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The effect of percontenous valve design on coronary perfusion

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The main goal of the study is to examine *the role of valve's design on diastolic flow*, and specifically *on coronary perfusion*. The expected results are the description of flow patterns in the aortic root and its effect of coronary proximal pressure and flow during the diastolic phase.

The chosen *method* for the investigation was a combination of *experimental* and *numerical* simulation study. In this report we describe the actions taken during the last 12 months of the numerical and experimental research.

Numerical Simulations

Development of the numerical model included: examination of different numerical packages, building a geometric model, definition a working numerical model, validation and result analysis.

1. **Selection of the suitable package for Fluid-Structure Interaction simulation**
   We examined several options for the simulation package. The requirements were for strong FSI coupling to enable the large and rapid deformation of the thin leaflets while preserving a proper mesh quality.
   The following simulation codes were examined for their possibilities, features and problems:
   A. Integrated system FlowVision + Abaqus (a combination of two packages): This method was previously used for simplified geometries of leaflets motion, however requires staggered-iterative coupling between the two packages and automatic mesh generation at each time-step. Therefore, this combination is very sensitive to coupling instabilities and thus might be problematic
   B. ADINA FSI package: ADINA offers a direct monolithic coupling between the fluid and structure domains in a one single program. Our group has a vast experience with its capabilities, including cases with large deformations and highly nonlinear responses, inelasticity and contact.
   After revising the two forerunner methods and preliminary tests with the two packages we have selected ADINA for its simplicity and speed of convergence. The major features of the numerical model are directly validated using the experimental study, reviewed below.

2. **The geometrical model**
   Two geometric models were built using SolidWorks. The first model is of an anatomic geometry taken from CT images of the aortic root (Figure 1a). The second model is of an axisymmetric geometry of the aortic root (Figure 1b), which will be used for validation purposes by comparison with the experimental measurements

(a) (b)

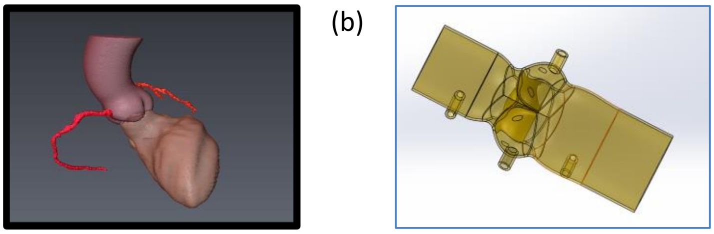

Figure 1- The anatomic aortic root model (a) and the simplified axisymmetric model (b)

3. The numerical model

At first, a simplified model of an axisymmetric valve was built which included the leaflets placed in a simple circular cylinder. The boundary conditions included a uniform inlet velocity and fluid-structure interaction conditions between the fluid and structure domains. The results are shown in Figure 2.

Recently, the more complex axisymmetric geometry was used for constructing ADINA models of the structural and fluid domains. The preliminary results of the coupled problem in the axisymmetric model are shown in Figure 3.

(a) (b)

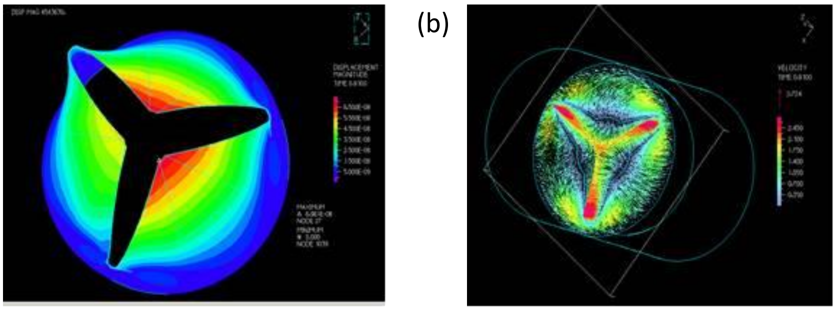

Figure 2- Results of structural displacements (a) and fluid velocity vectors (b) in the coupled simplified model

(a) (b)

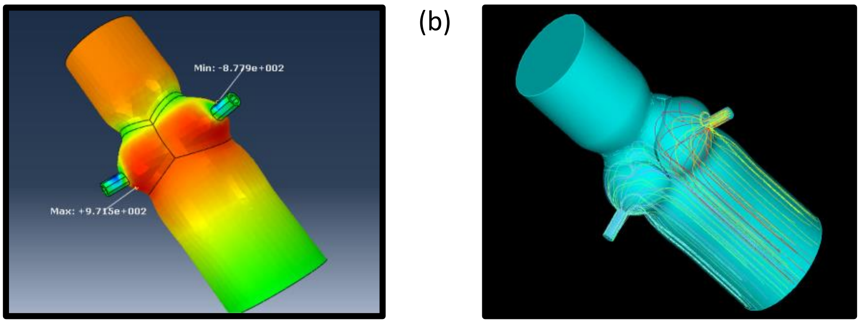

Figure 3- Preliminary results of structural displacements (a) and fluid particles trajectories (b) in the coupled axisymmetric model

The next stage in the numerical study will include model validation using mesh and time-steps independence tests, results analyses and comparison of the numerical results with the experimental results. After validation of the axisymmetric model, numerical models of the anatomic model will be defined and the effect of valve leaflets on flow patterns in the aortic root will be investigated, focusing on diastolic flow near the coronary origins.

