HOW DO SINUSOIDAL SCAFFOLDS AFFECT FLUID FLOW-INDUCED WALL SHEAR STRESS AND MASS TRANSPORT?

Theresia Baumgartner (1), Markus Bösenhofer (2,3), Olivier Guillaume (4,5), Aleksandr Ovsianikov (4,5), Michael Harasek (2,3), Margit Gföhler (1)

1. TU Wien, Institute of Engineering Design and Product Development, Vienna, Austria; 2. TU Wien, Institute of Chemical Engineering, Environmental and Bioscience Engineering, Vienna, Austria; 3. K1-MET GmbH, Area 4 – Simulation and Analyses, Linz, Austria; 4. TU Wien, Institute of Materials Science and Technology, Vienna, Austria; 5. Austrian Cluster for Tissue Regeneration (*https://www.tissue-regeneration.at*), Vienna, Austria

Introduction

Bone is one of the most transplanted tissues. About 1.6 million bone grafts are performed each year only in the United States [1]. This treatment has serious drawbacks, such as a higher risk of infections or even donor site morbidities. Therefore, an alternative is the use of scaffolds to create bone tissue. The role of scaffolds in bone tissue engineering is to mimic the native bone tissue and is used to provide a template that supports seeded cells to get an optimal environment for their proliferation [2] to re-build the damaged structure. Hence, an optimal scaffold design is important and must be found because even small changes in the geometry of the pore network of the scaffold influences the process of cell growth and mechanical properties [2,3]. Wall shear stress (WSS) has a significant role in the differentiation of cells, especially for bone. Even minor changes in the flow field, especially near the wall regions, can directly affect cell bioactivity. Therefore, in this work, we use computational fluid dynamics (CFD) simulations to investigate the WSS and the effect of the flow rate on mass transport rates in scaffolds. The numerical results were compared to µ-particle image velocimetry (PIV) experiments to evaluate the reliability of the CFD method.

Methods

Scaffolds, which have a sinusoidal channel featuring different frequencies, amplitudes, and characteristic lengths, are computationally created and meshed in SALOME®, while the simulations are carried out using the open-source CFD toolbox OpenFOAM®. An incompressible Newtonian fluid with a dynamic viscosity of 0.000001 m^2/s is assumed. A diffusive-advective mass transport equation is solved on a laminar flow field using the solver *scalarTransportFoam* to evaluate the nutrient distribution on the scaffolds. The fluid flow is numerically solved by the three-dimensional Navier-Stokes equation. For the µ-PIV experiments, the simulated scaffolds are printed into a channel using the Two-Photon polymerization technique. The 3D printing process is based on cross-linking of photosensitive polymers induced by femtosecond pulsed lasers. A water suspension with 5 % of 2 µm Polystyrene fluorescent tracer particles is used to investigate the flow field inside the sinusoidal channel.

Results

The CFD results show that increasing the frequency or amplitude of the sine waves of the channel above a threshold frequency or amplitude lead to a velocity decrease inside the sine cavities and a formation of secondary vortexes. The µ-PIV measurements confirm the numerical results. Furthermore, the CFD results indicate that the WSS changes with flow rate and geometry and decreases with increasing frequency. Fig. 1 shows that for an inlet flow rate of 5 mm/s the WSS is highest at the negative peaks of the sine waves where the channel is narrowest. Inside the sine cavities, the WSS is below 0.1 Pa due to the lower velocities.

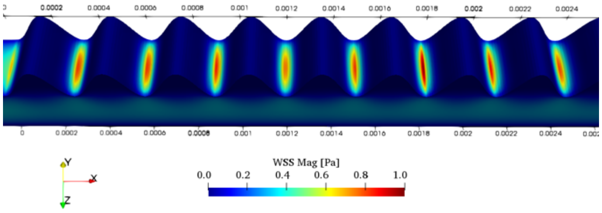

Figure 1: WSS for an inlet flow of 5 mm/s with a frequency of 3.5 mm^{-1} and an amplitude of 0.1 mm.

The mass transport of the nutrient inside the sinusoidal cavities is unevenly distributed and decreases, caused by lower concentration, over the length of the sinusoidal channel.

Discussion

As the results show, the sinusoidal texture decreases the WSS value below 0.1 Pa. This means that the sinusoidal geometry positively influences the WSS results and is compared to the channel wall at least 75 % lower. For the differentiation of cells to osteoclasts, a WSS lower than 0.057 Pa is recommended [4]. Besides the scaffold design, the flow rate is another important factor that affects the WSS results and can be decreased in the next step.

References

1. O'Keefe et al., Tissue Eng. Part B, Rev.: 389-392, 2011.
2. Campos Marin et al., Interface Focus, 5(2): 20140097, 2015.
3. Singh et al., Mater Today-Proc, 5: 18879-18886, 2018.
4. Porter et al., J. Biomech., 38(3): 543-549, 2005.