VIRTUAL BENCH TESTING OF MECHANICAL HEART VALVES: A PRELIMINARY FLUID-STRUCTURE INTERACTION STUDY

Mariachiara Arminio (1), Dario Carbonaro (1), Sara Zambon (1), Alessandro Scattina (1), Lorenzo Peroni (1), Umberto Morbiducci (1), Diego Gallo (1), Claudio Chiastra (1)

1. Department of Mechanical and Aerospace Engineering, Politecnico di Torino, Italy

Introduction

Aortic valve disease is a highly impactful condition. A primary treatment approach consists in replacing the native valve with a prosthetic one. According to recent guidelines [1], surgical mechanical prosthetic valves should be the first choice in patients under 50 years of age with no contraindication to anticoagulation therapy and they may be considered in patients up to 65 years of age. Over the last years, computational models have emerged as a powerful tool for the study of these devices. Fluid-structure interaction (FSI) simulation is currently the most exhaustive approach as it accounts for both the solid domain mechanics and blood flow dynamics [2]. In this context, this work presents a computational framework for the FSI simulation of mechanical aortic valves, aiming at providing a robust and affordable tool supporting their design and optimization, potentially replacing *in vitro* tests recommended by the standard ISO 5840:2021.

Methods

An idealized geometrical model of the aortic root including a portion of the ascending aorta and the left ventricular outflow tract was created using HyperMesh (Altair Engineering, MI, USA) [3]. A geometrical model of a commercial mechanical bileaflet aortic valve (St Jude Medical Regent bileaflet valve, Abbott Laboratories, IL, USA) with a size of 25 mm was generated using SolidWorks (Dassault Systèmes, FR) (Fig. 1A). The two models were assembled by placing the valve cuff in supra-annular position. The resulting model was meshed in HyperMesh. The fluid volume enclosed by the aortic root was discretized with ~931k hexahedral elements, valve leaflets were discretized with ~2,7k quadrilateral shell elements each, and valve frame and cuff were discretized with ~28k and ~26k tetrahedral elements, respectively. FSI simulations were performed using LS-DYNA 971 R13.0 (Ansys Inc., PA, USA), with an "operator split" Lagrangian-Eulerian approach, to model the interaction between the fluid domain and the valve. Physiological pressure waveforms were imposed at the inlet and at the outlet of the fluid domain (Fig. 1B). The no-slip condition was applied at the solid-fluid interface. The aortic root was assumed as a rigid wall boundary.

Results

The contour maps of the velocity magnitude confirm the capability of the FSI approach in replicating the expected kinematics of valve opening/closure and the resulting fluid dynamics (Fig. 1C). Regarding the latter, the FSI model appropriately replicates: (1) the three distinct jets configuration characterizing systolic flow, a consequence of the three-orifices configuration of the bileaflet mechanical valve; (2) the flow field during valve closure, when blood flow is accelerated across the closing leaflets; (3) the low velocities in the aortic root along late diastole, despite the expected minor leakage. The FSI simulation enabled the *in silico* evaluation of the effective orifice area (EOA), which for the case under study was equal to 2.46 cm^2, thereby satisfying the EOA requirement indicated by ISO 5840:2021.

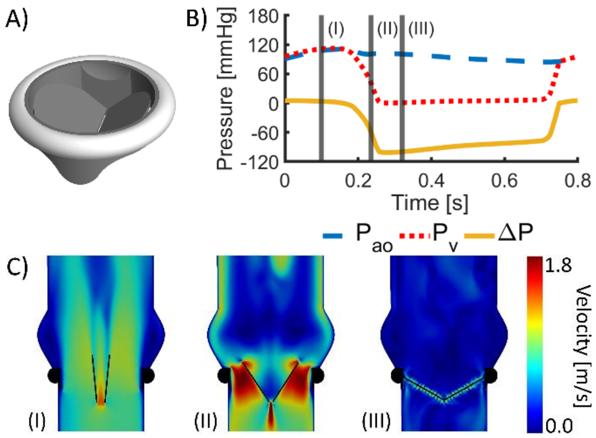

Figure 1: A) CAD model of the valve; B) Aortic pressure (P_{ao}), ventricular pressure (P_v), and transvalvular pressure drop (ΔP) waveforms; C) Velocity magnitude contours on a long-axis section during the systole (I), valve closure (II) and diastole (III).

Discussion

The preliminary results of this work suggest that the proposed FSI framework, based on a Lagrangian-Eulerian formulation, is capable of successfully capturing the kinematics and fluid dynamics features of a mechanical heart valve. In future research, this simulation approach will be adopted to study various scenarios with different anatomical aspects (e.g., aortic wall curvature, presence of the coronary arteries), methodological aspects (e.g., aortic wall distensibility, different blood rheological model), and mechanical valve designs.

References

1. Otto et al, Circulation, 143:e35-e71, 2021.
2. Nobili et al, J Biomech, 41:2539-2550, 2008.
3. Carbonaro et al, Struct Multidiscip Optim, 64:1825-1842, 2021.