Experimental measurements

The experimental setup contains the following components: the physical phantom model attached to the pulsating flow pump and the flow circuit, the optical measurement system and the control system.

The schematic description of the experimental model and its photograph shown in Figure 4a and b, respectively, includes an assembly of transparent elastic model of the aortic valve in the aortic root, which is also shown in details in Figure 4c, connected to the ascending aorta model (Figure 4d) and to the two main coronary arteries. The flow in the system is driven by a controlled piston pump (CCA, Hemo-Dynamics inc.) generating realistic flowrate and pressure boundary conditions (Figure 4e) .

The optical measurement system includes a high-speed camera (Bonito CL-400B) that is acquiring light from the fluorescent particles (Cospheric Inc. 532nm excitation to 552 nm emmision) excited by the laser (532 nm, CW diode laser) formed into a thin sheet of light. In addition, the high speed camera will record the kinematics of the valve leaflets for the comparison of structural and fluid motion in the numerical simulation. These are key parameters that can explain the role of the leaflets position and motion on the flow developing in their proximity and the following effect on coronary perfusion. Leaflet motion analysis results are given in Figure 5, where the motions of the valve leaflets were recorded for three heart rate conditions (of 60, 80 and 100 BPM) using the high speed camera. Frames were sampled for each case and the valve opening diameter was measured as a function of time (Figure 5c).

Our next stage in the experimental part is to obtain the flow fields in the proximity of the valve and measure the flowrate to the coronary during controlled experiments. It is important that the boundary conditions are replicated as precise as possible using the dedicated control system. The pressure signal from the pump will be sampled and the measurements will be phase-averaged in respect to the cardiac cycle.

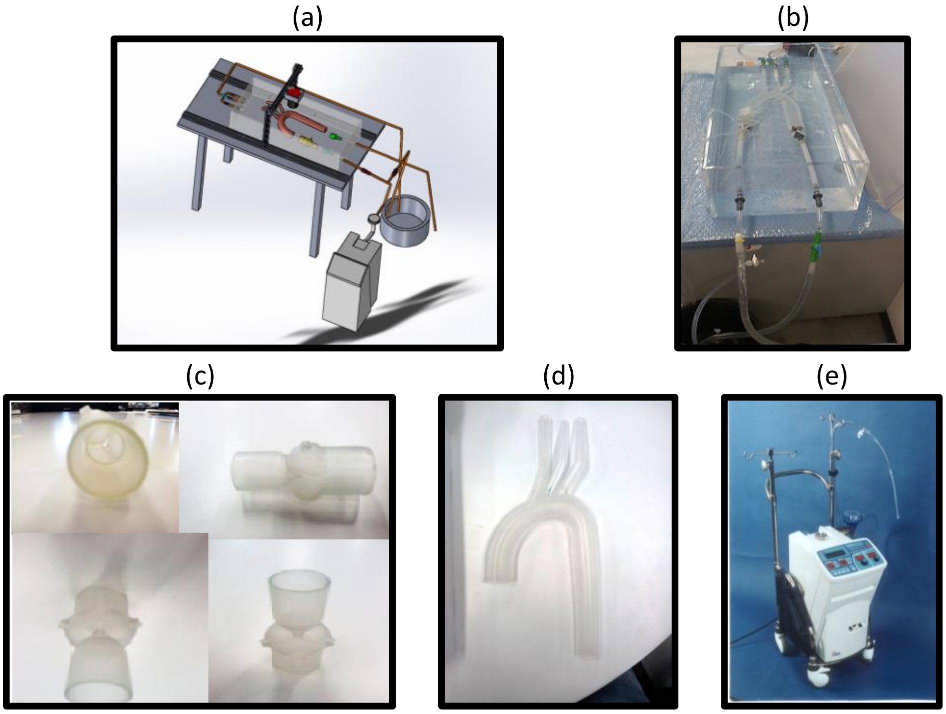

Figure 4- The experimental system: a schematic diagram of system components (a), a photo of the system assembly (b), the model of the aortic root (c), the silicon model of the ascending aorta (d) and the hydraulic piston pump (e)

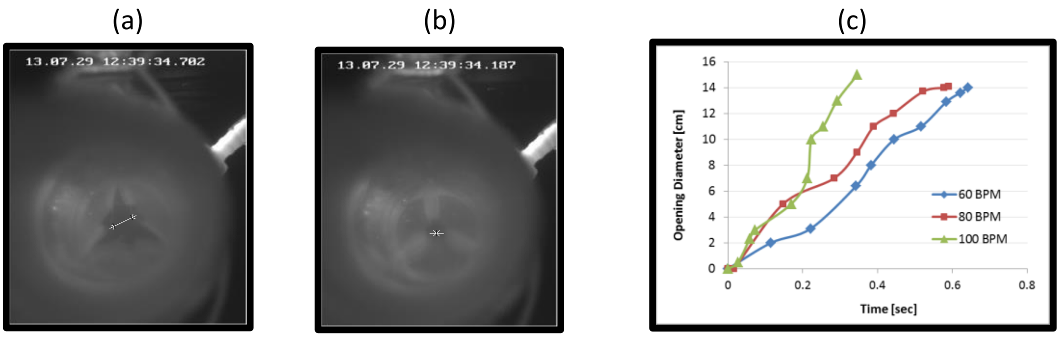

Figure 5- Preliminary results of leaflets motion. Examples of acquired frames of open (a) and closed (b) valve and the comparison of valve opening diameter for three different heart rates as a function of time(c)