

MODELING LYMPHATIC TRANSPORT: A COMPUTATIONAL MODEL OF A CONTRACTING LYMPHANGION

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1. INTRODUCTION

The lymphatic system is a somewhat neglected vessel system by the biomechanical community, despite its crucial role in maintaining the interstitial fluid balance, regulating immune defense mechanisms and the distress caused by lymphatic malfunctioning in lymphedema.

The lymphatic system is a one-way transport system. Interstitial fluid enters through the lymphatic capillaries (initial lymphatics) and is transported through our body via larger lymphatic vessels (collecting lymphatics). On its way, several lymph nodes are encountered. To pump the fluid (lymph) against adverse pressure gradients, the walls of the collecting lymphatics can contract to propel the lymph. Valves are regularly distributed along the way to prevent backflow. A contractile collecting vessel segment including two valves is called a lymphangion, which is the subject of our study.

2. MATERIALS AND METHODS

A model of a single lymphangion was made in COMSOL Multiphysics. The lymphangion was assumed to be 2D axi-symmetric to reduce the computational effort. The FSI (Fluid-Structure Interaction) multiphysics interface allowed to combine laminar flow and solid mechanics in order to model both the lymph flow and vessel wall deformations. The valves were modeled as porous media of which the permeability was defined as a function of the pressure difference across the valve, inspired by the equivalent circuit model of Bertram et al. [1]. This way, we could simulate opening and closing of the valves.

The pressures at the inlet and outlet of the lymphangion were kept fixed at 0 Pa. To simulate the contraction, a time varying load (start at $t = 0.5$ s, maximum at $t = 1.5$ s and end at $t = 2.5$ s) was applied on the outer part of the vessel wall in between the valves.

3. RESULTS AND DISCUSSION

Figure 1 displays how the applied load results in a pressure difference (solid lines) across the valves. This pressure difference determines the permeability (dotted lines) of the valves and as such also the valve state: open (high permeability) or closed (low permeability).

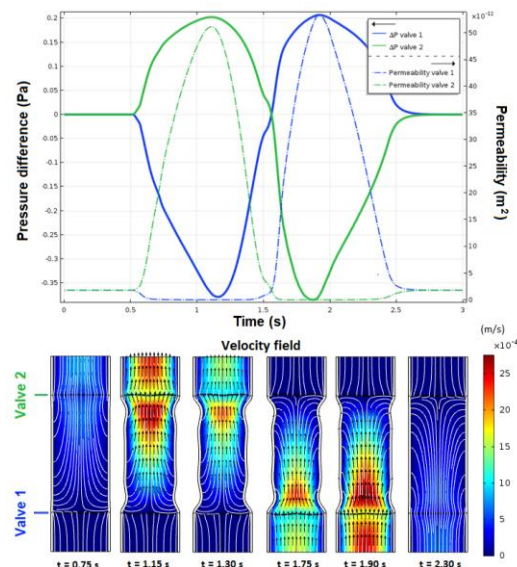


Figure 1: Evolution of pressure difference across the valves and permeability of the valves as a function of time (top) together with the velocity field (magnitude, streamlines and arrow surface) at different time points (bottom)

Overall, our COMSOL Multiphysics model succeeded in describing the normal physiological conditions of a single lymphangion. Backflow could be eliminated and velocities (0 – 2.5 mm/s) turned out to be in the same order of magnitude as reported in literature [2]. The model will be expanded to collecting vessels and multiple lymphangions in future work and validated against animal experiments.

References

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- [2] Rahbar, E. et al. *J Biomech*, 44(6), pp. 1001-1007, 2011. DOI: [10.1016/j.jbiomech.2011.02.018](https://doi.org/10.1016/j.jbiomech.2011.02.018)