Chondrocyte Deformations as a Function of Tibiofemoral Joint Loading

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Theme: Combining data-driven and mechanistic modeling techniques

Identification of the deformations of chondrocytes in the cartilage during activities of daily living may help establish the relationship between joint loading and chondrocyte mechanobiological response and damage. The goal of this study was to estimate chondrocyte deformations in tibial and femoral cartilage as a function of macroscopic tissue strains obtained at a given joint loading approximating body weight. Open Knee[1], a free and open source finite element representation of the tibiofemoral joint, was used to obtain macro level cartilage strain distribution. The macroscopic deformation gradients at element centroids for transitional zones of tibial and femoral cartilage were used as boundary conditions for a microscopic finite element representation incorporating a random distribution of 11 spherical chondrons[2]. A high-throughput post-processing approach was used for the multiscale analysis[3], utilizing FEBio as the finite element analysis software[4]. A total of 7,882 microscopic models were solved for each (deforming) element centroid to obtain cell deformation variables (change in cell aspect ratio, volume change, etc) as a function of macroscopic deformations. Macroscopic effective strains in transitional zone of the cartilage were up to 0.20. Corresponding changes in cell aspect rations were up to 23%. While there was a linear relationship between macroscopic and cellular deformations (change in aspect ratio ~ 1.14 x macroscopic effective strain), variation in cell deformations were apparent (R^2 = 0.979), possibly dictated by cell location[5], and the loading mode. This study attempted to establish the relationship between mechanical loading of the tibiofemoral joint and deformation of chondrocytes in the transitional zone of the cartilage as an example. Simulations resulted in the determination of a statistical model which can be used as a surrogate model to provide the possibility to quickly estimate chondrocyte deformation for other macroscopic loading scenarios. Such a procedure may help establish assessment of cellular damage risk or thresholds for activation of cell level mechanobiological responses as a function of joint loading. It should be noted that more elaborate representation of extracellular matrix properties, e.g., fiber-based, and detailed representation of biomechanical phenomena, e.g. biphasic analysis, will likely portray varying relationships between macroscopic loading and cell level variables. The results of this study should not be viewed as factual. Rather, they should be utilized for generating hypothesis about potential pathways of load sharing, from joint level forces to cell level deformations. Experimentation on cell-seeded constructs[6] and recent animal studies[7] have the potential to provide adequate data for validation in order to establish confidence in modeling procedures, which will in turn enable translational utility of this multiscale approach for musculoskeletal joint care.

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