Abstract

The present dissertation focuses on design of mechanical heart valves for smooth flow features and reduced blood damage. We have developed an immersed boundary based loosely coupled fluid structure interaction (IB-LC-FSI) method to predict the flow behavior due to motion of mechanical heart valve leaflets under pulsatile physiologically relevant blood flow conditions. This solver is tested over several benchmark problems. The stability of the present loose coupling scheme for simulating FSI of solids having low mass ratio is found to be determined by the local mass divergence, and hence on the spatial resolution near the intercepted cells. The present solver is optimized for GPU accelerators using openACC. We have used asynchronous data transfer using message passing interface (MPI) to accelerate the solver on multi-GPU systems using domain decomposition. A simplied model of aortic configuration is considered as planar sudden expansion geometry with pulsatile inflow. Different flow modes are observed as function of the reduced velocity and amplitude of the pulsation cycle. The symmetry-breaking bifurcation phenomena is studied for different pulsation parameters and the obtained critical Reynolds numbers for bifurcation are compared with that obtained from the Floquet analysis. The effects of blood rheology on the flow structures over hinged mechanical heart valves are studied. We have performed direct numerical simulation by deploying a mesh with a resolution of the order of the Kolmogorov length scale. It is noted that the predicted leaflet kinematics and the arterial wall shear stresses do not show significant sensitivity to the viscosity models. However, we have predicted significantly enhanced levels of blood damage index using Carreau rheology model as compared to the Newtonian fluid model. Mechanical heart valves causes a disorganized and incoherent flow in majority of the cardiac cycle, which inturn induces higher levels of blood damage index compared to the native or bioprosthetic counterparts. Hence, the present research attempts to ameliorate the flow features due to mechanical heart valves via design modifications of the shape of the leaflets. This is done by reducing the thickness of the leading and trailing edges of the leaflets. The modified valve model is found to substantially improve the flow dynamics past the valves and reduce the blood damage index considerably. The proposed valve model also attributes slightly higher effective orifice area and substantially reduced flow energy losses.
Keywords: Fluid structure interaction, GPUs, Sudden expansion flows, Hemodynamics, Vortex dynamics, Bi-leaflet Mechanical Heart Valves, Shape optimization.