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MITRAL VALVE MODELLING FOR LEFT VENTRICLE FLOW

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Introduction. Blood motion in the heart's left ventricle features the formation of vortices that develop from the mitral orifice and accompany the redirection of the incoming jet flows towards the outlet track. The vortex formation process is intrinsically dependent from the dynamics of the mitral leaflets while they interact with the blood flow that crosses the valve during ventricular diastole. There are a few clinical indicators that correlate mitral leaflet excursion or trans-mitral flow properties to the presence of cardiac pathologies. These indicators have a limited relation with first physical principles describing the actual valve dynamics, and their significance is assessed by clinical statistical studies only because mechanistic models of mitral function are not available.
Indeed, modelling the dynamics of a natural mitral valve represents a challenging issue. A rigorous mathematical formulation should be based on the equations of fluid mechanics for the flow, those of solid mechanics for the tissue, and tackle the problem of the numerical solution of the resulting coupled system. An essential ingredient of such a complete numerical modelling is the proper mechanical description of the valve large deformation regime and the knowledge of the actual nonlinear elasticity parameters, commonly inhomogeneous and anisotropic. In general, neither the valve material behaviour nor its parameters are known and they are difficult to assess in vivo. Medical imaging can, at most, provide some indication of the geometry of the mitral valve during a few phases of its motion but cannot provide information on tissue properties.
We introduce here a parametric model of the mitral valve geometry and describe its motion in terms of a few degrees of freedom. The dynamics of this model can be specified in an asymptotic limit, under the assumption that the valve moves with the flow. The asymptotic formulation permits expressing the valve opening dynamics on the basis of the matching between the fluid and tissue motion, without the need to specify either the material structure and its elastic properties. It is introduced in a numerical model of the intra-ventricular fluid dynamics to verify the role of leaflets motion on the vortex formation process.

Methods. We present a parametric description of the mitral valve geometry (figure 1, left side) with the objective to give an apparently realistic shape in the simplest mathematical terms. The varying shape, corresponding to different degree of opening, is described as a first approach by one degree of freedom: the angle opening. This approach corresponds to assuming that a real valve presents a given shape for a given level of opening that could, in

principle, be extracted through a reverse engineering process applied to medical imaging. On the basis of this simple model, more realistic geometry and additional degrees of freedom, like two independent leaflets, are discussed in terms of means to obtain the required information.
The valve is inserted into a numerical model of the ventricular fluid dynamics based on an efficient immersed boundary elements method. The mitral dynamics is then described through the assumption that the valve follows the flow, and it moves with the least resistance under the constraint of its given shape. This means that the valve, in this asymptotic limit, adjusts its velocity at every instant without affecting the mass balance. Generalization of such an approach, by introducing inertial or visco-elastic parameters, is discussed.

Results. The intra-ventricular fluid dynamics during diastole and the vortex formation process is analysed. The differences in leaflet motion and vortex properties are evaluated with respect to the different valve properties, like the relative placement in the ventricle and leaflet asymmetry. It will be shown that vortex formation dynamics (see figure 1, right side) immediately reflects minor differences in the mitral valve geometry and leaflet dynamics.
This type of fluid-tissue interaction represents an asymptotic model, when the tissue moves with the flow, and provides a limiting reference for more complete models. It may also permit a functional description of real valve parameters in terms of its geometry and dynamics that can be recorded by medical imaging.

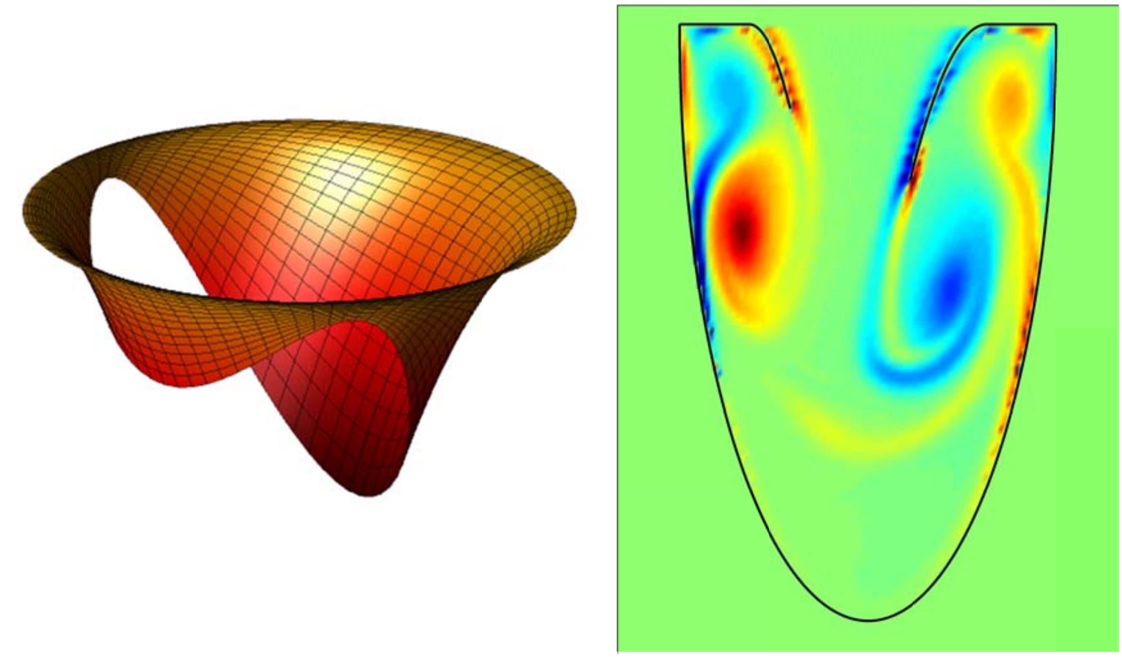

Figure 1. Parametric model of the mitral valve (left); (right) preliminary example of vortex formation employing the mitral valve model, the picture shows the vorticity on a plane across the ventricle.