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PERMEABILITY AND WALL SHEAR STRESS ANALYSIS IN SMOOTHED VS NON-SMOOTHED TPMS SCAFFOLDS

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Summary: When designing scaffolds for Bone Tissue Engineering (BTE) two fundamental characteristics to consider are the permeability of the scaffold and the Wall Shear Stress (WSS) that will affect the cells inside the scaffold. This is because different levels of WSS and permeability lead to different mechanical signals for the cells, which will in turn cause differences to the cellular differentiation process. These parameters are affected by various factors, with the major ones being the scaffold porosity, the scaffold geometry, and the topology of the scaffold surfaces. Accordingly, this study is focused on analyzing the differences in permeability and average WSS, in various Triply Periodic Minimum Surfaces (TPMS) scaffolds, with either smoothed or non-smoothed wall surfaces.
For this study two different TPMS structures were used (Schwartz D (SD), Gyroid (SG)), each one with three different levels of porosity (60%, 70% and 80%), resulting in a total of six different scaffold geometries. For each original geometry, a hexahedral mesh of a single cubic unit was created, alongside an empty chamber before and after the scaffold to allow the fluid flow to stabilize. Afterwards, a Laplacian smoothing step was applied to the inner surface of the scaffolds to obtain the smoothed scaffold geometries in an analogous tetrahedral mesh. Both the original and smoothed design were then studied using FLUENT® ANSYS® (Ansys Inc., Canonsburg, Pennsylvania, USA) to perform a Computational Fluid Dynamic (CFD) analysis to determine their average WSS and pressure difference. After obtaining these results, the permeability values of the scaffolds were calculated using Darcy's law. For these CFD analyses, the parameters chosen for the simulation were a fluid density of 1000 kg/m3; dynamic viscosity of 0.001 Pa.s and an inlet velocity of 0.0001 m/s.
Comparing the average WSS of the original scaffold surface with the analogous smoothed surface, the smoothed scaffolds had an average WSS increase of 26%, considering a minimum of 24.7% for the SG60 scaffold and a maximum of 27.2% for SG80. Regarding the permeability, the smoothed scaffolds had an average pressure drop decrease of 4% when compared to the original scaffold geometry, with a minimum of 3.6% for the SG60 scaffold and a maximum of 4.5% for the SD80 scaffold.
The WSS outputs showed a significant difference between the original and the smoothed TPMS scaffolds, with the smoothed surfaces allowing for higher WSS as theoretically expected. This difference highlights how the original jagged surfaces are not the best option to computationally analyze the average WSS of scaffolds, seeing as the increase in surface area compared to the smooth scaffold results in a much lower WSS. In contrast, the permeability results showed that, even thou the original scaffold design might not be suitable to study WSS, they present an appealing, lower computational cost method of study the pressure drop (and consequently their permeability) of BTE scaffolds.