# Experimental Mechanical Modelling of the Mitral Valve

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**Abstract.** The mitral valve (MV) is the most complex valve in human heart and has a crucial role in preventing the backflow of blood from the left ventricle to left atrium during ventricular systole. MV diseases are one of the most common heart valve diseases. Given the high prevalence and significance of structural MV pathologies and lack of diseased, large animal models to study them, it is imperative to develop a platform for modelling and testing of synthetic MVs. This will enable insight on the effects of MV mechanics on its performance and the overall performance of the human heart. In this work, elastomeric silicone materials were characterized and used to fabricate a physical MV model with an anatomically informed geometry and controlled leaflet thickness. Moreover, a pulsatile benchtop cardiac simulator was designed and constructed to test the physical MV model under physiological conditions. The synthetic MV model had a realistic motion and closure. This platform shows excellent promise in providing durable and repeatable MV models which can be utilized for simulation of structural valvular diseases as well as advanced medical device development and testing.

**Introduction.** One of the main causes of MV disease, can be mitral annular calcification (MAC), which is highly prevalent and can lead to blood backflow (mitral regurgitation) and constriction of blood path through the mitral valve (mitral stenosis) and eventually to heart failure [1]. Lack of large animal models for valvular disease and also lack of benchtop cardiac models with dynamic annulus conforming with physiological states [2] are a big obstacle in simulating and studying structural MV diseases. Moreover, mitral valve samples vary anatomically from one animal to another. Extensive literature review of cardiac simulators revealed that in relation to valvular treatment strategies, the primary focus of studies to date has been on valve hemodynamic competency and representative physiological left ventricular contraction. In this work, a repeatable synthetic model of the MV with dynamic annulus at healthy state was developed to enable studying the MV from a mechanical perspective and determine the role of MV mechanics in valve function.

## Materials and methods

**Mechanical characterization of elastomeric silicone.** Various un-reinforced and reinforced elastomeric silicone materials were mechanically characterized using uniaxial tensile tests following ISO 37 and ISO 13934 standards and compared against the tensile test results of native human MV leaflets reported by Prescott, et al. [3]. Ecoflex 00-30 reinforced with gauze fabric to enhance its tensile strength was selected based on the results of the tensile tests shown in Fig. 1 and synthetic MV models fabricated by others [4–6].

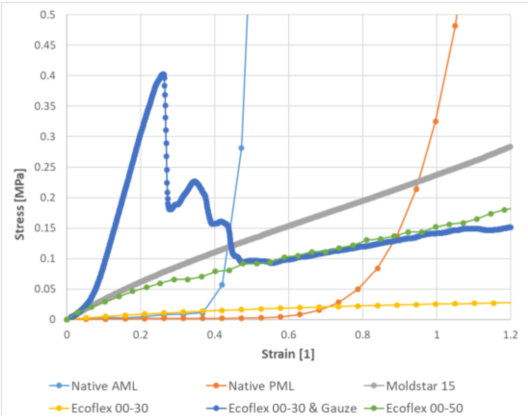


Figure 1. Uniaxial tensile test results of un-reinforced and reinforced elastomeric silicone materials compared with those of human anterior and posterior mitral leaflets (AML and PML) [3].

**Synthetic MV fabrication.** Based on the anatomically informed MV geometry created in SOLIDWORKS, an MV mould was design and 3D printed using Polylactic Acid (PLA). Gauze fabric was laid out on the MV mould, covering the MV leaflets area and also a 1 cm margin next to the MV annulus for better integration into the atrioventricular interface. A total of 18 polyethylene nylon fishing strands were cut according to the specific cord rest lengths and placed on top of the gauze fabric, slightly extending from the margins to the body of the leaflets for better integration into the leaflets. Ecoflex 00-30 was cast into the mould and on top of the gauze and the cords; after fully embedding the gauze and chords in itself and curing at room temperature, the fabricated MV was embedded from its annulus and the 1 cm margin into the atrioventricular interface created by casting Moldstar 15. The cords were bundled together and inserted into 3D printed hollowed pieces representing papillary muscle posts, where they were glued to get fixed and preloaded as required.

**Cardiac simulator setup.** A pulsatile flow rig consisting of left ventricle, left atrium, compliance and reservoir chambers, mechanical aortic valve, and a check valve was designed in SOLIDWORKS (Fig. 2a) and constructed to test the synthetic mitral valve under physiological loading (Fig. 2b). A linear motor system was utilized as a piston pump with a soft plastic seal to actuate the system and pressurize the LV chamber, pumping the phantom blood at a constant rate of 64 ml per beat at 70 bpm. This was achieved by time-dependant control of slider position as seen in Fig. 3. A total of 8 digital pressure sensors were installed, two before and two after the synthetic MV and the mechanical aortic valve to acquire chamber and transvalvular pressure data using two Arduino UNO's.

