MULTI-OBJECTIVE OPTIMIZATION OF TPMS SCAFFOLDS FOR IN VITRO BTE APPLICATIONS

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KEY-WORDS: Permeability; Wall Shear Stress; Computational Fluid Dynamics; Direct Multisearch

1 INTRODUCTION

Multiple factors must be considered when designing scaffold geometries meant for *in vitro* cellular processes, such as the scaffold's permeability and the average Wall Shear Stress (WSS) experienced by the cells [1]. Both parameters are important to take into consideration since both impact the cells behavior. Accordingly, the present work is focused on optimizing both parameters on Triply Periodic Minimum Surface (TPMS) scaffolds using a Direct Multisearch (DMS) algorithm regarding Bone Tissue Engineering (BTE).

2 METHODOLOGY

DMS is a derivative-free solver for multi-objective optimization problems which returns several solutions as a Pareto front [2]. In this work, this solver is used to optimize the permeability and the average WSS of TPMS Schwartz Diamond (SD) and Schoen Gyroid (SG) scaffolds for BTE. Two design variables were considered: the length of the single unit TPMS scaffold and the porosity of the structure. Two objective functions were defined, one for the permeability and one for the average WSS. Seeing as more permeable structures are preferable for cellular processes, the first objective function was defined as the minimization of the negative of the scaffold permeability. Regarding the average WSS, when designing scaffolds meant to promote osteogenic differentiation, the WSS experienced by cells needs to be between 0.1 and 10 mPa [3]. Therefore, a target average WSS of 5 mPa was defined as the second objective function for the DMS optimization, as an average value between the two edges of the accepted physiological levels. To determine these fluidic properties, a Computational Fluid Dynamic (CFD) analysis was performed for each optimization step.

3 RESULTS

The DMS optimization returned a Pareto Front with 79 and 116 solutions for the SD and SG scaffolds respectively (Figure 1). The permeability values ranged from $4.8*10^{-9}$ m^2 and $20.0*10^{-9}$ m^2 for the SD geometry and values between $4.4*10^{-9}$ m^2 and $31.8*10^{-9}$ m^2 for the SG geometries. The difference between the target average WSS and the average WSS from the simulations ranged from a difference of 0.01 mPa and up to a difference of 2.64 mPa for the SD and between 0.01 mPa up to 3.20 mPa for the SG. A possible solution for an optimal scaffold design parameters would be one which maximizes the permeability of the structure without deviating too much from the desired average WSS, as happens with the optimized scaffolds illustrated in table 1; these present, for each TPMS geometry, the design values as well as their permeability and average WSS (lower than 10% difference from the target 5 mPa).

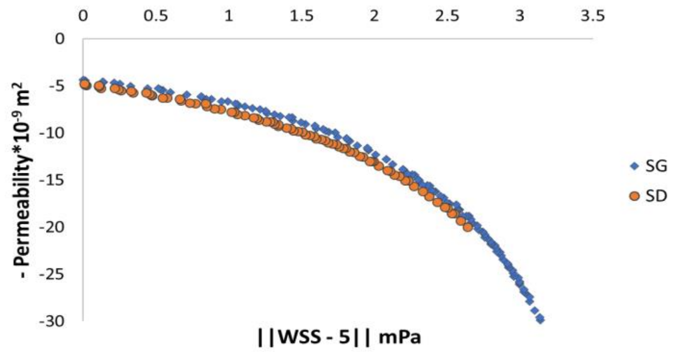

Figure 1 – Pareto front of the DMS optimization for the SD and SG scaffolds between permeability and target WSS.

Table 1 - Optimized scaffold parameters with the highest permeability with difference from the target WSS lower than 10%.

Geometry	Scaffold Length (mm)	Porosity (%)	Average WSS (mPa)	Permeability (10^{-9} m^2)
SD	2.75	61	4.53	6.0
SG	2.00	61	4.56	5.3

4 Discussion

The framework presented on this work proved to be an effective tool in assisting in the design of scaffolds for BTE. As expected, the CFD simulations demonstrated how maximizing the permeability of the scaffolds lead to a considerable decrease in the average WSS. The results also shown that for permeabilities lower than the maximum of $20.0*10^{-9}$ m^2 registered for the SD geometries, these scaffolds had a better permeability-WSS relation when compared to the SG ones. The present optimization framework using DMS can be adapted to analyze other geometries such other TPMS designs or lattice scaffolds, as well as other relevant factors in cellular differentiation such as surface curvature [4] or fluid flow velocity. Furthermore, this process can also be utilized in other applications besides BTE such as promoting cell differentiation into cartilage instead of bone tissue by adjusting the parameters of the objective functions.

ACKNOWLEDGMENTS

This work was supported by FCT, through PhD Grant 2020.04417.BD and projects LAETA Base Funding (DOI: 10.54499/UIDB/50022/2020) and LAETA Programatic Funding (DOI: 10.54499/UIDP/50022/2020)."

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