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DEVELOPMENT AND CROSS-VALIDATION OF A CT-COMPATIBLE LOADING DEVICE FOR MECHANICAL TESTING OF TRABECULAR BONE SPECIMENS

Jonathan Kusins, Nikolas Knowles, Mohammadreza Faieghi, Andrew Nelson, Louis Ferreira

Western University, Canada
jkusins@uwo.ca, nknowle@uwo.ca, mfaieghi@uwo.ca, anelson@uwo.ca, Louis.Ferreira@sjhc.london.on.ca

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Summary: Introduction: MicroFE models, derived from micro-CT imaging, are commonly used to characterize load transfer of trabecular bone. However, experimental methods to validate these computational models are lacking – primarily at the microscopic level. The present work entails the development and cross-validation of an experimental micro-CT compatible hexapod loading robot coupled with microFE simulation.

Methods: A custom-designed six degree-of-freedom hexapod robot was fabricated with six carbon fiber strut sections for compatibility with a cone beam micro-CT scanner. Two specimens were cored (⌀≈9.8 mm) from cancellous-grade sawbone analog (density=0.32 g/cm3) and subsequently potted in polymethyl methacrylate. A compressive 54N axial load, equivalent to 0.5% strain, was applied to both specimens. Micro-CT scans (31.5 µm resolution) were captured for the pre- and post-loaded conditions. Additionally, microFE models were derived from the corresponding pre-loaded scan and meshed with eight-node brick elements. A threshold value, used to segment the images, was selected to match volume fraction reported by the manufacturer to the microFE models. Homogeneous and isotropic material properties (E=2156 MPa, v=0.3) were assigned and the experimental loading conditions were modeled.

Overall strain calculated by the microFE model was compared to the experimentally prescribed 0.5% strain. Direct comparison between the post-loaded micro-CT scan and microFE model was performed using linear regression in the X, Y, and Z directions. Slope (m), coefficient of determination (R2) and root-mean-square error (RMSE) were determined.

Results: Overall strain determined by the microFE model resulted in errors of 6% and 24% compared to the predicted strain for specimens 1&2, respectively. For specimen 1, the microFE model closely matched the experimental results in the X (m=0.9990, R2=1.0, RMSE=17.0 µm), Y (m=0.9989, R2=1.0, RMSE=17.3 µm), and Z (m=1.0003, R2=1.0, RMSE=19.8 µm) directions. Similar results were observed for specimen 2 in the X (m=1.0004, R2=1.0, RMSE=16.9 µm), Y (m=0.9998, R2=0.99, RMSE=21.4 µm), and Z (m=1.0001, R2=1.0, RMSE=17.3 µm) directions.

Conclusion: The current work encompassed the development of a multi-directional CT compatible mechanical testing device and its performance evaluation compared to a microFE model. Initial results show promise for this novel loading mechanism in acquiring high-resolution micro-CT scans of cancellous bone samples under multi-directional loads.