Patient-specific predictions of Mitral valve closure following annuloplasty repair surgery

Amir H. Khalighi\textsuperscript{1}, Bruno V. Rego\textsuperscript{1}, Robert C. Gorman\textsuperscript{2}, Joseph H. Gorman III\textsuperscript{2}, and Michael S. Sacks\textsuperscript{1}

\textsuperscript{1}Willerson Center for Cardiovascular Modeling and Simulation, The University of Texas at Austin
\textsuperscript{2}Gorman Cardiovascular Research Group, University of Pennsylvania

Introduction: Ischemic mitral regurgitation (IMR) is a highly prevalent valvular disorder that affects up to half of the population that has suffered from myocardial infarction. Unfortunately, current IMR treatments still have less than optimal long-term patient survival outcomes in addition to a high rate of failure and need for reoperation. It is believed that IMR surgical treatments need to become more personalized to account for patient-specific variations, in terms of valvular structure and disease progression path. At the same time, computational models provide excellent resources to predict valvular response to repair and explore novel repair scenarios. In this work, we developed individual mitral valve (MV) models for 3 IMR patients based on 3D echocardiographic images of the valve prior to annuloplasty surgery. We then used these models to predict the MV closure upon corrective repair surgery and demonstrated the high fidelity of our framework to predict post-surgical state of the MV.

Materials and Methods: Three patients were selected from our extant repository of echocardiographic images of the MV for IMR patients. The images were then processed to develop geometrical representations of the MV leaflets for both end diastole (fully open) and end systole (fully closed) states. We then applied a hyperelastic registration technique implemented within a finite element framework to build consistent correspondence between the open and closed MV leaflets [1]. Next, functionally equivalent chords were constructed and attached the MV leaflets in the fully closed configuration following our recent work on the development of such models through topology optimization [2]. Finally, the full MV models were calibrated to account for the correct rest length of the chords in the open state and used to predict the valve’s closing behavior following annuloplasty surgery.

Results and Discussion: Our predictive post-surgical simulations showed prefect agreement with previously reported observations on the effect of mitral annuloplasty ring implantation on the MV leaflet strain patterns. In particular, the results revealed significant reduction in circumferential Green strains while the radial component of strain tensor remained mostly the same. This has been shown previously to trigger cell biosynthetic pathways in the direction of deleterious remodeling of the valve tissue.

![Figure 1](image-url) Figure 1. (a) shows the clinical imaging data that was processed to extract the MV leaflets geometry (b). We developed functionally equivalent chords (c) to build a full MV that was then applied to simulate MV’s closing behavior pre- and post-surgery.

Conclusions: In this study, we developed complete MV models purely from clinical imaging data to predict the valvular response to annuloplasty repair surgery. The missing MV chordal part in the clinical images was replaced with novel functionally equivalent chords that assured the fidelity of models in predicting MV closure at both pre- and post-surgical states. We believe that our modeling framework can be applied to the current patients in the clinic at the time of surgery to quantitatively compare the performance of different annuloplasty rings and hence improve the MV repair surgical outcomes.