

CALCULATING THE VARIABILITY OF ENDPLATE PERMEABILITY IN THE LUMBAR VERTEBRA AND INFLUENCE ON INTERVERTEBRAL DISC MECHANOBIOLOGY

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Introduction

Spine bony endplates (BEP) are a preferential path for metabolite and fluid exchanges at the vertebra-disc interface. BEP permeability may be thus relevant to the intervertebral discs (IVDs) biophysics. Since no robust protocol seems to exist to quantify such permeability, this study calculated it by simulating the permeation of 3D BEP micro models. Relation to the tissue porosity, as well as the influence of the natural variations of permeability on the IVD cell nutrition was explored.

Methods

μ CT scans from eight human lumbar vertebrae were used (Fig. 1a). 29 BEP samples ($2.5 \times 2.5 \times 3 \text{ mm}^3$) were modelled for computational fluid dynamic analyses (CFDA) (Fig. 1b). An axial mass flux Q_{in} was applied, and the out-flow pressure P_{out} was null (Fig. 1c). The macroscopic intrinsic permeability k was evaluated by using the Darcy relation, $k = \mu Q_{in} L / \rho A (P_{in} - P_{out})$, where A , μ and ρ are the cross section, the water dynamic viscosity and density, respectively. Changes in axial hydraulic resistance allowed the evaluation of both the functional BEP thickness L and the inlet pressures P_{in} (Fig. 1c). Relation to k of both the porosity and specific surface was assessed through Kozeny-Carman models [1].

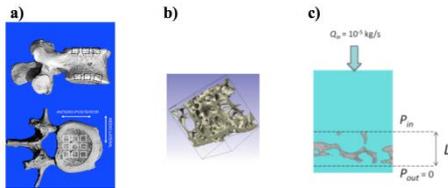


Figure 1. a) BEP samples within the vertebra. b) 3D reconstruction. c) Planar projection of the simulation conditions for the CFDA.

The BEP permeability effect on the disc nutrition was assessed with a finite element (FE) mechano-transport model of a L4-L5 IVD [2]. Two cases of extreme BEP porosity and permeability (the highest and the lowest) from the above CFDA were simulated. Two daily cycles of axial compression were applied: 16 hours at 0.5 MPa and 8 hours at 0.1 MPa.

Results and Discussion

Axial pressure drops clearly revealed the functional thickness for permeability calculations (Fig. 2a).

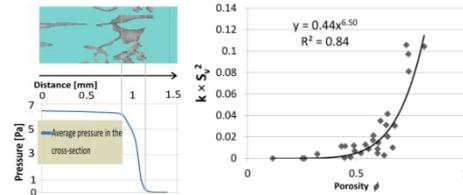


Figure 2. a) BEP functional thickness delimited by the area of pressure drop. b) Permeability-porosity correlation through the Kozeny-Carman model.

Permeability correlated positively with porosity by using both the Kozeny-Carman model (Fig. 2b) and general porosity-permeability relationships, together with other measurements from the literature. Calculated permeability values ranged from 2.60×10^{-14} to $1.56 \times 10^{-9} \text{ m}^2$ and porosities from 11% to 81%, covering part of the measured trabecular and cortical bone ranges [1]. The mechano-transport simulations performed with the above extreme values revealed relative differences lower than 1% in terms of oxygen and lactate concentrations. To our knowledge, this is the first explicit evaluation of the BEP-type bone permeability, independent from the subjacent cartilaginous endplate. Relevant to patient-specific studies, permeability could be easily derived from porosity via clinical CT images. We did not consider that BEP porosity changes might affect boundary concentrations of solutes. Nevertheless, varying both porosity and permeability over a large range did not affect the distribution of metabolites within the disc, which is affected chiefly by volume changes [2]. Thus, generic BEP poromechanical parameters may be used to study numerically disc tissue mechanobiology.

Acknowledgements

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References

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