Effect of Permeability Diminution in Nutrient Diffusion in Intervertebral Disc

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Abstract

Intervertebral discs (IVD) are fibro-cartilages situated between vertebrae providing their joint flexibility. They play a major role in the transmission and absorption of load through the spine. The disc can undergo progressive structural and quantitative changes in its composition and morphology related to mechanical load applied to the spine which can lead to disc degeneration; this disease is one of the most common cause of low back pain.

IVD is an inhomogeneous saturated porous media mainly constituted of a solid and a fluid phases. The extra cellular matrix (ECM) of the solid phase is synthetised by the disc's cells and therefore, disc viability is related to the ability of the cells to receive their nutrients throughout the fluid phase of the disc media. The nutrients transport is achieved mainly by diffusion in the aqueous phase. This study is dedicated to the effect of the disc permeability variation in the nutrients diffusion during a compressive load.

A realistic 3D IVD porcine geometry is built up from MRI data (figure 1). The porous media is considered by the coupling of two physics: structural mechanics for the solid phase with a Mooney-Rivlin constitutive law and a modified Darcy equation for the behavior of the fluid phase. The solid phase strain induces a decrease in both disc porosity and permeability which increases the interstitial pressure. The later contributes in the evaluation of the spherical part of the Cauchy stress tensor. The permeability is considered constant in a first case then variable following the work of Argoubi et al. 1996. The nutrients diffusion is considered by two transport equations of diluted species in order to deduce oxygen and lactate concentrations. The coupling between nutrition and mechanics is ensured by the disc porosity (figure 2). Finite deformations are considered and the equations are solved in the material referential. The first step consists in a stationary study to obtain a prestressed unloaded state : from a set of non physiological initial conditions, the disc reaches its homeostasis equilibrium. In the second step a compressive load is applied for a short period and then remains constant until the total relaxation of the disc.

The concentration field of lactate exhibits clearly the production zone located nearly the disc center. Lactate concentration slowly decreases toward the disc boundaries to reach the values

defined by the plasma at the endplates and the external annulus. Results show that the difference in concentration values between constant and variable permeability is weak: 0.2% and 0.7 % of difference in lactate and oxygen concentration respectively (figure 3).

Mechanical load applied to disc initiates a fluid motion which is discharged from the disc to the outer environment throughout the endplates. Variable permeability affects the delay of relaxation with an increase of 62.8 % (figure 4). Ongoing researches concern the modeling of the interactions between permeability and fibrous porous medium.

Reference

1. M. Argoubi and A. Shrazi-Adl, Poroelastic creep response analysis of a lumbar motion segment in compression, Journal of Biomechanics, 29, 1331-1339(1996)

Figures used in the abstract

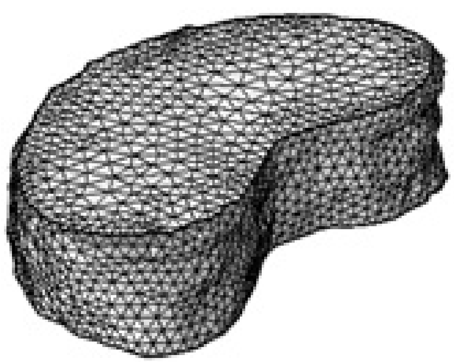

Figure 1: IVD geometry

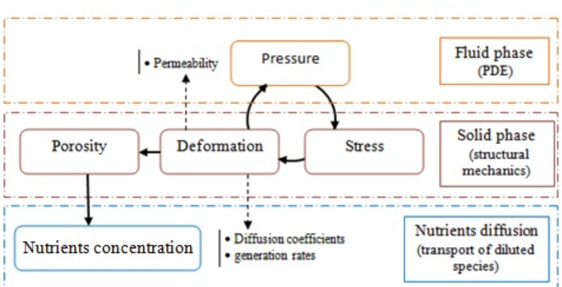

Figure 2: Model coupling

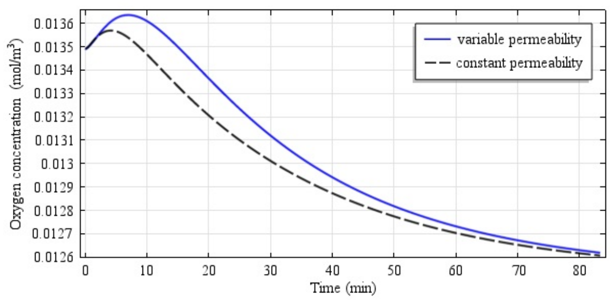

Figure 3: Evolution of oxygen concentration with time

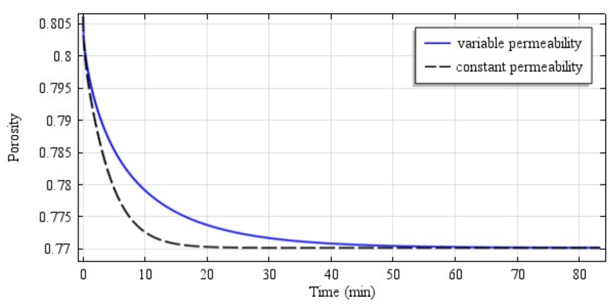

Figure 4: Evolution of porosity with time