3D Simulation of the Effect of Lumbar Disc Degeneration on Oxygen Levels Under Compression
Andrea Malandrino, Jerôme Noailly, Damien Lacroix
Corresponding Author: amalandrino@ibec.pcb.ub.es
Institute for Bioengineering of Catalonia, Barcelona, Spain

Introduction
Low back pain is a major disease in industrialized countries and is often linked to degenerative changes in lumbar intervertebral discs (IVDs). Complex mechanisms relate the degenerative changes in the disc to nutritional pathways, such as oxygen from surrounding blood vessels\(^1\). Numerical models can predict nutrient concentrations under different loadings, helping to understand the interaction between material properties and metabolic parameters to support tissue engineering regenerative strategies. Using a 3D mechanical IVD model, an oxygen reactive-convective-diffusive transport model was proposed to explore disc degenerative changes (DDC) mechanisms.

Materials and Methods
A finite element model for the L4-L5 IVD was created, including the nucleus pulposus (NP), the fibre-reinforced annulus fibrosus (AF) and cartilage endplates (CEPs). Biphasic tissues were assumed. Hydraulic permeability and oxygen diffusivity were related to strain-dependent water contents and oxygen cell consumption was modeled using Michaelis-Menten kinetics. With respect to a non-degenerated disc taken as a reference, DDC were first modeled by simulating material property changes, loss of NP swelling pressure, height and cell density\(^2,3\). Additionally, endplate sclerosis effect was explored by simulating the CEP as cortical bone. A compressive load of 1000 N was maintained for 3 hours. Boundary oxygen concentrations were applied via outer AF and CEP in all simulations, assuming that DDC do not alter peripheral oxygen sources.

Results
Comparing oxygen levels predicted in the normal disc to those in the degenerated discs with and without calcified CEP, we found maximum relative differences of 15%. In the NP, oxygen concentration was 6% higher for the degenerated than for the normal disc. Calcified CEP gave similar concentrations to those of the normal disc. In the AF, degenerated disc models presented reduced oxygen concentrations, mainly posteriorly and laterally (about 10% reduction).

Discussion and Conclusions
Different effects arose from the simulation, involved in DDC physiopathology: disc height reduction enhancing diffusion, water loss decreasing diffusivity, CEP calcification increasing fluid-driven solute escape and cell density loss reducing oxygen consumption rate. After creep, NP with degenerated properties experiences both increase or reduction of oxygen levels under the same blood contribution, depending on modeled CEP sclerosis. AF shows in all degenerated cases a regional dependent decrease of oxygen levels. This model can also be used to simulate different disc regenerative biomaterials under transient loadings and metabolic interactions.

References
2. BIBBY SR et al. (2005) Spine, 30, 487

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