# Influence of Prosthetic Mitral Valve Orientation on Left Ventricular Flow

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## Abstract

*The geometry and orientation of implantation of prosthetic heart valves have a major influence on the flow pattern in the left ventricle. Consequently for the developers of prosthetic heart valves knowledge of the flow properties in the ventricle is of great importance to optimization of the designs, and to determination of the optimal orientation. The objective of this study is to analyse the flow in a left ventricle model by means of an experimentally validated 3D computational method. The computational method, using an arbitrary Euler-Lagrange finite element method to solve the instationary Navier-Stokes equations for newtonian fluids, was applied to two orientations of a model mitral valve prosthesis and showed significantly different flow fields for the two cases. Quantitative experimental measurements using Particle Image Velocimetry were carried out to enable validation of the computational method.*

## 1. Introduction

It has been reported in literature that the flow pattern in the ventricle is greatly influenced by the orientation and geometry of prosthetic heart valves[1, 2]. This means that knowledge of the flow properties in the ventricle is of great importance to the optimization of the designs and to the determination of the optimal orientation of the valve prosthesis. The objective of this study is to analyse the flow in a left ventricle model by means of an experimentally validated 3D computational method. The method is used to investigate the influence of the orientation of a bileaflet mitral valve prosthesis (as shown in figure 1) on local flow phenomena in the left ventricle. A transparent rubber model of a ventricle, geometrically based on MRI images of a young healthy volunteer, together with an in-vitro experimental set-up were developed in which physiologically relevant pressure and flow pulses were generated in a viscosity matched newtonian fluid. Global velocity fields in several planes were visualized. To simulate these velocity fields numerically, a 3D computational model using an arbitrary Euler-Lagrange finite element method to solve the instationary Navier-Stokes equations for newtonian fluids was used. Mesh

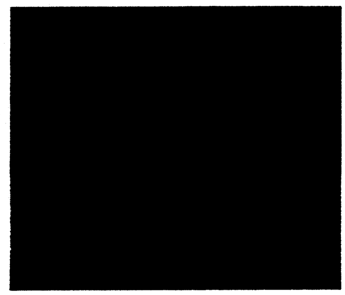

Figure 1. Carbomedics bileaflet heart valve prosthesis

deformation was prescribed such that the wall movement mimics that of the experimental model. Reynolds numbers up to 1000 were applied. Both the experimental visualization and the computational model showed that mitral valve orientation indeed is important for the flow pattern downstream of the valve. A 90 degree rotation of the mitral valve prosthesis resulted in significantly different flow fields. The 3D computational model of the left ventricle at this stage incorporates a simple valve model. In order to develop a more complex valve model a 2D computational model of the aortic valve was studied. For validation purposes an experimental setup of the aortic root with a sinus cavity was built in which 2D Particle Image Velocimetry measurements were performed. Improvement of the present 3D computational model of the left ventricle is expected to result in simulations for physiologically relevant Reynolds numbers while quantitative experimental measurements using Particle Image Velocimetry will enable thorough validation of the computational method. This computational method may enable the prediction of optimal valve orientation in a patient specific clinical situation and contribute to improved surgical planning.

## 2. Methods

### 2.1. Computational method

A 3D computational model of the left ventricle was developed using an arbitrary Euler-Lagrange finite element method to solve the instationary Navier-Stokes equations for newtonian fluids:

$$\rho\left(\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} - \mathbf{g}) \cdot \nabla \mathbf{v}\right) = \nabla \cdot (-p\boldsymbol{I} + 2\eta \boldsymbol{D}) \quad (1)$$

$$\nabla \cdot \mathbf{v} = 0 \quad (2)$$

where $\rho$ denotes the density, $t$ the time, $\mathbf{v}$ the fluid velocity, $p$ the pressure, $\eta$ the dynamic viscosity of the fluid, $\boldsymbol{D}$ the deformation tensor, $\nabla$ the gradient operator and $\mathbf{g}$ the grid velocity.

Computations were performed on the mesh shown in figure 2 which consists of 1620 quadratic 3D brick elements (27 nodes per element).

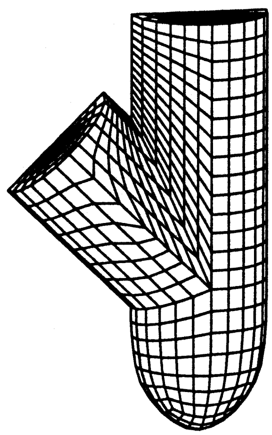

Figure 2. Mesh for finite element computations

The deformation of the mesh was prescribed such that the wall movement mimics the wall movement of the experimental model. The mitral valve was modeled as a thick plate placed in the mitral orifice. The valves were modeled opened or closed, without transition. In order to develop a better valve model a 2D model of the aortic root was studied. Fluid-stucture interaction was modeled using a fictitious domain method as described in [3, 4]. Using this method coupling of fluid and solid velocities is achieved by enforcing along the fluid-solid interface boundary the velocity constraint $(v_f - v_s) = 0$.

## 2.2. Experimental method

A transparent EPDM rubber model of the ventricle geometrically based on MRI images was mounted in a plexiglass box (see figure 3).

