A FINITE ELEMENT ANALYSIS OF CARTILAGE IN CYCLIC TRIAXIAL COMPRESSION

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INTRODUCTION

When compared to other forms of mechanical testing of articular cartilage, triaxial testing holds the unique advantage of accommodating independent modulation of physiologically relevant shear stress states within the matrix, by varying the axial and radial (transverse) applied loads. However, owing to the proximity of loading/constraint boundaries, stress heterogeneities may confound the interpretation of *in situ* experiments performed in this configuration. A poroelastic finite element (FE) model of a cartilage specimen in cyclic triaxial compression testing was developed in order to investigate the effect of variation in loading conditions, geometry and material properties.

METHODS

A baseline FE model of a cartilage explant (4 mm diameter, 1.5 mm thick) and containment sheath (0.0254 mm thick) was created to mimic triaxial testing conditions [1]. The specimen was modeled using axisymmetric, poroelastic elements. In the radial (*r-z*) plane, the specimen was discretized into 150 8-noded bi-quadratic elements. The sheath was modeled using 100 2-noded axisymmetric shell elements. The experimentally measured modulus of the containment sheath was 5.5 GPa and Poisson's ratio $\upsilon = 0.4$. The cartilage had an initial void ratio (volumetric ratio of fluid to solid) of $e = 4.0$, $\upsilon = 0.1667$, a depth-dependent modulus ranging from 10 MPa in the superficial zone to 20 MPa in the deep zone, and void ratio-dependent permeability [2].

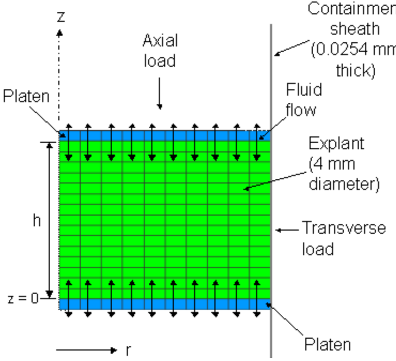

Figure 1a.

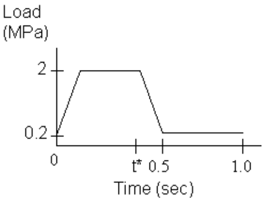

Figure 1b.

The cartilage explant was compressed between two rigid porous platens (diameter = 4 mm). Consequently, the interstitial fluid was free to flow in and out of the surfaces adjacent to the platens (Fig 1a). Transverse fluid flow was assumed to be restricted by the impermeable containment sheath. Six hundred cycles of trapezoidally-modulated loading were applied at a frequency of 1 Hz (Fig 1b); axial and transverse load magnitudes were 0.2 to 2.0 MPa.

Parametric testing was performed by independently modifying model attributes from the baseline model. The series included the cartilage radius, thickness, modulus, Poisson's ratio, and initial void ratio, as well as load magnitude, rate, and frequency. For the purpose of this abstract, only the results from the thickness and void ratio parametric series are shown. In all cases, data were collected at the centroid of each element. The thickness was decreased from the 1.5 mm baseline case to 0.75 mm and 0.375 mm. In the void ratio series, three models were run in addition to the baseline case ($e = 4.0$) in which the initial void ratio was 2.0, 8.0, and 16.0.

RESULTS AND DISCUSSION

Throughout the 600 cycles, the cartilage peak-to-peak axial strain range decreased and total strain increased for all cases (Fig 2). As the thickness decreased from the baseline, peak-to-peak strain increased, in addition to the maximum strain for each cycle.

The pore pressure is shown (Fig 3) at 0.1 mm off the symmetry axis of the cartilage at time t* (Fig 1b) for the 1st and 600th cycles of loading. At the onset of loading, pore pressures were higher compared to 600 cycles, where the effect of the different void ratios was seen.

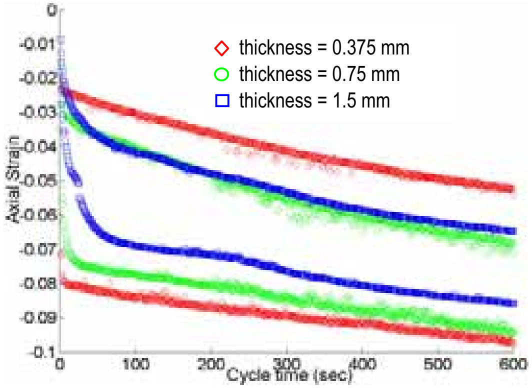

Figure 2. Peak-to-peak axial strain.

This FE model is a powerful tool to explore cartilage behavior for a wide range of physiological conditions. Additionally, changes in thickness, water content, permeability, stiffness, etc. are commonly associated with cartilage degradation [3], and can therefore be simulated to better understand these pathological conditions.

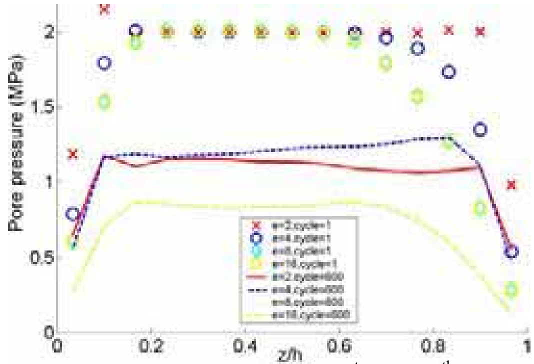

Figure 3. Pore pressure at t* for 1st and 600th cycles.

REFERENCES

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