Mechanoregulation model of the intervertebral disc


Introduction
Regenerative therapy is a promising treatment for early intervertebral disc (IVD) degeneration. It may restore tissue functionality via biomaterials containing stem cells, growth factors or agents blocking tissue catabolism (Fig. 1).

Degeneration
Regenerative strategies

• Change in cell phenotype or density
• Tissue degeneration

• Cells
• Growth factors
• Anti-catabolic agents

Fig. 1. Healthy and degenerated disc: Characteristics of a degenerated IVD (left) and potential regenerative strategies (right).

The long term functional benefit to the disc may be assessed by computational studies. Up to now, numerical models of the IVD have only focused on the mechanical behavior of the tissue and the nutrient supply to the cells as two independent mechanisms. However, these two processes are related by the cell activities.

Objective
The goal of this project is to develop a computational mechanoregulation model of a degenerated IVD to evaluate the effectiveness of regenerative strategies.

Methods

We are developing an iterative mechanoregulation model (Fig. 2) including:
• prediction of cell behavior based on their mechanical environment [1][2],
• influence of nutrient concentration on cell activities,
• effect of cells on matrix composition [2].

Fig. 2. Schematic representation of the computational model.

Fig. 3. Axisymmetric finite element mesh of an intervertebral disc.

We apply a physiological compressive load on an axisymmetric model (Fig. 3) of a healthy disc. Initially for model development, the nutrient and cell models are artificially kept independent.

Preliminary results

Fig. 4. Initial cell phenotypes (left), prediction after 20 days (right).

The sharp distinction between the outer and inner disc tissue fades away after few days (Fig. 4).

Fig. 5. Oxygen (left) and lactate (right) concentration at equilibrium.

The nutrient concentration model (Fig. 5) shows good correlation with other validated numerical data [3] although extreme values are somewhat overestimated.

Discussion
The variation in the cell type prediction over time might be due to simple assumptions for the mechanical model (axisymmetry, axial load, boundary condition).

In the nutrient concentration model, the extreme values must be improved, discrepancies with other data might be caused by modeling issues.

References