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Fluttering of an aortic valve bioprosthesis with the Lattice Boltzmann method coupled to a finite element solver for fluid structure interaction

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In order to deal with fluid structure interaction, an immersed boundary method (IBM) is coupled to a Lattice-Boltzmann solver (ProLB) based on the Hybrid Recursive Regularized[1] (HRR) collision model, and a finite element solver (Calculix) with the explicit Hilber-Hughes-Taylor method. An explicit coupling between the Lattice Boltzmann solver and the finite element solver is developed[1].

We use this numerical framework to analyze the behavior of the opening bioprosthesis aortic valve, and more specifically to investigate the flutter of the valve leaflets. The complex structure of the valve is performed by a hyperelastic and anisotropic model, and the blood is approximated with a Newtonian fluid.

Valve leaflets fluttering is a common fluid-structure instability that may occur during aortic valve opening. This phenomenon is likely to disrupt the hemodynamics and behavior of the valve. 2 different types of flutter are identified, a very high amplitude one, seemingly problematic, and one with relatively low amplitude. A parametric study of the valve geometry is carried out. Variation in leaflet diameter, thickness, and curvature are shown to play an important role for the flutter intensity.

Hemodynamic criteria such as maximum velocity, valve pressure gradient, and mechanical criteria such as opening area and wall shear stress are analyzed. The results show that large-amplitude flutter causes high blood acceleration across the valve, which greatly disrupts flow. In addition, the leaflets oscillations results in periodic additional stresses several times per cardiac cycle.

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[1]T. Fringand et al., *Journal Comput. Methods Appl. Mech. Engrg* **421**, 116777 (2024)