A Computational Fluid Dynamic (CFD) Tool for Optimization and Guided Implantation of Biomedical Devices

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We are developing computational tools to perform virtual surgeries under physiological conditions with patient-specific anatomies. Virtual surgery can revolutionize the biomedical device (BMD) design and implantation by: enabling the optimization of BMD on the specific patient's anatomy and flow conditions, which has already been shown to significantly affect the hemodynamics; and facilitating surgical planning to select the best location/orientation for BMD implantation. As shown by past research the difference in the implantation, for example, of a bileaflet mechanical heart valve (BMHV) can affect the performance and hemodynamics of the valve. We have developed a powerful CFD tool that can simulate the blood flow through biomedical devices with moving boundaries and the fluid-structure interaction (FSI) under physiologic conditions. This tool has been tested in different applications with complex anatomic configurations, such as aneurysm hemodynamics, Fontan surgeries, and BMHV flows. The FSI simulations of a BMHV flow was validated against in vitro experiments and could capture all the flow features with great accuracy. We have recently carried out FSI simulations of a BMHV implanted in a anatomically realistic aorta in which the left ventricle (LV) was replaced by a pulsatile inflow waveform. In this work, we propose to extend our method to simulate the flow through a BMHV driven by the actual LV motion. The anatomy of the heart is obtained from MRI scan of unhealthy volunteer (St. Jude Hospital) and the left ventricle and the aorta geometry are extracted. The first step is to simulate the flow through a stationary LV with an implanted BMHV to test the capabilities of FSI-CFD tool in real anatomical setting. The second step is to impose theoretical kinematics for LV motion and test the interaction of the BMHV with the flow. The last step is to extract the real patient-specific LV wall motions from MRI data and specify it into the simulation. The shear stress and other parameters will be calculated in the flow field and the cardiovascular walls to identify the locations with high chance of blood cell damage. This work is supported by NIH Grant RO1-HL-07262 and the Minnesota Supercomputing Institute.

Design and Characterization of a Magnetically Driven Valveless Micropump for Drug Delivery

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Micropump, an actuation source to transfer the fluid from reservoir to the target place with accuracy and reliability, plays an important role in microfluidic devices. A broad range of micropump applications in biomedical fields are found in the fluid fine regulation and precise control systems for implantable drug delivery, chemical and biological detection, as well as blood transport in cardiology system. A polydimethylsiloxane (PDMS) magnetic composite membrane based on microfabrication with dimensions of 6 mm and 65 μm in diameter and thickness respectively, is employed to actuate a proposed micropump. In micro pumping operation, the fluid flow effects on the actuation and dynamic response of an oscillating membrane are curial to the design of the micropump. Therefore, the resonant frequency of this micro device is estimated considering the added mass and fluid damping to understand the behaviors of the valveless micropump. In this study, the membrane actuation is implemented by a miniaturized electromagnet, which provides an external time-varying magnetic field. The magnetic force on the membrane is proportional to the gradient of the magnetic field and the magnetization of the micro particles embedded in the membrane. The alternating attractive and repulsive magnetic forces on this composite membrane are computed by Finite Element Analysis (FEA). The basic design issues of the electromagnetic actuator involving air gaps, input current signals, and distribution of magnetic flux in the magnetic circuit are presented. Moreover, the magnetic-structure coupling analysis is conducted to determine the maximum deformation and stresses on the membrane, which result from the action of these magnetic forces. Finally, frequency-dependent flow rate of a dual-chamber configuration micropump has been studied. The pumping rate increases almost linearly with the excitation frequency at low ranges and there exists resonant frequencies at which the flow rate will reach a maximum value. After the flow rate peaks, the pumping rate decreases sharply along with the actuating frequencies. The maximum flow rate for the dual-chamber remains at $27.73\mu\mathrm{l/min}$ under 0.4 A input current with an excitation frequency of 3 Hz. For comparison, a single-chamber micropump reaches a maximum flow rate of $19.61\mu\mathrm{l/min}$ with a resonant frequency of 4.36 Hz under the same condition.

Keywords: MEMS, magnetic actuator, composite membrane, valveless micropump, PDMS

