

Development of a computational platform for numerical investigation of blood flow-heart valve interaction

General context

According to the Global Burden of Disease (GBD) study in 2019, CardioVascular Diseases (CVD) still remains the leading cause of global mortality and a major contributor to disability^[1]. Valvular Heart Disease (VHD) is a major type of CVD, which involves the failure or dysfunction of one or several heart valves, such as the aortic valve stenosis and regurgitation etc. In case of severe VHDs, it is often recommended to carry out the valve replacement operation through a surgical or transcatheter intervention^[2].

Comparing with rigid mechanical heart valves, deformable bioprosthetic valves generally have better biocompatibility and better hemodynamic performance. Up to now, most bioprosthetic valves are made of either bovine pericardium or porcine aortic valves, such as the Sapien 3 of Edwards Lifesciences, etc. The main risk of bioprosthetic valves is the reoperation due to the limited durability^[3].

As an alternative to experimental test, numerical simulation plays an important role in the design and optimization processes for improving the performance and durability of bioprosthetic valves. Hence, it is of primary importance to have a powerful numerical tool allowing for efficient and robust simulation of the blood flow-heart valve interaction problem. However, to simulate the targeted Fluid-Structure Interaction (FSI) in an efficient and precise way remains a challenging task, as this type of FSI problem generally has some difficulties such as the complex geometries, large structural deformation and contact problems between leaflets, as shown in Fig. 1.

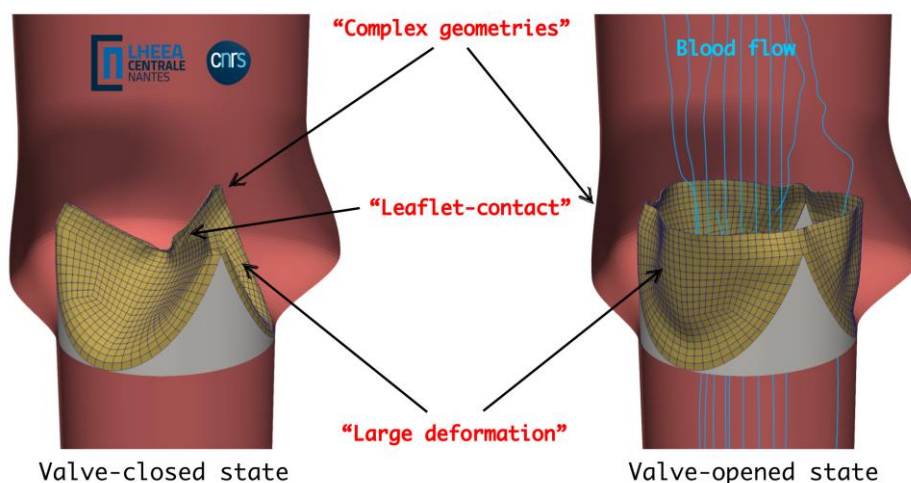


Fig. 1 Challenges in numerical simulation of blood flow-heart valve interaction

Scope and objectives

In recent years, the MELUHSINE research group at the LHEEA laboratory has developed a computational framework for simulating blood-valve interactions^[7]. This FSI framework integrates in-house computational codes based on advanced numerical methods, allowing for the modeling of transient intracardiac blood flows using Lattice Boltzmann Method (LBM)^[4] through the aortic valve with leaflets modeled by non-linear Finite Element Method (FEM)^[6]. The LBM-FEM coupling is ensured via Immersed Boundary Method (IBM)^[5].

In this PhD study, the focus is given on the enhancement of the developed computational platform in terms of robustness and efficiency, in order to take into account more physical phenomena in realistic physiological conditions, such as the leaflet contact, the movement of the left ventricle wall as well as the mitral valve, etc.

Major steps

- 1) The PhD research work will proceed with a thorough bibliographic review on the existing numerical frameworks;
- 2) Propose and implement computational techniques for the above mentioned physics in realistic physiological conditions;
- 3) Carry out 3D FSI numerical simulation of blood-heart interaction using personalized MRI measurements;
- 4) Validate the developed platform with existing numerical and experimental references;
- 5) Explore the applicability of the platform serving for assessing surgical intervention strategies.

Expected skills

The PhD candidate should have an educational background (Master degree) in mechanics and/or applied mathematics with solid knowledge and competence in numerical analysis and computational programming. He/she should be passionate about numerical simulation methods such as FEM, LBM etc. The candidate should have coding experience with programming languages such as Fortran or C/C++. He/she should be interested in developing novel numerical schemes and applying them in biomechanical applications.

Supervision

This PhD study will be supervised by Dr. Guillaume Oger (guillaume.oger@ec-nantes.fr) who is the leader of the research group MELUHSINE inside the LHEEA fluid mechanics laboratory at Ecole Centrale de Nantes.

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