ANATOMY AND MORPHOLOGY-BASED SMOOTH FINITE ELEMENT MODELS OF HUMAN VERTEBRAL BODIES

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Introduction

Anatomy-based voxel finite element (FE) models can give better predictions of vertebral stiffness and strength than DEXA for clinical CT data. Smooth models have become an attractive alternative, but none so far accounted for variations in trabecular morphology and shell thickness [Imai *et al*, 2006]. In fact, most FE models are calibrated with material properties that are not really consistent with experimental measurements. In this study, we aim at comparing anatomy-based voxel models with novel smooth FE models using fabric-based elasticity for the trabecular core and variable thickness for the compact shell.

Methods

pQCT images (82µm, Scanco) of nine fresh human vertebral bodies compressed until failure were converted to 0.656mm and 1.312mm voxel models with heterogeneous, anisotropic elasticity for trabecular bone [Chevalier *et al*, 2007]. Scans were also converted to smooth FE models with distinct cortical shell and cancellous bone regions. The cortex and endplates were modelled with 1.5mm pentahedrons with thickness measured locally from the images and isotropic elastic properties based on nanoindentation measurements. Trabecular bone was modelled with 1.5mm tetrahedrons with orthotropic elastic stiffness tensors mapped from the images using density- and fabric-based relations presented by Pahr and Zysset [2006] (Fig.1). For all models, PMMA elements were extruded beyond the endplates.

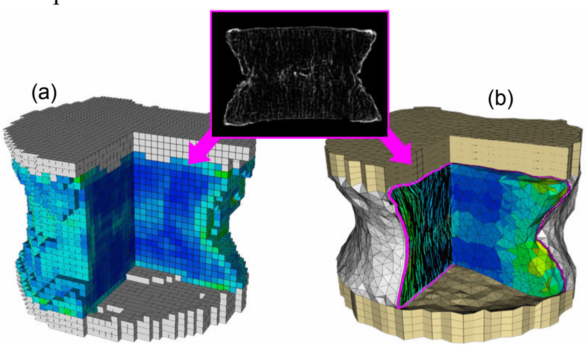

Figure 1: pQCT images were converted to voxel models (shown at 1.312mm, a) as well as smooth FE models with variable cortical shell thickness and fabric-based elasticity for trabecular bone (b).

Linear analyses in axial compression were then performed (ABAQUS 6.6) with top nodes displaced 0.5mm while bottom nodes were fixed. The global vertebral stiffnesses were related to the experimental results and the strain energy density (SED) distributions were compared.

Results

Despite a substantial quantitative overestimation, the excellent correlation obtained between the smooth FE models and *in vitro* stiffness (R^2=0.94) compared advantageously with the ones obtained for the voxel-based method at 0.656mm (R^2=0.67) and 1.312mm (R^2=0.62). The smooth models could also capture the high strain energy concentration in the cortical shell (Fig.2).

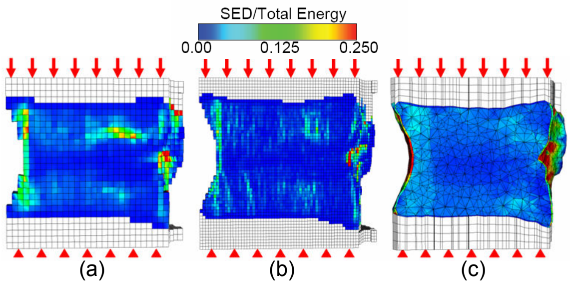

Figure 2: Normalized strain energy density distributions in the bone regions at 0.5mm displacement for voxel models at 1.312mm (a) and 0.656mm (b) and for a smooth fabric-based model including a variable cortex (c).

Discussion

Classical FE models with heterogeneous cortex thickness and an experimentally-validated fabric-based elasticity relation for the trabecular core could predict vertebral stiffness without further adjustment of the material data. This is a promising step towards a more reliable prediction of vertebral failure using high resolution CT data. Future development will include clinically more relevant boundary conditions, heterogeneous and orthotropic compact bone properties as well as bone damage.

References

Imai *et al*, Spine, 31:1789-1794, 2006.
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Pahr and Zysset, JBiomech, 39 (Supp):S426, 2006.