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COMPUTATIONAL ANALYSIS: FLUID STRUCTURE INTERACTION MODEL OF THE MITRAL VALVE LEAFLET

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ABSTRACT

In the mitral valve, regional variations in structure and material properties combine to affect the biomechanics of the entire valve. Previous study, we know that mitral valve leaflet tissue is highly extensible. So, the objective of this study was to investigate the correlation between the rigidity of mitral valves leaflet and backflow problem based on critical parameter of blood. Two stages of mitral valves analysis systolic and diastolic stages and also with and without ventricle were investigated. Two dimensional models of the mitral valve leaflet were created in ADINA-FSI for computational fluid dynamic analysis. The results show linear correlation between rigidity of the mitral valves leaflet and volume of backflow. In conclusions, these computational techniques are very useful in the study of both degenerative valve disease and failure of prostheses. Findings are the prediction of the behavior of the mitral valves leaflet and blood flow which can assist the medical practitioners in their decision on the patient treatments.

Keywords: Mitral Valve leaflet, Biomechanics, Systolic, Diastolic

INTRODUCTION

The experience of the last few years shows a change in concepts for mitral valve surgery. A trend toward simplified and streamlined reconstruction techniques allowing more often the successful repair of the mitral valve and not replacement with artificial prostheses observed. To repair the mitral valve is considered choice of procedure and it seems to be generally accepted to valve replacement. Numerical simulation is one of method that can be applied to simulate mitral valve function and evaluate proposed surgical repair. Therefore a fluid structure interaction model of the mitral valve has been generated to improve the surgical repair with understanding the correlation between backflow and mitral valve rigidity. However, several numerical modeling of the mitral valve have been developed but there are fewer that investigate backflow and rigidity of mitral valve and also not consider with ventricle model (Bernardo *et al*., 2002).

METHODS

Models of the mitral valve leaflet were created in ADINA-FSI for computational fluid dynamic analysis. 2D geometries of mitral valve leaflet were created in ADINA with meshed. In ADINA, we will consider fluid and structure model. In fluid model, blood is not strictly a fluid but rather a suspension of particles. The blood viscosity increases when the deformation rate decreases because the red blood cells tend to aggregate. In the small vessels, the blood viscosity decreases when the vessel radius decreases because red blood cells move to the central part of the vessel (Einstein *et al*., 2005). In this study, we only consider large vessels and the fluid will be therefore assumed to be Newtonian applied as equation 1.

$$p_{ij} = -p\partial_{ij} + \mu\left(\frac{\partial v_i}{\partial x_j} + \frac{\partial v_j}{\partial x_i} - \frac{2}{3}\partial_{ij}\nabla .v\right) \quad (1)$$

Where, μ is the dynamic viscosity, p is the pressure and v is the velocity. In structure model, a 2D FSI model of the mitral valve leaflet was generated using ADINA-FSI. Lagrange multipliers have been used to apply the pressure exerted on the deforming structure due to the flow of fluid as has been done for other heart valve FSI simulations (De Hart *et al.*, 2003). Structural deformation and fluid dynamics are determined simultaneously. An Arbitrary Lagrange Euler (ALE) mesh was used to allow FSI simulations to be performed. The ALE formulation of incompressible viscous shown as equation 2 (Ling Chen *et al*., 2004).

$$\rho\frac{d_m u}{dt} + \rho\left(u - \hat{u}\right)\nabla u = \nabla .T + f \quad (2)$$

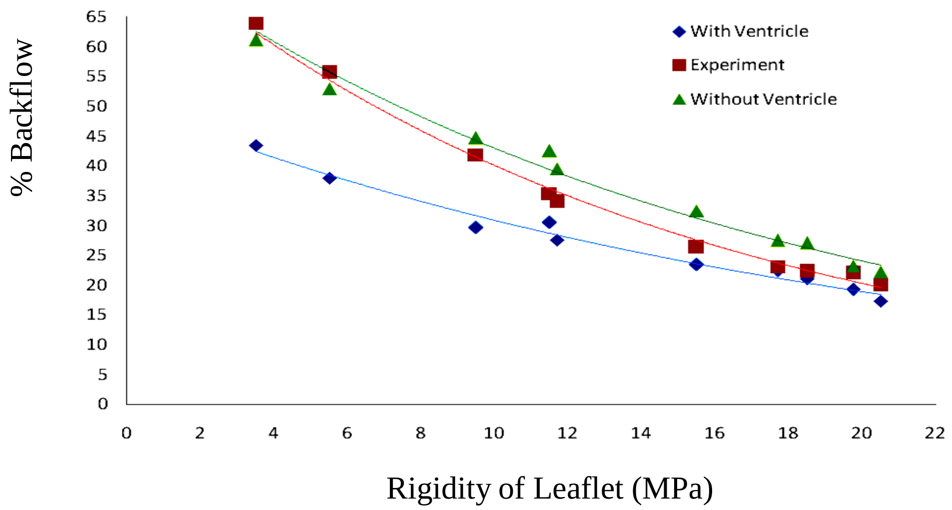
Where, μ is the dynamic viscosity, p is the pressure, T is the stress, $\hat{u}$ is the mesh velocity and u is the velocity. The blood and properties of the mitral valve leaflets were obtained from the literature (Reul *et al*., 1980), shown as table 1.

