Influence of prosthetic mitral valve orientation on left ventricular flow

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Introduction
The valves of the heart direct the blood pumped by the cardiac muscle from venous to arterial side. Due to pathological changes, the function of a valve may be compromised to the extent that it needs to be replaced. In many cases a mechanical prosthesis will be chosen due to its high durability (figure 1). Prosthetic mitral valve orientation affects ventricular flow and consequently might affect mitral-aortic valve-valve interaction and related cardiac output. As depicted in figure 2, two different valve orientations result in a significantly different vortex structure. In these preliminary computations the valve was modeled as a rigid obstacle.

Figure 1: Prosthetic heart valve

Figure 2: Preliminary computations with a simple valve model in two orientations at peak flow rate during filling (top). Red means upward flow, blue downward. Below, the corresponding experimental visualizations are shown.

Objective
- In this work the influence of prosthetic mitral valve orientation on left ventricular flow is studied.
- Furthermore, valve dynamics, resulting mitral-aortic valve-valve interaction and related cardiac output will be looked into. To this end a more sophisticated valve model is needed.

Methods
A 3D computational model is developed using an arbitrary Euler-Lagrange finite element method to solve the instationary Navier-Stokes equations for Newtonian fluids. The velocities of the valves and the fluid are coupled using a fictitious domain method. Experimental validation was done with Particle Image Velocimetry measurements.

Results
The computational method was applied to a 2D aortic valve model with sinus cavity and validated with PIV measurements (figure 3). Next, the computational method was used to study interaction between valves in a simplified ventricle geometry. A physiologically relevant flow rate and transvalvular pressure gradient were applied. The results (figure 4) show that a certain amount of fluid regurgitates during valve closure, affecting the cardiac output.

Figure 3: Results of the aortic valve model

Figure 4: Fluid velocities, valve velocities and valve positions in a simple ventricle model at eight equidistant points in the flowcycle.

Conclusions and Discussion
- A preliminary 3D model shows that a 90° rotation of a simple valve in the mitral orifice results in a significantly different ventricular flow field.
- A fictitious domain method was successfully used to model moving rigid valves in a fluid with a high transvalvular pressure gradient in closed state.
- The results also show that the cardiac output depends on the dynamics of the valve.

A realistic 3D model will enable the prediction of optimal prosthetic mitral valve orientation for specific patients preoperatively and allow for improved cardiac performance after implantation. Furthermore, the 3D model can be used to improve and optimize new and existing valve designs.

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