

A NANO-CT-BASED APPROACH TO INTERVERTEBRAL DISC ENDPLATE POROSITY AND FLUID FLOW MODELING

Ahmad Alminnawi (1)(2), Carla Geeroms (2), Liesbet Geris (1)(2)

1. GIGA In Silico Medicine, University of Liège, Belgium; 2. Skeletal Biology and Engineering Research Center, KU Leuven, Belgium

1. Introduction

Lower back pain (LBP) is the leading cause of disability worldwide, outpacing 290 other medical disorders [1]. Intervertebral disc (IVD) degeneration, a key contributor to LBP, is linked to dysfunction in the endplate (EP), which facilitates nutrient and waste exchange for the avascular nucleus pulposus [2]. Degeneration of the EP, characterized by increased stiffness and calcification, disrupts nutrient transport, exacerbating IVD degeneration. Additionally, the EP's mechanical environment, specifically wall shear stresses (WSS), regulates mechanotransduction pathways that influence key cellular behaviors. To study these effects in perfusion bioreactor experiments, it is essential to quantify the fluid flow through the samples. Therefore, we developed a semi-automated in silico tool for nano-CT-based modeling to analyze the mechanical environment and predict the osteochondral integrity of the EP.

2. Materials and Methods

Fresh bovine tails were obtained from a local abattoir, and osteochondral explants (OCX) were extracted and fixed in formaldehyde. To enhance visualization, samples were treated with Hexabrix under optimal conditions for IVD imaging [3] and scanned using CT at a 4 μm resolution. The resulting scans were processed using our in silico tool, which integrates three packages. First, the modeling package employs a Python script utilizing 3D Slicer to generate 3D surface STL models, refine them in MeshLab, and calculate pore diameters. Second, the simulation package, implemented via a Bash script, uses OpenFOAM to convert the surface model into a hexahedral-meshed volume and simulate steady-state incompressible flow through OCX pores, calculating velocity, pressure, and WSS distributions. Finally, the visualization package applies a Python script to operate ParaView, generating both quantitative and qualitative results.

3. Results

The pore diameter of OCX samples varied between specimens, resulting in non-uniform fluid flow despite identical experimental conditions, including inlet and outlet pressures and fluid properties. Consequently, even OCX samples from the same bovine experienced different average WSS, as shown in Figure 1.

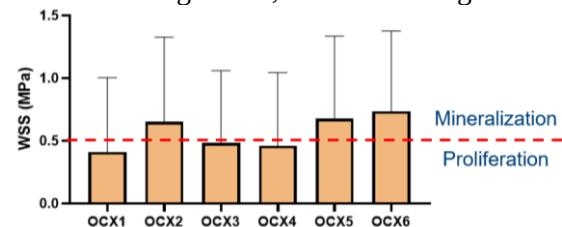


Figure 1: WSS experienced by samples of the same bovine under identical experimental conditions.

4. Discussion and Conclusions

Melke et al. [4] identified a WSS threshold that governs the transition from proliferation to mineralization. Despite maintaining identical experimental conditions, our results revealed that variations in pore diameter led to differences in fluid flow and WSS, causing some OCX samples to exceed this threshold. Such variability could introduce confounding effects in studies investigating external factors like media composition or mechanical compression. These findings highlight the importance of quantifying the WSS in perfusion bioreactor experiments to ensure reproducibility and reliable interpretation of results.

5. References

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