Table 1: Parameter of Blood and Mitral Valve.

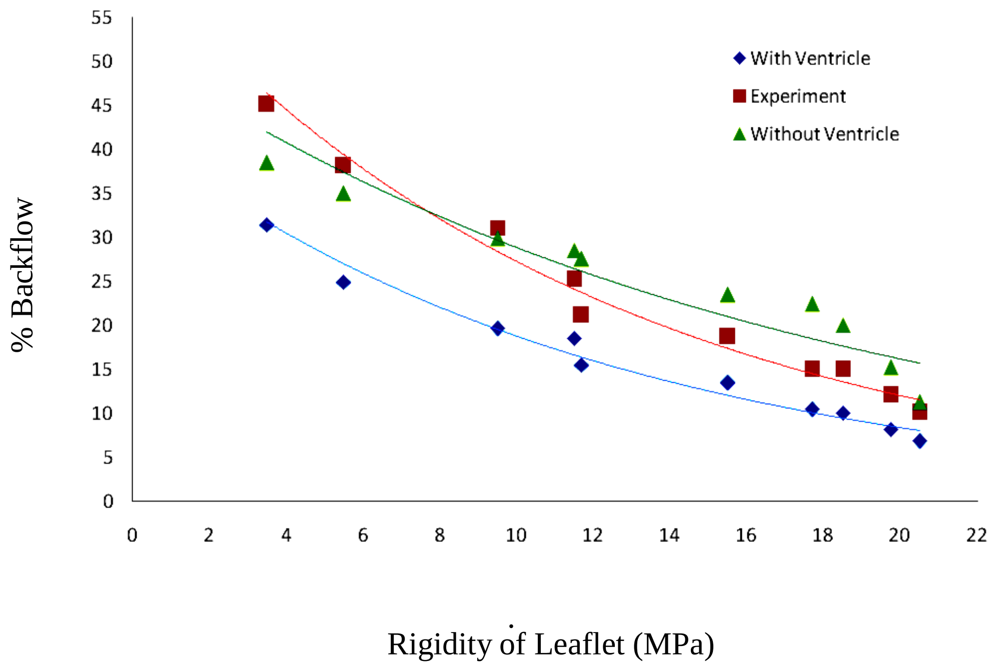
Parameter	Value
Blood density, *kg/m*^{3}	1.06×10^3
Blood viscosity, *Pa.s*	2.70×10^{-3}
Diastolic Pressure, *mmHg*	82
Systolic Pressure, *mmHg*	132
Anterior leaflet Young's Modulus, *MPa*	2.0×10^6
Posterior leaflet Young's Modulus, *MPa*	1.0×10^6
Normal Mitral valve area, *cm*^{2}	4.0 – 5.0
Normal Mitral Valve Thickness, *mm*	3.5 +/- 0.8
Mitral Valve Leaflet density, *kg/m*^{3}	1.06×10^3
Leaflet Poisson's ratio	0.49

RESULTS AND DISCUSSION

Figure 2(a) and figure 2(b) show the overall results for variation of mitral valves rigidity. The graph shows bigger backflow volume for models without ventricle. In general, the results show linear relationship between rigidity of mitral valves leaflet and volume of backflow. The plots for systolic and diastolic states push the level of backflow volume to the higher limit, approximately 65 percent and 45 percent.



(a)



(b)

Figure 2: (a). During systolic state and (b). During diastolic state. Note that the figure shows backflow vs. rigidity of mitral valve leaflet.

The model with ventricle shows smaller backflow volume as compared to the model without ventricle. It could be caused the geometry difference between the two models. There is more turbulence in the model with ventricle than in the model without ventricle. This is due to curves in the model with ventricle which did not exist in the model without ventricle. In the simulation, the results of the percentage of backflow are representing the severity of the mitral valves prolapse. This is proven by the increase of the percentage of backflow as the condition of the mitral valves worsens. The data predicted by the simulation will assist the medical practitioner to find the approximation of the condition of the mitral valves based on the backflow data obtained through echocardiogram.

CONCLUSION

In this study, the fluid structure interaction models were developed with two considerations which are mitral valve with and without ventricle wall. Correlations between backflow and heart valve conditions were obtained and were found to be linear between the two parameters which show that the backflow will increase as the mitral valves condition worsen. The result show differences less than 10 percent of backflow on average between the two models for both systolic and diastolic states with various conditions of mitral valves. The findings are actually the prediction of the behavior of the mitral valves leaflet and blood flow in various conditions of the mitral valves rigidity. These findings are helpful to medical practitioners is they can decide better treatments for their patients in terms of the reinforcement or replacement of the valves.

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NOMENCLATURE

a	Thermal diffusivity $m^2\ s^{-1}$
A	Area m^2
E	Young's Modulus MPa
f	Friction Factor
P	Pressure Pa
Q	Volume flow rate m/s^3
Re	Reynolds Number
T	Temperature ^oC
t	Time t
U	Mean Velocity m/s^2

Greek symbols

ξ	Vortices Component tangent to Streamline
ν	Kinematic Viscosity
η	Vortices Component normal to Streamline
μ	Dynamic Viscosity Ns m^{-2}
$\boldsymbol{\Omega}$	Voracity Vector
ρ	Density kg m^{-3}