LOCAL μFE IN HUMAN TRABECULAR BONE – A COMPARISON TO IMAGE-GUIDED FAILURE ASSESSMENT

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Introduction

Local interpretations of micro finite element (μFE) simulations play a pivotal role for studying bone structure-function relationships such as microstructural bone remodelling, stress concentrations around osteocyte lacunae, crack initiation and failure. Successful validations of μFE codes have focused on apparent properties such as apparent strain and ultimate stress. Although nano-indentation experimental studies have reported intratrabecular heterogeneity of Young's modulus, linear elastic apparent level properties seem to be only marginally influenced by heterogeneity of Young's modulus [Gross, 2012]. Attempts for local validation of strains are sparse and the resulting low correlations with experiments were explained by limited image quality affecting the experimental and simulated strains [Zauel, 2006]. Addressing these limitations, we performed image guided failure assessment (IGFA) of human trabecular bone samples using synchrotron radiation micro-computed tomography (SRμCT).

Methods and Materials

Human trabecular bone specimens (Ø6mm x 9mm, n=12) were cored from cadaveric vertebrae in cranial-caudal direction. Unloaded as well as loaded bones were imaged (SRμCT) at a resolution of 7.4μm. Deformable image registration [Christen, 2012] allowed the calculation of local displacements. Furthermore, μFE with homogenous material properties of a single trabecula - virtually extracted from the trabecular network - was performed by applying the exact displacements from the deformable image registration as boundary conditions (BC).

Results

Figure 1 visualizes a subset of a single trabeculae loaded in the specimen network. The colored dashes indicate the direction and magnitude of the first principal strain computed from image registration. Principal strains within the red box lie roughly in a 45° direction whereas the direction in the blue box follows the apparent loading direction. In Figure 2 the experimental (left) and simulated (middle) von Mises strain equivalent are visualized for the same single trabecula.

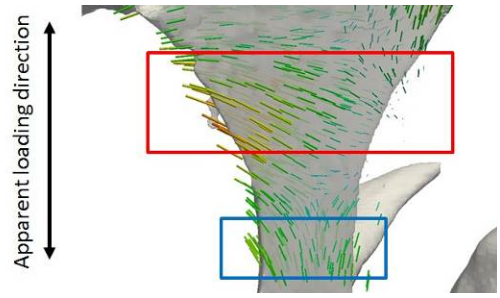

Figure 1: Single trabecula loaded in network under apparent compression. Principal strain vectors indicate local shear (red box) and bending (blue box) loading.

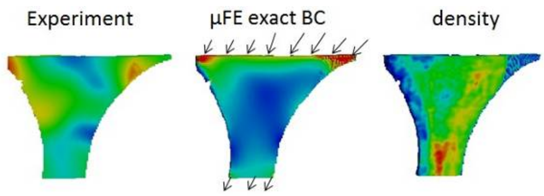

Figure 2: Von Mises strain equivalent: experimentally measured (left), μFE with experimental BC (middle). Mineral density (right)

Discussion

The direction of the first principal strain in the red box of Figure 1 indicates shear deformation whereas the blue box indicate axial loading coming from bending or compression. Although the exact experimental BC were applied to the μFE, simulated and experimental strains differ. This demonstrates that the assumption of homogenous material properties leads locally to inaccurate strains. Our SRμCT images containing quantitative local heterogeneity of bone mineral density (Figure 2, right), combined with deformable image registration, will allow to study effects of heterogeneous Young's modulus on local μFE behavior.

References

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