LUMPED-PARAMETER MODEL OF A CHAIN OF LYMPHANGIONS IN SERIES – A PARAMETER SENSITIVITY STUDY

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Abstract

The lymphatic system has several vital roles in the human body including immune response. It collects 4 liters of interstitial fluid per day and pumps it back to the venous system to maintain fluid and protein balance. The pumping mechanism of lymphatic vessels makes the system interesting to an engineer. Valves are ubiquitous in the vessels to enable the one-way pumping process. Computational modeling of the pumping mechanism is providing better understanding of its mechanical behavior. The results can potentially help understand how to treat complex pathologies of the lymphatic system such as edema.

Our eventual goal is to develop a multi-scale model of the lymphatic network. So far a lumped-parameter model of a chain of lymphangions (lymphatic vascular segments) in series has been developed. Even at this early stage of development, there are many parameters involved in the model. Parameter sensitivity analysis has been performed in an initial attempt to determine the parameters that affect lymphangion pumping most strongly. Once the critical parameters have been identified, more accurate measurement of these parameters through experiments *in vivo* or *in vitro* will be required to refine their values. The results of a simple parameter sensitivity study of a chain of lymphangions in series are presented here.

Equations of conservation of mass, conservation of momentum and of vessel-wall force balance were solved for each lymphangion. The system of equations was solved in Matlab (R2010b). Single parameters were varied while all the other parameters remained constant. The sensitivity of the system to the parameter varied was assessed as the change in time-average flow rate (Q_{mean}) of the last lymphangion. The simulation outcomes were then compared to determine the parameters with the highest effect. For co-dependent parameters, both of the parameters were varied while all the others were constant. The model parameters can be classified into two main groups: lymphangion parameters and valve parameters. Among the lymphangion parameters, maximum active wall tension ($M_{1\text{max}}$) and lymphangion length (L) had the largest effect. Variation in L resulted in 5× increase in Q_{mean}. Maximum Q_{mean} was observed at L = 0.2–0.3 cm for most cases. Two-parameter sensitivity analysis for L and $M_{1\text{max}}$ showed that maximum Q_{mean} occurs at smaller lengths as $M_{1\text{max}}$ increases. Maximum valve resistance (R_{Vmax}) had the largest effect among the valve parameters, and caused up to 2.5× increase in Q_{mean}. These results suggest that future experiments should focus on more accurate measurements of geometrical features of lymphangions, particularly length, and better estimation of active wall tension.