Δ Advanced Imaging Evaluation of Distal Radius Fractures Using Finite Element (FE) Analysis of High-Resolution Peripheral Quantitative CT

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Purpose: The objective of our study is to develop a numerical model that is capable of accurately predicting the mechanical behaviors of distal radius fractures (DRFs), including the stiffness of the fractured wrist, throughout the fracture healing process. The performance of 3 finite element (FE) methods, 2 density-based (continuum) methods and a homogeneous micro-FE (μFE) method, was evaluated. High-resolution peripheral quantitative CT (HR-pQCT) images were used to generate continuum and homogeneous μFE models. Stiffness of the fractured wrist was compared to stiffness of the uninjured contralateral wrist to quantify the change in stiffness over time.

Methods: Serial micro-CT imaging was collected for patients with DRFs over 6-month follow-up. The three types of μFE models generated included a homogeneous μFE approach and 2 continuum μFE approaches. The homogeneous μFE models were generated from segmented images through the direct conversion of voxels to 8-node hexahedral elements. A global threshold of 320 mg HA/cm3 was used to segment the distal radius bone. The resulting bone elements were assigned linear elastic material properties, with a Young's modulus of E = 8748 MPa and a Poisson ratio of v = 0.3. The 2 continuum μFE models were generated from the grey-scale HR-pQCT data using methods developed by Homminga et al or Shefelbine et al to define material properties. The Homminga and Shefelbine approaches relate densities to elastic moduli through an exponential and a piecewise linear relationship, respectively. All models were subjected to uniaxial compression and torsional loading. Models were solved using a custom FE solver.

Results: There were 30 participants in this study (27 females and 3 males), with an average age of (51.8 ± 16.5 years). Each participant had imaging performed at 2, 4, 6, 8, 12, and 26 weeks. For uniaxial compression, an initial change in stiffness of –10%, –20%, and –54% is predicted by the Homminga, Shefelbine, and homogeneous μFE models, respectively. The results of continuum and homogeneous μFE models demonstrated 1% and 3% of recovery of stiffness per week, respectively. The Homminga μFE approach did not capture significant longitudinal changes during the early follow-ups for either loading condition. The Shefelbine approach appears to be more sensitive to stages of fracture healing than the Homminga approach. The homogeneous μFE model illustrated a rapid recovery of stiffness.

Conclusion: Both the Shefelbine and homogeneous μFE approaches captured significant longitudinal changes in fracture stiffness. The homogeneous μFE method produced a rapid recovery of stiffness, suggesting it is more sensitive than continuum μFE approaches; therefore, it may better predict the mechanical characteristics of the injured wrist during fracture healing.

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