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INFLUENCE OF MICROSTRUCTURE DIMENSIONS ON PREDICTION OF LOCAL TISSUE STRAIN IN BONE

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ABSTRACT

Bone tissue adapts continuously its structure to its mechanical load environment. The underlying mechanisms by which bone cells respond to mechanical stimuli are not well understood. It is also not clear how mechanical loads act on osteocytes housed in lacunae in bone. In this study a multilevel FE approach is applied to predict local cell deformations in bone tissue. Cell deformations are predicted from detailed linear FE analysis of the microstructure, consisting of an arrangement of cells embedded in bone matrix material. This work has related the loads applied to a whole femur during the stance phase of the gait cycle to the strain of a single lacuna and of canaliculi.

The analysis was divided into three separate problems. A FE analysis of the macroscale problem was performed to determine the strain distribution of the femur during one-legged stance. The results of the macroscale FE analysis were used to define the applied boundary conditions of a separate mesoscale FE model, representing a quadrant of the cylindrical shell of femur diaphysis with length of 10 mm. In turn, the results of the mesoscale FE analysis were used to determine boundary conditions for a microscale FE model, representing a lacuna with canaliculi emerging from it (Fig. 1). For the discritization of macroscale and microscale models the same element type (SOLID 92) was used.

Cortical bone was assumed to be linearly elastic, homogeneous and transversely isotropic with a Young's modulus of 17 GPa and Poisson ratio of 0.41 in the axial direction and 11.5 GPa and 0.38 in the transverse directions, respectively. The same material properties values were used in macroscopic and mesoscopic levels of analysis. Cancellous bone was assumed to be isotropic material with E=206 MPa and Poisson ratio of 0.33.

The local structure of the matrix dictates the local mechanical environment of an osteocyte. A parametric analysis of the dimensions of the structural elements of bone tissue, diameter of the Haversian canal, distance between two adjacent Haversian canals, diameter of the canalicular channel and number of canaliculi emerging from a single lacuna, lacunar dimensions, was performed in order to determine the influence of microstructure on local tissue strain.

The predicted bone matrix strains around osteocyte lacunae and canaliculi, were nonuniform and differed significantly from the macroscopically measured strains. Peak stresses and strains in the walls of the lacuna were up to six times those in the bulk

extracellular matrix. Significant strain concentrations were observed at sites where the process meets the cell body. The dimensions of the lacunar axes influenced slightly the local strain. Knowledge of local strains at the cellular level can aid in understanding of the process of mechanosensory.

Fig. 1. The microscale model of bone tissue, representing a lacuna with canaliculi emerging from it.