

nCT-Based Calculations of Perfusion-Induced Wall Shear Stresses in Osteochondral Explants of Intervertebral Discs

Cartilage endplates (CEP) are thin layer that separate bony endplates (BEP) from the intervertebral disc (IVD). They serve as the primary gateway for nutrients and waste exchange between the IVD and the vascular elements playing a crucial role in maintaining the health of the IVD.

A key factor linked to CEP health is wall shear stresses (WSS), which influences cellular behaviors such as growth, differentiation, and extracellular matrix production. These responses are mediated by mechanotransducers that regulate gene expressions and protein synthesis. Replicating relevant WSS is essential for studying IVD health in perfusion experiments. To support these studies, we developed an in-silico tool that quantifies WSS and calculates pore diameters of the osteochondral explants (OCX). This tool provides valuable insights into the mechanical environment of the IVD under different conditions, enabling precise replication of in vivo scenarios in experimental setups.

The in-silico tool takes CT scans of the OCX, pressures at the inlet and outlet, and fluid viscosity as inputs. It returns a 3D model of the OCX with its pore diameter in addition to inlet and outlet velocities with respect to time and WSS at the last time point of the simulation, either at steady state or after a preassigned duration. Firstly, 3D-slicer is used to create the model of the OCX and the connecting tubes. Secondly, MeshLab is run to refine the model before sectioning it into inlet, outlet, and walls. Subsequently, OpenFoam is used, meshing the model using localized mesh controls before running the computational fluid dynamics (CFD) analysis using a steady-state solver for incompressible flow following the SIMPLE (Semi-Implicit Method for Pressure Linked Equations) algorithm.

The tool has been tested on 21 OCX from 3 different fresh bovine tails. The results are specific to each sample as the natural morphology changes not only from one individual to the other but also with respect to vertebra level and side of the vertebra.

The pore diameters were determined to be on average $27\mu\text{m}$ which includes calcified CEP and BEP pores. From literature, we know that calcified CEP pores are typically below $10\mu\text{m}$, and that of BEP, including marrow spaces, are typically over $50\mu\text{m}$ but these sizes vary with age, degeneration, and disease conditions. The histograms show 6 different samples of one bovine tail. The two peaks suggest that there are indeed two types of pores present where one is less than $10\mu\text{m}$ and the other is larger than $20\mu\text{m}$ which is consistent with literature findings. Literature also showed that the lower bound of fluid-induced WSS for chondrocyte degeneration is 0.21 Pa . In our simulations and based on constant pressure differences of 1MPa between the inlet and outlet of the samples, we calculated that the average WSS would be around 0.57 MPa which exceeded the lower bound and would be useful to study OCX degeneration experiments.

The tool presented here enables the calculation of stresses in biological tissues, allowing a quantification of the required fluid flow rates in bioreactor setups to mimic physiological and pathological conditions in organ culture.

