Incorporating Cortical Bone Property Variability into Simulations of Isolated Ribs under Anterior-Posterior Bending

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Introduction:

Experimental measurements of isolated ribs under anterior-posterior bending have resulted in force-displacement measurements with significant variation between samples. There are numerous sources of variation, for example, external geometry, cortical bone thickness, and material properties of the cortical and trabecular bone. This research focuses on the interaction of external geometrical variability and material property variability and its effect on the force-displacement corridors. For that, a dataset of subject specific geometries is simulated with uncertain material properties of the cortical bone.

Objective:

The objective of this study is to evaluate the influence of variability in cortical bone material properties on the mechanical response of ribs. Simultaneously, we aim to develop a simulation framework that integrates subject-specific geometric data with statistically defined distributions of material properties. This approach enables the generation of force-displacement corridors that reflect realistic biological variability, rather than relying only on average material values.

Methodology:

A computational study was conducted using 150 Finite Element models and the explicit solver of LS-DYNA. Each model included a subject-specific rib external geometry from scans that are part of a larger dataset generated by the Injury Biomechanics Research Center at The Ohio State University. The cortical bone material properties were characterized by three key parameters of an isotropic bilinear elastoplastic model (MAT24): elastic modulus, yield strength and plastic modulus. To simulate realistic biological variability, these material properties were varied across the 150 models using statistical distributions. Material parameters were randomly sampled across the dataset. Each rib model was subjected to simulated anterior-posterior bending with boundary conditions that matched those used in physical experiments. The force and displacement responses were recorded for each simulation and analyzed to quantify the variability introduced by geometry alone, and the combined effect with the material.

Results:

The simulations revealed a notable spread in the force-displacement responses due to variations in both external geometry (40 to 140 N) and cortical bone material properties. When variations in material properties (elastic modulus, yield strength, and plastic modulus) were introduced according to their distributions, the resulting response corridors widened further, indicating an impact of material heterogeneity on the rib's mechanical behavior. The shape of these corridors could be improved by modifying the bilinear material model and incorporating tension-compression asymmetries. All simulations were run for the same duration, since fracture was not included in the model.

Conclusions:

This study demonstrates that incorporating variability in both rib geometry and cortical bone material properties is essential to comprehend the corridors that represent the mechanical behavior of isolated ribs under anterior-posterior bending. Subject-specific geometric data combined with statistically representative material property distributions provide a robust framework to capture the experimentally observed variability in force-displacement response. These findings highlight the importance of accounting for biological variability in biomechanical modeling and suggest that simplified mean property models may underestimate the range of rib mechanical behavior. Future work could focus on including the variability of the cortical bone thickness.