The model was deformed by changing the volume of the plexiglass box. Physiological flow and pressure pulses were generated in a viscosity matched newtonian fluid. 3D Particle Image Velocimetry is used to measure the flow

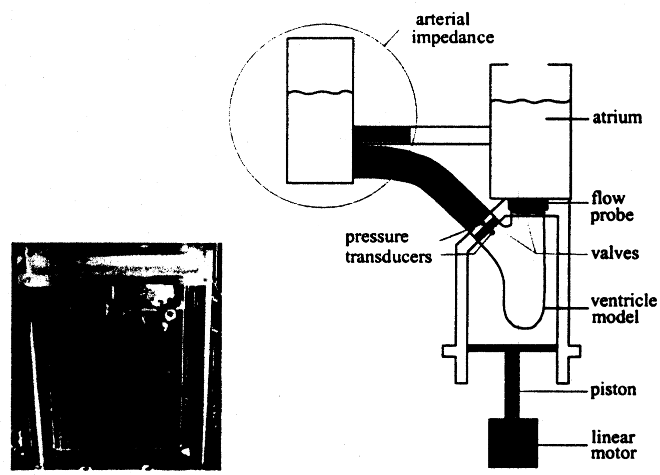


Figure 3. Experimental setup to study ventricular flow

in the experimental model of the left ventricle. For this purpose the fluid inside the model is seeded with small light-reflecting particles which are illuminated by a laser sheet at which 2 cameras are focused. Using a correlation technique on the camera images three components of the velocity in the illuminated plane can be reconstructed. Additional measurements are conducted in a 2D model of the aortic root with a sinus cavity as shown in figure 4. In the cavity a rigid leaflet is fixed along one edge, allowing rotation of the leaflet.

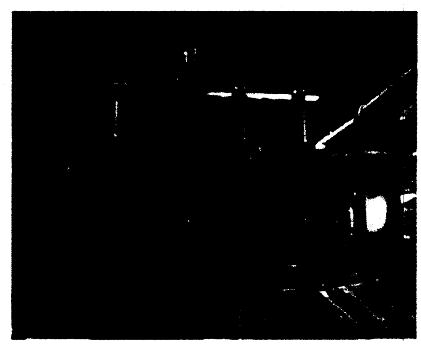

Figure 4. Experimental setup of aortic root with sinus cavity

## 3. Results

### 3.1. Computational

The results of the computations presented in figure 5 show significant differences in the flow fields in the model ventricle if the orientation of the valve is rotated over 90 degrees.

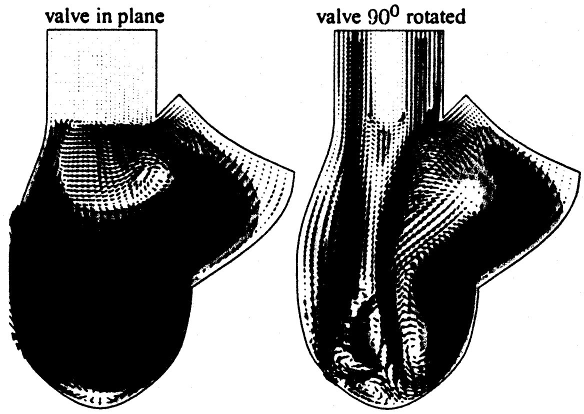


Figure 5. Results of FE computations with two valve orientations.

In figure 5 the computed velocity fields in an intersection of the ventricle (four chamber view) are presented. In the left plot the valve is in the plane of the intersection while in the right plot the valve is perpendicular to this plane. The velocity field in the left plot shows mostly blood flow in the direction of the valve base while in the right image two jets with flow towards the apex can be seen with reversed flow along the heart wall. Furthermore it can be seen that there are some vortices near the apex in the case of the rotated valve which are not present in the other case. Furthermore 2D computations of the fluid-structure interaction model of the aortic valve have been performed. The results show a large vortex developing in the sinus cavity during deceleration of the fluid and are shown in figure 6.

## 3.2. Experimental

2D PIV measurements have been performed on a pulsatile flow in the experimental setup of figure 4. Results of these measurements are shown in figure 6.

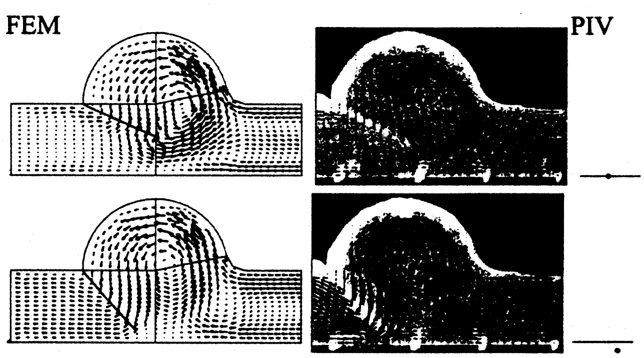


Figure 6. Computational (left) and experimental (middle) results of 2D flow in aortic valve model and point in flow pulse (right).

The results of the PIV measurements show the development of a large vortex in the sinus cavity during deceleration of the fluid and some smaller vortices downstream the cavity.

## 4. Discussion and conclusions

3D computations in a left ventricle model with a simple valve model have been performed which show a significant influence of the orientation of the model valve on the development of the flow field in the ventricle. Quantitative experiments have not yet been performed but visualizations confirm the computational results. Improvement of the present computational model is expected to result in simulations for physiologically relevant Reynolds numbers while quantitative experimental measurements using PIV will enable validation of the computational method. 2D computations of a fluid-structure interaction model using a fictitious domain method have been performed. The 2D experimental PIV results match the computations. Extension of both experimental and computational methods to 3 dimensional flow will enable to analyse the flow in the left ventricle and the influence of mitral valve orientation thereon. This 3D model may enable the prediction of the optimal valve orientation for specific patients pre-operatively and allow for improved cardiac performance after implantation of heart valve prostheses. Furthermore the model may be used to improve and optimize new and existing valve designs.

## References

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