Providing Innovative Solutions

The IMPETUS Afea Solver®

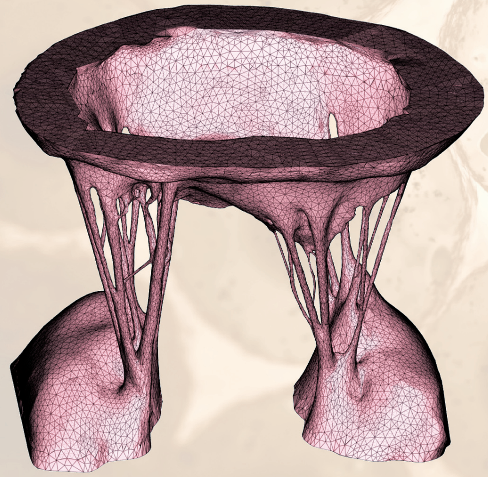
Mitral Valve Simulations

CASE STUDY

The Cardiovascular Fluid Mechanics Laboratory, Wallace H. Coulter Department of Biomedical Engineering, Georgia Institute of Technology has been using the IMPETUS Afea Solver® to perform their research. One of the projects involves simulating the motion of a Mitral Valve (MV). The project covers experimental investigation and numerical modeling which includes Fluid-Structure Interaction (FSI).

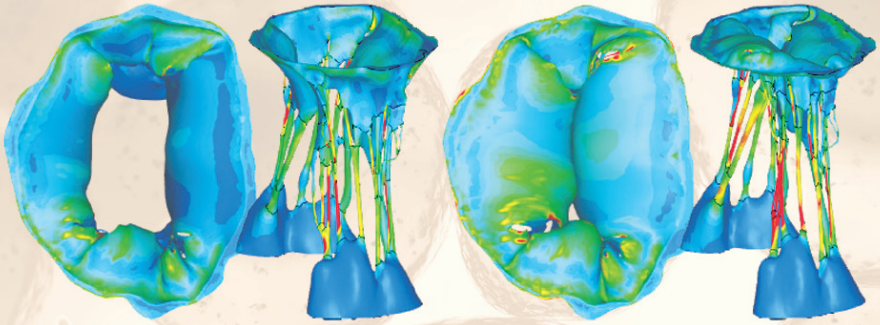
The Mitral Valve is located between the left atrium (LA) and the left ventricle (LV), passively enforcing one-way flow of oxygenated blood through the left heart. It is made up of two asymmetric leaflets that are attached to the mitral annulus. Chordae tendineae attach the free edge of mitral leaflets to the walls of the LV via papillary muscles (PMs), and facilitate proper closure of the MV when the LV contracts. This prevents the backward flow of blood into the atrium (known as mitral regurgitation) and forces ejection of blood into the aorta during systole. Common diseases of the MV include stenosis (resistance to forward blood flow), regurgitation and prolapse (displacement of leaflets towards the atrium). These are all pathological conditions that can result from valvular tissue abnormalities and disruption.

A plethora of surgical techniques and devices exist to attempt to restore MV function. However, one of the main issues with MV repair is the inability to predict the optimal repair strategy for each patient. Computational models of the MV enable surgeons and engineers to evaluate the efficacy of repair procedures and devices, before performing a surgical procedure which may eliminate the need for more costly testing modalities.



Acquiring high resolution images of the MV geometry is necessary for accurate computational modeling. Currently, it is difficult, if not impossible, to obtain full details of MV anatomical structure using existing clinical imaging modalities, due to inadequate spatial or temporal resolution. Therefore, the Cardiovascular Fluid Mechanics Laboratory utilized an extensively validated Georgia Tech Left Heart Simulator to fixate an explanted bovine MV with the leaflets open. The fixated-open MV was then imaged using Micro computed tomography (Mct). To date, this imaging technique offers unmatched spatial resolution for imaging explanted soft tissue. The images were then reconstructed to render a 3D model.

A high quality robust mesh of this 3D model is created, typically using tetrahedral elements. The classic shortcomings of using tetrahedron elements in explicit Finite Element Solvers are eliminated with the use of the Aset™ Elements in the IMPETUS Afea Solver®, which handles well the large deformation of the MV parts. Fluid motion and boundary interaction were solved with the IMPETUS Afea γSPH Solver and the IMPETUS Lagrangian Solver, thus the fluid is represented by particles which contact the structural parts using penalty contact. Both solvers take full advantage of GPU Technolgy that provides massively parallel processing on a single workstation, thus avoiding the need for large computer clusters.



Constructing, tuning, and validating these computational models rely upon extensive *in vitro* characterization of valve structure, function, and response due to diseases. μCT images of the closed MV were also obtained and reconstructed for validation of the FSI results. Further validation included comparison of the simulated forces on the chordae tendineae throughout the cardiac cycle with the experimental data [1]. It was clearly demonstrated that fully resolved 3D models of the mitral valve require an FSI analysis to correctly load the valve which is a significant observation [2]. This fully validated MV model can now be used to analyze the biomechanics of various chordae related pathologies and mechanical implications of various repair techniques.

[1] Toma et al., Fluid-Structure Interaction Analysis of Papillary Muscle Forces Using a Comprehensive Mitral Valve Model with 3D Chordal Structure, Annals of Biomedical Engineering, 2016, 44(4): 942-53.

[2] Toma et al., Fluid-Structure Interaction and Structural Analyses using a Comprehensive Mitral Valve Model with 3D Chordal Structure, International Journal for Numerical Methods in Biomedical Engineering, 2017, e02815.

Key Features and Benefits:

- Aset™ Elements provide accuracy and define the real three dimensional stress state.
- Element technology allows for a tetrahedron mesh even for the chordae tendineae.
- The γSPH solver is computationally fast and can handle 40+ million SPH particles.
- Use of γSPH gives accurate pressure fields to load the Mitral Valve.
- Fluid domain particle packing is done automatically.
- Fluid-Structure Interaction is easily specified.
- User friendly set up of the model leads to increased productivity.
- Advanced element technology makes it possible to use less complicated constitutive models.
- GPU Technology for efficient massively parallel processing resulting in fast runtimes.

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