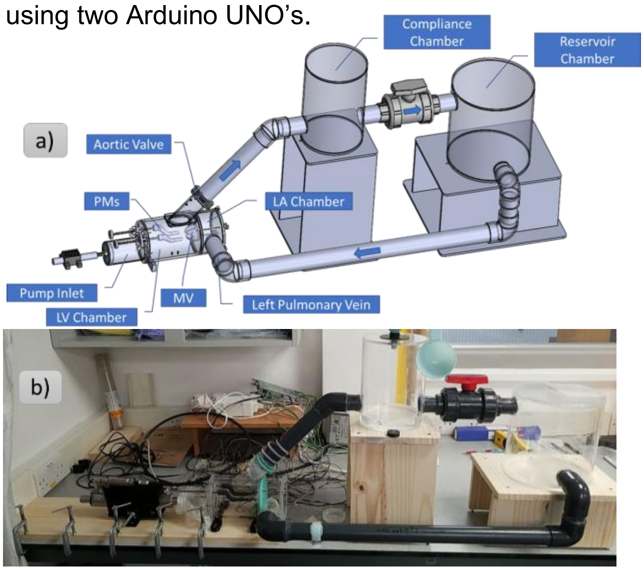


Figure 2. a) Cardiac simulator design in SOLIDWORKS
b) Constructed cardiac simulator based on the design

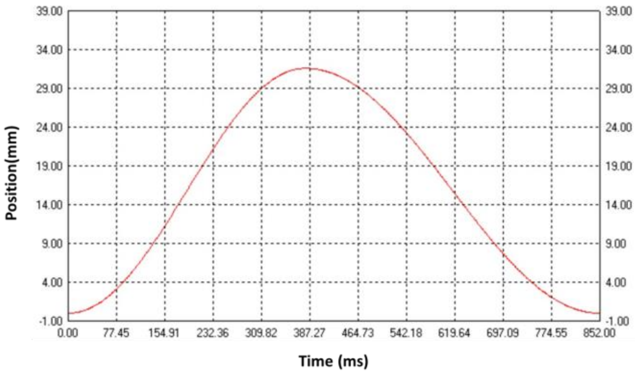


Figure 3. Position vs time plot of the pump in a cardiac cycle

**Results.** The synthetic mitral valve had realistic motions and closure in response to the pressure gradient between the LA and LV chambers as depicted in Fig. 4. The annulus of the MV showed a contractile motion along with the atrioventricular interface towards the LA chamber, which shows good conformation with anticipated in-vivo measures.

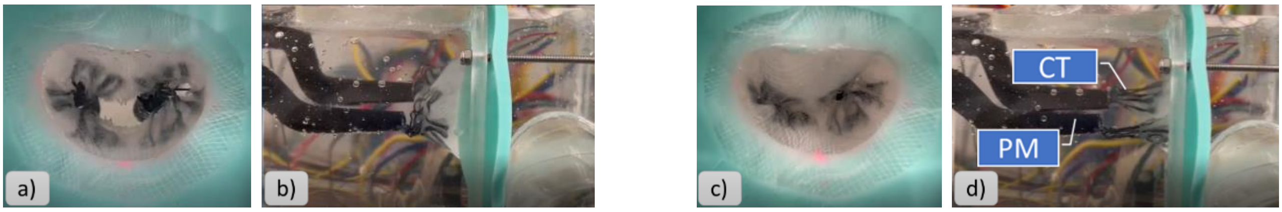


Figure 4. Synthetic MV actuated in the cardiac simulator: a) Front view at mid-diastole (fully open). b) Side view at mid-diastole. c) Front view at mid-systole (fully closed). d) Side view at mid-systole. CT: Chordae Tendineae

**Conclusion.** The elastomeric MV model along with the pulsatile cardiac simulator proved to be a valuable platform allowing for mechanical modelling and structural investigation of healthy and pathological mitral valve and advanced medical device design with added benefits of durability and repeatability. Additionally, the mesh pattern of the gauze fabric can be utilized to analyse and map the displacement and strain on MV leaflets using optical techniques such as digital image correlation (DIC) or digital volume correlation (VIC).

## References

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