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Influence of prosthetic mitral valve orientation on left ventricular flow

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Introduction
General geometrical properties of prosthetic heart valves in mitral position but also the alignment of implantation are believed to significantly influence the flow pattern in the left ventricle. Therefore, knowledge of the flow properties in the ventricle is of great importance to the optimization of valve designs and to the determination of the optimal orientation of a prosthetic mitral valve. The latter point was confirmed by preliminary computations and experimental visualization. In these preliminary computations a simple valve model that consists of a thick plate placed in the mitral orifice was used. Results of two orientations are shown in figure 1.

Results
Experimental
2D PIV measurements have been performed on a pulsatile flow in the experimental setup of figure 2. Figure 3 shows the results of these measurements. Reynolds numbers of 1000 during peak flow were reached.

Computational
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 valve and the fluid are coupled using a fictitious domain method.

Discussion
The 3D model shows that a 90° rotation of a rigid obstacle in the mitral orifice results in a significantly different ventricular flow field.

Methods
Experimental
3D Particle Image Velocimetry (PIV) will be used to measure the flow in an experimental model of the left ventricle.

Computational
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 valve and the fluid are coupled using a fictitious domain method.

Figure 1: Preliminary computations with two valve orientations at peak flow rate during filling

The general objective of this study is to analyse the flow in a left ventricle model by means of an experimentally validated 3D computational model. This model will be used to study the influence of mitral valve orientation on ventricular flow. In order to develop a more sophisticated valve model that can be used for both mitral and aortic valves, a 2D model of the aortic valve is studied.

Figure 2: Measurement section of experimental setup

Measurements are conducted in a 2D model of the aortic root with a sinus cavity as shown in figure 2. In the cavity a rigid leaflet is fixed along one edge, allowing rotation of the leaflet.

Figure 3: Results of computations (left) and experiments (right) after the flow pulse (top) and during regurgitation (bottom)

Discussion
The 3D model shows that a 90° rotation of a rigid obstacle in the mitral orifice results in a significantly different ventricular flow field.

In the 2D model, where a fictitious domain method is used for modelling moving valves in a fluid, the experimental PIV results match the computations.

Extension of both experimental and computational methods to 3D flow will enable to analyse the flow in the left ventricle and the influence of mitral valve orientation. This 3D model will enable the prediction of optimal prosthetic mitral valve orientation for specific patients pre-operatively 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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