Influence of Pericellular Matrix on Cell Strains in the Intervertebral Disc

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INTRODUCTION

Mechanical signals on intervertebral disc cells are important determinants of biosynthetic activity and can result in cell death if excessively large. Computational modeling demonstrated that a narrow pericellular matrix (PCM) surrounding the chondrocytes substantially alters the cell's micromechanical environment [1]. In cartilage, alterations to the cell and PCM are implicated in the initiation and progression of arthritis [2,3]. The PCM has been observed around the cells of the annulus and nucleus of the intervertebral disc with the suggestion of increasing PCM thickness with degeneration [4,5]. However, the role of the PCM in determining the micromechanical environment of cells in the disc has not been investigated. The purpose of this study is to investigate the influence of PCM thickness on cell strains in the three different regions of the intervertebral disc.

METHODS

Cells in the outer annulus fibrosus (AF) region of the disc are elongated and embedded in a highly anisotropic extracellular matrix whereas cells in the nucleus pulposus (NP) are spherical and surrounded by isotropic tissue. The cells of the transition zone (TZ), or inner annulus, are ellipsoids and surrounded by matrix with a moderate degree of anisotropy. To model the micromechanical environment in and around the cells a 2-D transversely isotropic axisymmetric model of the cell, PCM and tissue was developed using FEMLAB (Comsol, Natick, MA). The model computed the volume averaged cell strains normalized by the far-field matrix strains as a function of varying PCM thickness. For all disc regions, the PCM thickness was varied from 0 to 3 microns. Uniaxial loading conditions were applied, and effective strain fields were calculated. Material properties and geometries for the cell, PCM and the extracellular matrix in the three disc regions were taken from literature [6] and assumed linearly elastic. To further elucidate the effects of cell aspect ratio and extracellular matrix anisotropy on cell strains, four baseline cases were investigated (spherical-isotropic, spherical-anisotropic, non-spherical-isotropic and non-spherical-anisotropic) and cell averaged radial, azimuthal and axial strains were calculated. Anisotropy was simulated by varying the matrix modulus along the axial (E_z) and radial (E_r) directions and cell aspect ratio (a/b) was varied from 1 to 5.

RESULTS AND DISCUSSION

For uniaxial loading, relative variations in effective strain both within and across the cells in the TZ were larger than that for the cells in the AF region (Figure 1). The presence of the PCM 'amplified' the cell strains in a nearly linear increase in strain with PCM thickness (Figure 2). Anisotropy in the extracellular matrix enhanced the dependence of cell-strains on PCM thickness while cell-elongation reduced the dependence.

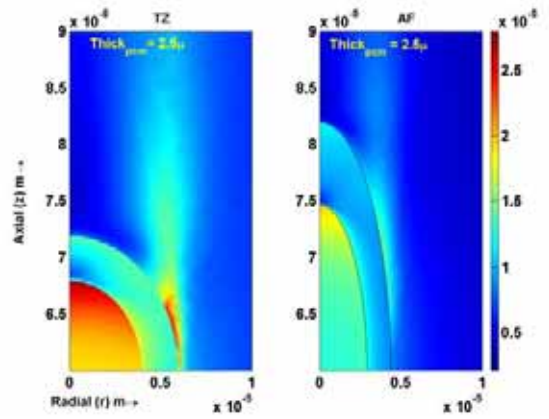

Figure 1: Effective Strain fields for TZ and AF regions

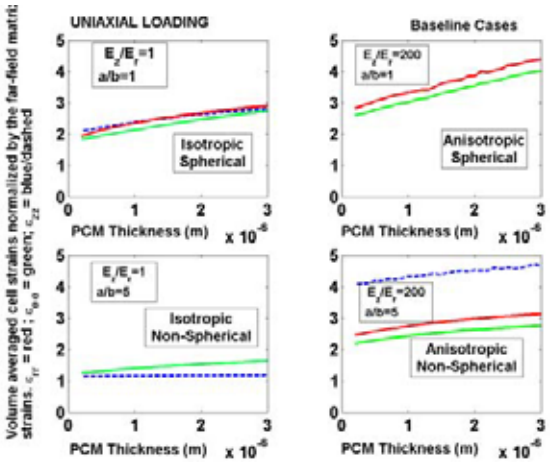

Figure 2. Average cell strains for the baseline cases

Thus cell strains are a function of the competing effects of anisotropy and cell elongation. Large strain amplification in the TZ region is consistent with increased apoptosis in this region found in a mouse tail model of degeneration [7]. This model coupled with detailed information on microstructural geometry, properties and other loading conditions will help in understanding the mechanobiology of health and disease.

REFERENCES

1) Guilak F and Mow VC. *J Biomech*, **33**, 1663-1673, 2000.
2) Poole CA. *J Anat* **191**, 1-13, 1997.
3) Horikawa O et al. *J Orthop Sci* **9**, 29-36, 2004.
4) Gruber HE et al. *Biotech Histochem* **77,** 1, 37-41, 2002.
5) Trout JJ et al. *Anat Rec* **204**, 4, 307-314, 1982.
6) Baer AE & Setton LA. *J Biomech Eng* **122**, 245-251, 2000.
7) Lotz JC et al. *Spine* **23,** 2493-506, 1998.

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