
Abstract

by

Joshua Gargac

Three-dimensional imaging and image processing provide tools that ultimately improve measurements in biomechanics research. With appropriate processing techniques, images can be used directly to assess bone geometry, or converted to more detailed computational models that can be applied to analyze the local mechanical environment of bone. The objective of this dissertation was to study bone healing, damage, and adaptation through the novel application of computational modeling and image processing techniques.

The local mechanical environment is vital to study of bone biomechanics. However, it is often difficult to determine the mechanical behavior of whole bones, because bone has a complex geometry, heterogeneous composition, and the relevant features span multiple length scales. For this reason, specimen specific finite element
models coupled with complimentary experiments have become a common tool for analyzing the stress and strain distributions in whole bones.

In an initial study, image-processing was employed to evaluate the efficacy of a hydroxyapatite-reinforced collagen scaffold for the treatment of critically-sized defects in rat femurs. Ten weeks following implantation, the scaffolds failed to induce healing. However, bone formation was improved when compared to defects implanted with porous collagen, or left open. Image processing allowed the time course of healing to be quantified for each experimental group, and identified important trends with only a small number of animals.

In a second study, specimen specific finite element models of rat femurs were used to interpret the outcomes of a fatigue loading experiment. Femurs that had been loaded in three-point bending to induce damage were analyzed. The locations of microdamage were correlated to the strain distribution using a probabilistic model. The results demonstrated that damage was dependent on strain, but also had random component attributed to presence of pores and other flaws smaller than the spatial resolution of the models. A Weibull distribution function was used to predict the damage distribution.

Finally, poroelastic finite element models of porcine femurs were applied to characterize the mechanical environment of bone marrow in a long bone. This is essential to the eventual understanding of the importance of mechanical signaling in the marrow to bone adaptation and other diseases associated with marrow abnormalities. To improve the fidelity of these models, orthotropic material orientations were first
applied in the directions of principal stress, and then validated through microscale modeling. A poroelastic constitutive model enabled the calculation of pore pressures resulting from whole bone compression loading, and these were validated against experiments. The pore pressure results were further applied to estimate the shear stress using a drag model. Although this is a simplified model, shear stress was estimated far in excess of the mechanostimulatory threshold, suggesting that whole bone loading is mechanostimulatory to marrow cells.

Overall, this work has developed new approaches to the application of medical imaging to biomechanics analysis. These approaches can be applied to a wide range of biomechanical studies. The initial multiscale techniques that have been developed have opened up the potential for simulations that span from whole bones to tissues, and potentially the cellular level.