PORE NETWORK MODELLING OF TPMS-BASED SCAFFOLDS FOR TISSUE ENGINEERING APPLICATIONS

Jorge E. Santos (1), Pedro S. Martins (2,3), Paulo R. Fernandes (1), André P. G. Castro (1,4)

1. IDMEC, Instituto Superior Técnico, Universidade de Lisboa, Portugal; 2. INEGI, Faculty of Engineering, Universidade do Porto, Portugal; 3. ARAID, i3A, Universidad de Zaragoza, Spain; 4. ESTSetúbal, Instituto Politécnico de Setúbal, Portugal

Introduction

The purpose of a Tissue Engineering (TE) scaffold is to provide support for cells adhesion, proliferation and differentiation into a specific phenotype. These cellular phenomena depend on the scaffold design and its structural properties (geometry, porosity, pore size, pore interconnectivity and surface area (SA)).

Pore size has been reported to influence the differentiation of Mesenchymal Stem Cells (MSCs) [1], as well as the scaffold fluid dynamics, which in turn plays an important part in cellular activity regulation. Therefore, pore size control (and quantification) is crucial to design scaffolds for complex tissue regeneration as in the osteochondral interface.

The objective of this work is to implement Pore Network Modelling (PNM) approaches for extraction of porous phase topological information as pore size distribution; additionally, to perform phase simulations over TPMS-based scaffolds for TE applications. We will use the simulation outputs to validate the models by comparing Darcian permeability values with experimental and CFD outputs from previous works [2], [3].

Methodology

We used the SNOW algorithm [4] and an adaptation of the Maximum Ball Algorithm (MBA) to perform the segmentation of the porous phase of 3D TPMS binary images into pores and throats that we used to perform phase simulations. Then, we choose the Hagen-Poiseuille equation (1) as our pore-scale physics model to calculate the pressure drop along throats.

$$\Delta P = g_h^{-1} \times Q = \frac{8\mu L_t}{\pi {r_t}^4} \times Q \qquad (1)$$

Finally, a StokesFlow algorithm applies a flow rate over the network and calculates its pressure drop assuming outlet pressure = 0. The algorithm builds the coefficient matrix from the existing values of hydraulic conductance (g_h) and adjusts the matrix to solve for pressure in each pore, storing the results. The pressure field is, therefore, immediately calculated and the absolute permeability of the network can be calculated using Darcy's law (Eq. 2):

$$Q = \frac{kA}{\mu L} \times \Delta P = \frac{kA}{\mu L} \times (\mathrm{Pin} - 0) \qquad (2)$$

Results

The implemented models allowed for permeability estimation in TPMS scaffolds with different porosities and basic designs (figure 1).

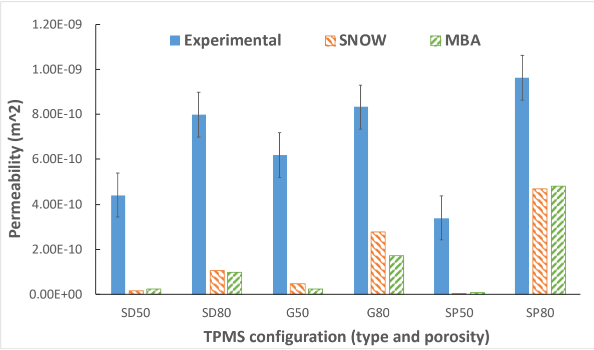

Figure 1: Darcian permeability of TPMS scaffolds calculated with two alternative PMN algorithms in comparison with the analogous experimental results.

Discussion

These algorithms still need some refining to completely resemble the transport of these (and other) TPMS scaffolds. In detail, improvements are necessary on the topological discrepancies of the methods used, and on fine-tuning the geometrical models implemented to the acquired network. However, the acquired permeability results are closer to the ones we estimated using the computationally more demanding CFD approach [3], still keeping the same hierarchy in terms of increasing permeability for increasing porosity.

Future work shall not only complete the refinement of the PMN approach, but also allow for the design of TPMS scaffolds for the osteochondral interface as a function of the pore size and transport properties.

References

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