Immersed boundary model of aortic heart valve dynamics with physiological driving and loading conditions

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Simulations Done Using NYU HPC Cluster

The opening and closing dynamics of the model aortic valve
The lower inset shows the prescribed driving pressure (blue curve) and computed loading pressure (green curve). The upper inset shows the computed flow rate through the model valve (blue curve). Net flow through the model valve is approximately 65 ml per cardiac cycle, which is within the physiological range. Notice that the flow rate is not specified in the model; rather, it emerges during the course of the fluid-structure interaction simulation.

The opening and closing dynamics of the model aortic valve

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The opening and closing dynamics of the model aortic valve along with the axial (streamwise) fluid velocity

The fluid velocity is shown on a plane that bisects the model vessel and one of the model valve leaflets. Forward flow is indicated in red, reverse flow is indicated in blue. Notice that, except for the first beat, the model valve permits essentially no regurgitation during closure.

Figure 6. Results from a multibeat simulation of aortic valve dynamics. The familiar S2 (“dup”) heart sound is clearly visible in the flow trace (panel A) and the aortic loading pressure (panels B and C). Notice that the model, which is driven by a periodic left-ventricular pressure waveform, rapidly approaches a periodic steady state. A. The flow rate through the valve as a function of time. Mean stroke volume is approximately 65 ml for both the second and the third beat, and the peak flow rate is approximately 420 ml s⁻¹. We emphasize that the flow rate is not specified in the model; rather, it emerges from the fluid-structure interaction simulation. B. The prescribed left-ventricular driving pressure \( P_{LV}(t) \) and the computed loading aortic pressure \( P_{Ao}(t) \). The pressures \( P_{Ao}(t) \) and \( P_{Wk}(t) \) determined by the coupled Windkessel model.

Figure 7. The opening dynamics of the valve during the second cardiac cycle, shown at equally spaced time intervals. A. The valve leaflets, as seen from the downstream boundary of the model. B. The model valve and vessel and the streamwise (\( u_3 \)) component of the flow velocity along a plane that bisects one of the valve leaflets. C. Similar to B, but also showing the adaptively refined Cartesian grid.

Figure 8. Similar to fig. 7, but here showing the closing dynamics of the valve during the second cardiac cycle. Notice that although there is minor regurgitation during valve closure, fig. 6A shows that once closed, the valve permits no further leak.

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