Multi-physics Simulation of Human Intervertebral Disc Degeneration and Repair

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ABSTRACT

Introduction: Understanding degenerative processes in human intervertebral disc (IVD) is challenging, due mainly to the complicated interactions among biological, chemical, electrical, and mechanical signals. The objective of this study was to develop a novel multi-physics model for human IVD for simulating and predicting disc degeneration and repair.

Methods: A 3D finite element model for IVDs was developed based on a recently developed, cell-activity-coupled mechano-electrochemical mixture theory [1]. In this model, the disc was considered as an inhomogeneous, porous, mixture consisting of a charged solid phase (with cells), an interstitial fluid phase, and a solute phase (with multiple species of solutes, e.g., Na^+, Cl^- , glucose, oxygen, and lactate). The governing equations were cast in terms of solid matrix displacement, cell density, and (electro)chemical potentials of the constituents. The material properties, such as tissue fixed charge density, hydraulic permeability, solute diffusivities were nonlinearly coupled with tissue deformation (or tissue hydration), and cell metabolism and viability were nonlinearly related to nutrient levels in the disc. The degenerative disc disease caused by poor nutrition supply was simulated. The repair of degenerated discs with biological therapies was also investigated.

Results and Discussion: Changes in cell density, oxygen concentration, glucose concentration, swelling pressure, glycosaminoglycan (GAG) content, water content, mechanical stress and strain, and disc height during tissue degeneration (up to 55 years) process were simulated. It was predicted that the progression of human IVD degeneration was in general very slow. Simulations of disc repair with biological therapies were also conducted.

The findings from this study provide new insights into nonlinear interactions among biological, chemical, electrical, and mechanical events in the disc during its degenerative or repairing progression.

REFERENCES

[1] Q. Zhu, X. Gao, and W Gu, “Temporal changes of mechanical signals and extracellular composition in human intervertebral disc during degenerative progression”, *Journal of Biomechanics*, 47:3734–3743, 2014.