A PIPELINE FOR MECHANOBIOLOGY-DRIVEN DESIGN OF SCAFFOLD

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Introduction

Porous scaffolds are used for providing favorable micromechanical environments for cellular activities (e.g., cell attachment, differentiation, proliferation, etc.)[1]. To design the scaffold porous geometry for tuning micromechanical environment, the current available software (such as MSLattice and NTopology) has mainly focused on varying porosity. However, pore size, which is also an important parameter is largely ignored. In addition, numerous possibilities of scaffold geometries may cause high cost for trial-and-error scaffold design based on micromechanical environment. Therefore, in this study we aim to build a pipeline for mechanobiology-driven design of scaffold. This includes: (i) development of a software that allows precise and automatic generation of scaffold geometries for input variables of both pore size and porosity for different pore topologies; (ii) investigation of the porous geometry-influenced the fluidic properties - wall shear stress (WSS) and permeability for efficient mechanobiology-driven design of scaffold.

Methods

The triply periodic minimal surfaces (TPMS) topology has been commonly applied to scaffold design due to its advantages, such as high surface area to volume ratio, less stress concentration, and increased permeability. In our software development, different TPMS structure topologies (such as gyroid, FKS, etc.) were expressed using trigonometric equations combined with the level-set method as described in reference [2]. So, altering the level constant for these trigonometric equations and varying the overall dimensions of a structure could allow for pore size and porosity to be specified. To apply this software for investigating the scaffold porous geometry-influenced WSS and permeability, the following scaffolds were created: (i) TPMS structures (gyroid and FKS topologies) with the porosity and pore size of 50% – 90% and 600 – 1000μm; (ii) non-TPMS structure (cylindrical-beam struts) with the same porosity range and pore sizes of 300 – 1000μm, as a comparison. For saving the computational cost, these geometries were then simulated using a previously developed multiscale computational fluid dynamics (CFD) model [3]. An inlet fluid velocity of 1mm/s and an outlet pressure of 0Pa were applied to the macro model.

Results

Firstly, the scaffold design software that can accurately control the pore size, porosity for different TPMS pore topologies has been developed in this study (e.g., in Fig. 1). Secondly, from the CFD simulations, it was found that increasing pore size caused clear increases in permeability and decreases in WSS. Importantly, increasing porosity caused a slight increase in WSS and permeability, contrasting to pore size which had larger effects on both for all structures (TPMS and non-TPMS in Fig. 2). Furthermore, to allow fast estimation of WSS based on permeability, the empirical models were proposed to correlate these two parameters of the scaffolds (Fig. 2).

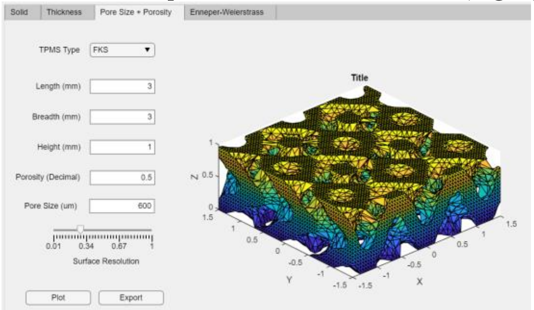

Figure 1: User interface of the scaffold design software, e.g., FKS geometry generated in it.

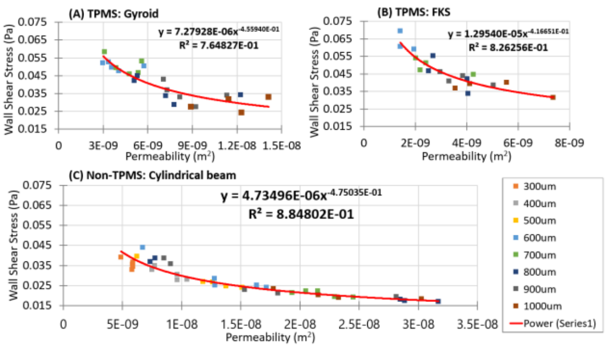

Figure 2: Permeability and WSS obtained from CFD simulation for the scaffolds with (A) gyroid structures, (B) FKS structures, (C) cylindrical-beam structures.

Discussion and Conclusion

The results indicate that pore size is an important variable for the fluidic properties. So, having a software, which comprehensively considers the porosity and pore size for TPMS structure generation is therefore necessary. For the application of this pipeline, the results of porous geometry-influenced WSS and permeability (Fig. 2) may help the users to determine the scaffold geometries according to their needs. Thereafter, the geometries will be generated in the design software. Moreover, the software allows the geometric data to be transferred to 3D printer for manufacturing. Furthermore, the empirical model will be useful for the circumstance that researchers need fast estimation of the WSS within scaffold based on the known permeability.

References

[1] Pires et al., Proc R Soc A: Math Phys Eng 478, 2257, 2022.
[2] Walker et al., Prog Addit Manuf 2, 99-108, 2017.
[3] Zhao et al., Biomech Model Mechanobiol 18, 1965-77, 2019.

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