Immersogeometric Fluid–Structure Interaction Analysis of Patient-Specific Aortic Valve Designs

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ABSTRACT

In this work we present fluid–structure interaction (FSI) modeling and simulation of patient-specific aortic valve designs. The patient-specific aortic root geometry is reconstructed from the medical image data using a non-uniform rational B-spline (NURBS) surface. We then parametrically design prosthetic valves according to the aortic root, using a Rhino/Grasshopper-based interactive geometric design platform. Due to the complex motion of the heart valve leaflets, the blood flow domain undergoes large deformations, including changes of topology. Our immersogeometric method directly analyzes a spline-based surface representation of the heart valve geometry immersed into an unfitted trivariate NURBS discretization of the surrounding fluid domain. A hybrid immersogeometric/arbitrary Lagrangian–Eulerian methodology allows us to efficiently perform a computation that combines a boundary-fitted, deforming-mesh treatment of the artery with a non-boundary-fitted treatment of the leaflets. We simulate the coupling of the deforming, patient-specific aortic root and valve, and the surrounding blood flow under physiological conditions through an entire cardiac cycle. The attachment edge of the valve is coupled with the arterial wall motion using a penalty approach. The results demonstrate the effectiveness of the proposed techniques in practical computations with greater levels of physical realism. A parametric study is carried out to investigate the influence of the geometry on valve performance. Finally, the simulation results of flow patterns in the artery are compared with phase-contrast MRI data.