Abstract — The mitral valve is located in the heart. It controls the unidirectional blood flow from the left atrium to the ventricle. Due to various reasons, the mitral valve and its chordae may be damaged, causing mitral regurgitation. The purpose of this study is to examine the blood flow through the mitral valve in both experimental and numerical heart models, aiming to develop a reliable protocol to assess the effectiveness of various mitral valves repair methods.

Keywords — Mitral valve, surgical repair methods, flow visualisation, computational fluid dynamics

1. Introduction

The mitral valve is a heart valve located between the left atrium and left ventricle. It opens when the left ventricle relaxes, allowing blood to flow into the ventricle from the left atrium; it closes when the left ventricle relaxes, preventing blood in the ventricle from flowing back into the atrium. The mitral valve consists of the mitral valve leaflets and the subvalvular apparatus, namely, the chordae tendineae and papillary muscles.

At times, the mitral valve fails due to damaged subvalvular apparatus, such as the loosening of the chordae tendineae, which are the chords preventing the valve from flopping back into the atrium causing a condition known as mitral valve prolapse which causes regurgitation of blood back into the atrium [1].

There are various methods of repairing the mitral valve surgically [2]. Different medical professionals have different opinions of which surgical repair method is most effective. Due to ethical reasons, surgeons cannot test these methods on patients. According to the Hippocratic Oath which states that as medical professionals, they should first do no harm [3], therefore surgeons are not to treat patients with any method that they do not consider the best. There have been attempts to test the effectiveness of surgical repairs in vitro based on pressure drop required to cause mitral valve prolapse which have been carried out by Espino et al [4].

The objective of the study is to develop a platform to visualize the flow structure through a mitral valve, with the aim of further developing it into an effective protocol to assess the effectiveness of mitral valve repair in vitro.

2. Methodology

This research is carried by experimental means. Computational fluid dynamics models are generated and used for validation purposes.

2.1 Experimental

2.1.1 Mitral Valve Extraction

The heart valves were extracted from porcine hearts which were stored in the refrigerator before use. The mitral valve was removed by extracting a section with the mitral valve annulus and the anterior and posterior leaflets papillary muscles.

2.1.2 Experimental design

The mitral valve annulus is sutured onto a ring structure to attach the specimen to the experimental set-up. The papillary muscles of the mitral valve specimen are attached to a wire set-up which is connected to the ring structure.

2.2 Numerical Simulation

Numerical simulation was carried out using computational fluid dynamics ANSYS FLUENT C.2-dimensional geometries of the left atrium and ventricle with opened and closed mitral valve were generated using echocardiographic measurements of the left heart chambers [5]. The open valve is simulated with the inlet at the left atrium and no outlet. The closed valve is simulated with the inlet at the apex and the outlet at the left ventricular outflow tract.

A 2D simulation of the experimental set-up was also performed which is to be evaluated against the experimental results. Half of the geometry was generated and the bottom axis was used as a mirror to reflect the geometry generated to obtain a plane from the experimental results.

A steady-state simulation using glycerin as the fluid was carried out. This is because a solution of glycerin has similar properties as blood. The density and viscosity of glycerin is 1060kg/m³ and 0.0027Pa.s respectively [6]. The velocity of the fluid flow is 0.12 m/s, representing blood flow through the mitral valve into the left ventricle. No-slip conditions were used for the walls; this includes the walls of the valves. The turbulence model used was realizable k-ε turbulence model. The simulation was carried out using the SIMPLE solver.

3. Results and Discussion

The results from the experimental and numerical simulation are reported.

3.1 Experimental Results

It is seen from the experimental results in Fig. 2 that flow through a healthy mitral valve produces two vortices behind the mitral valve leaflets.

The set-up is shown in the Fig. 1 below. Water is used as the blood analogue fluid. The manometer is used to measure the pressure drop.

The flow of the fluid in the apparatus is visualized using silver coated hollow glass beads at 10µm particles illuminated by a scattered laser beam. A DSLR camera (Nikon D7000) was mounted on tripod. A shutter speed of 1/6s was used with an ISO of 100 and an aperture of f/16.

![Fig. 1 Experimental Set-up](Image)
Two vortices are formed in the simulated results, the two vortices are relaxation; is similar to the numerical simulation results generated. The numerical simulation of the experimental design is used as validation for the experimental results. It is seen that the generated numerical results is comparable to the actual blood flow in the left heart chambers, and therefore can be used as a tool to be compared with the results obtained from the designed protocol.

3.2 Numerical Results

The simulation results were compared to the visualization of blood flow through the mitral valve in vivo using various imaging technologies. The result was validated with pathline visualization of 4D velocity mapping using cardiovascular magnetic resonance imaging, CMR [8].

For the opened mitral valve, it can be seen that CMR image of left ventricular during diastasis, the middle stage of the ventricular relaxation; is similar to the numerical simulation results generated. Two vortices are formed in the simulated results, the two vortices are also formed in the heart during diastasis.

The numerical simulation of the closed mitral valve simulates the period of peak diastole. No vortices are formed inside the ventricle during this stage as seen in Fig. 4a. This is comparable with the CMR image during systole.

It is seen that the generated numerical results is comparable to the actual blood flow in the left heart chambers, and therefore can be used as validation for the experimental results. The numerical simulation of the experimental design is compared to the flow through the experimental design and the CMR images of an opened mitral valve during diastasis. The simulated results of the experimental model shows the formation of vortices as the fluid flows through the opened mitral valve. This is comparable to both the experimental results (Fig.2) and the actual flow through the mitral valve in the human heart (Fig. 3a).

4. Conclusions and Recommendation

Flow through a healthy mitral valve produces two vortices. Vortices are important as they help propel the flow from the ventricle. The simulated results of the idealized geometry and the experimental model agree with the experimental result obtained as well as the CMR images. The numerical results can therefore be employed as a tool to be compared with the results obtained from the designed protocol.

The set-up can be further developed to test various mitral valve repair methods and implemented for more personalised healthcare. A patient’s mitral valve failure can be evaluated through various medical imaging methods and the data obtained may be used to simulate a physical model which can be used as an analogue to be placed inside the chamber. Various repair methods may be tested on the damaged mitral valve analogue. The method which yields the flow structure closest to a healthy mitral valve will be chosen for the patient.

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References