ON THE MECHANICAL PROPERTIES OF VERTEBRAL BONE ASSESSED BY QUANTITATIVE COMPUTED TOMOGRAPHY
– STUDY ON SYNTHETIC MODEL –

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INTRODUCTION

Assessment of bone mechanical properties from quantitative computed tomography (QCT) and predictive relationships is commonly used to personalize biomechanical finite element analyses (FEA). Such models are then used to predict bone mechanical behaviour under various loading conditions.

Results of previous studies revealed important discrepancies between mechanical behaviour predicted from QCT and experimental results [1-2]. Our hypothesis is that bone microstructure is an important biomechanical parameter for the establishment of predictive relationships of bone properties, which is usually not considered in QCT-based methods. The purpose of this study was to investigate the influence of microstructure on vertebral bone's apparent structural response.

METHODS

Sixty compression specimens (dia 19.05 mm x 25.40 mm) and twelve synthetic vertebrae were fabricated out of acrylonitrile butadiene styrene by an additive fabrication process (Prodigy Plus, Stratasys, MN, USA). Three structural parameters were controlled (Figure 1): spacing between filaments (air gap), layer orientation and raster orientation. Two sets of predictive relationships were established between the QCT density (ρ) and the measured elastic modulus (E) of the compression specimens: one taking into account all structural parameters and the second confounding some or all parameters. Structural parameters were considered when defining relationships by regrouping together compression specimens with the same structural parameter. Apparent elastic moduli within CT-scanned vertebrae were estimated using all derived E-ρ relationships and utilised to define the mechanical properties of vertebral FEAs. The overall structural stiffness of vertebrae predicted with the FEA was then compared to the mechanical behaviour obtained from compressive tests.

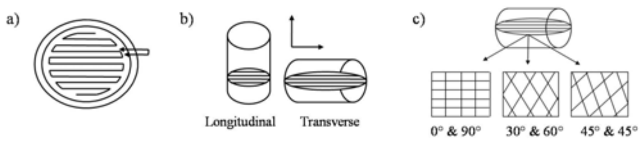

Figure 1: Structural parameters controlled during fabrication: (a) air gap, (b) layer orientation and (c) raster orientation.

RESULTS AND DISCUSSION

Second order polynomial relationships were found between the density and the elastic modulus of the test specimens (Table 1). Higher coefficients of determination were obtained when structural parameters were considered into the relationships.

Table 1: Predictive relationships and coefficient of determination (R^2) between density and elastic modulus

Layer orientation	Raster angle	Predictive relationships	R^2
Confounded	Confounded	$E = 3295,7\rho^2 - 2373\rho + 671,81$	0.943
Confounded	0°&90°	$E = 1757\rho^2 - 386,33\rho + 130,69$	0,930
Transverse	Confounded	$E = 4325,7\rho^2 - 3726,2\rho + 1100$	0,961
Transverse	30°&-60°	$E = 5086,1\rho^2 - 4750,1\rho + 1372,9$	0,988
Transverse	45°&-45°	$E = 5333,9\rho^2 - 5126,4\rho + 1467,6$	0,989
Longitudinal	0°&90°	$E = 2504,2\rho^2 - 1264,7\rho + 466,07$	0,995
Transverse	0°&90°	$E = 1925\rho^2 - 695,26\rho + 128,56$	0,999

Figure 2 compares the stiffness measured experimentally with the prediction using the FEA. The difference between the model's prediction and the experimental data was significantly smaller (p=0.04, Wilcoxon test) when mechanical properties of vertebrae were estimated considering the structural parameters (7 ± 4% compared to 13 ± 9%).

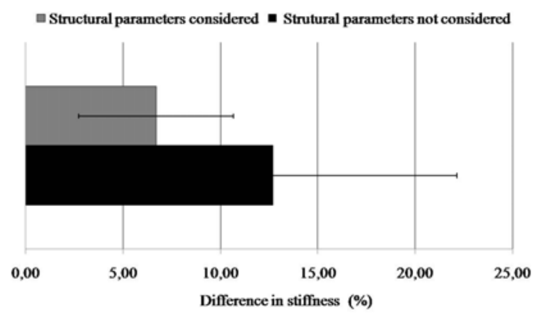

Figure 2: Percentage of stiffness difference between experimental data and predicted values.

CONCLUSIONS

Results suggest that considering structural parameters significantly improves the predicted mechanical behaviour of vertebrae using FEA. Therefore, microstructure is important to take into account for the prediction of bone's apparent structural response.

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