Influence of Material Heterogeneity on the Numerical Prediction of the Mechanical Response of an L5 Vertebra

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Accurate numerical prediction of vertebral mechanical response depends strongly on the adopted constitutive assumptions and representation of material heterogeneity. Simplified homogeneous material models can potentially affecting the reliability of stress and deformation predictions. The present study investigates the influence of material heterogeneity on the numerical response of an L5 vertebra model under compressive loading.

A three-dimensional finite element model of the L5 vertebra was developed, with geometry based on a commercial anatomical model from Sawbones® (see Fig. 1). Three material modeling strategies were considered: (i) a homogeneous isotropic model with uniform elastic properties defined as a volume-weighted average of the properties of cortical and trabecular bone, (ii) a region-based heterogeneous isotropic model distinguishing cortical and trabecular bone with different constant elastic parameters, and (iii) a region-based heterogeneous orthotropic model assigning direction-dependent properties to cortical and trabecular regions. Quasi-static axial compression was applied to evaluate global stiffness, displacement fields, and stress distribution patterns.

(a) (b)

Figure 1: Finite element model of the L5 vertebra: (a) overall geometry, (b) cross-section highlighting cortical (green) and trabecular (orange) regions.

The preliminary results indicate that introducing material heterogeneity and orthotropic behavior affects both local stress concentrations and predicted structural stiffness. Although the overall load–displacement response remains qualitatively similar across all models, the heterogeneous isotropic and orthotropic formulations predict higher stress levels and larger deformations compared to the homogeneous model.

These findings demonstrate the sensitivity of vertebral finite element simulations to constitutive modeling assumptions and emphasize the importance of appropriate representation of tissue heterogeneity and anisotropy for reliable numerical prediction. The study contributes to assessing the impact of model simplifications in computational analyses of spinal biomechanics and constitutes a preliminary numerical investigation of the influence of material heterogeneity on vertebral mechanical response.