EFFECT OF VORTEX GENERATOR ON BLOOD FLOW CHARACTERISTIC ON REAL PATIENT SPECIFIC DATA

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A report is submitted in fulfilment of the requirements for the degree of Bachelor of Mechanical Engineering with Honours

Faculty of Mechanical Engineering

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DECLARATION

I declare that this project "Effect of Vortex Generator on Blood Flow Characteristic on Real Patient Specific Data" is the result of my own work except as cited in the references.

Signature	**:………………………..**
Name	: Nursyasya Amanina Binti Mohd Fizal
Date	**:………………………..**

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APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

Signature	**:………………………..**
Name of Supervisor	**:**Dr. Mohamad Shukri Bin Zakaria
Date	**:………………………..**

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ABSTRACT

Blood clot coagulation is the main concerned for people who are using Bileaflet Mechanical Heart Valve to replace the ruptured valve. Different design of vortex generator can affect the blood flow at the vicinity of the mechanical heart valve and therefore the velocity, pressure drops and wall shear stress are needed to be investigated. The study only includes steady state condition during peak systole at the aorta. The blunt edges vortex generators (without the aorta) showed lower average velocity with value of 0.80 m/s compared with the sharp edges of vortex generator. The blunt edges of vortex generator also improved the pressure gradient of the blood flow and the result was found 3.64 mmHg compared to the previous study which shows pressure gradient of 10.45 ± 0.94 mmHg. Meanwhile, the wall shear stress was found 10.24 Pa which shows some reduction compared with the sharp edges of vortex generator. A blunt edges of Co-rotating vortex generator is considered a good application as it reduce the flow separation at the vicinity of the leaflets as well helps in reducing the formation of thrombosis. However, to compare with the mechanical heart valve with aorta, the result with the aorta is less prone to blood clotting. A reduction with results of 2.3955 mmHg and 8.845 Pa in pressure drop and wall shear stress respectively indicates more delayed flow separation compared with the mechanical heart valve without aorta. This shows the simulation with the aorta needs to be included to investigate the reduction in blood clot.

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ABSTRAK

Pembekuan darah beku adalah kebimbangan utama bagi orang yang menggunakan Injap Jantung Mekanik Bileaflet untuk menggantikan injap yang rosak. Reka bentuk penjana pusaran yang berbeza boleh mempengaruhi aliran darah di sekitar injap jantung mekanikal dan oleh itu halaju, penurunan tekanan dan tekanan ricih dinding perlu diselidiki. Kajian ini hanya merangkumi keadaan stabil semasa puncak sistol di aorta. Penjana pusaran berbucu tumpul (tanpa aorta) menunjukkan halaju purata yang lebih rendah dengan nilai 0.80 m/s berbanding dengan penjana pusaran berbucu tajam. Bucu tumpul penjana pusaran juga meningkatkan kecerunan tekanan aliran darah dan hasilnya didapati 3.64 mmHg berbanding kajian sebelumnya yang menunjukkan kecerunan tekanan 10.45 ± 0.94 mmHg. Sementara itu, tegasan ricih dinding dijumpai 10.24 Pa yang menunjukkan sedikit pengurangan berbanding dengan penjana pusaran berbucu tajam. Bucu tumpul penjana pusaran yang berbentuk berpusing bersama dianggap sebagai aplikasi yang baik kerana ia mengurangkan pemisahan aliran di sekitar injap jantung dan juga membantu mengurangkan pembentukan trombosis. Namun, jika dibandingkan dengan injap jantung mekanikal dengan aorta, hasilnya dengan aorta kurang terdedah kepada pembekuan darah. Pengurangan dengan keputusan 2.3955 mmHg dan 8.845 Pa pada tekanan kecerunan dan ricih dinding menunjukkan pemisahan aliran yang lebih lambat berbanding dengan injap jantung mekanikal tanpa aorta. Ini menunjukkan simulasi dengan aorta perlu disertakan untuk menyiasat pengurangan pembekuan darah.

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LIST OF ABBREVIATIONS

BMHV	Bileaflet Mechanical Heart Valve
MHV	Mechanical Heart Valve
RSS	Reynolds Shear Stress
VG	Vortex generators
CFD	Computational Fluid Dynamics
WSS	Wall Shear Stress
CT	Computerized Tomography
MRI	Magnetic Resonance Imaging
Re	Reynolds number
SCCH	Swept Constant Chord Half-model
PG	Pressure Gradient
CAD	Computer-Aided Design

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LIST OF SYMBOLS

ρ	Density of fluid
g_i	Body force in i-direction
μ	Dynamic viscosity of the fluid
u	velocity

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Heart valve replacement surgery is a one kind of surgery that quit popular these days. This surgery involves patient that happen to have damaged heart valve due to some diseases, infections or accidents (Zakaria et al., 2017). If the heart valve disease is uncured, people can suffer from stroke, chest pain, or even die due to heart attack. Aortic valve stenosis is one of the heart valve diseases which causes the heart's aortic valve become narrow and soon can prevent the blood from flow through the aorta. A clear diagram of aortic valve stenosis is shown in Figure 1.1 (a). According to a research, about 400,000 people died due to cardiovascular disease which major on heart valve disease in between 1998 and 2004 in Germany (Bongert et al.,2008). In 2006, the heart valve surgery became popular for the local and demand on skilled heart surgeon increased (Bongert, M., Geller, M., Pennekamp, W., Roggenland, D., & Nicolas, V., 2008). Meanwhile, an estimated 2.9 to 5.8 million more adults in the U.S. experienced aortic valve disease in 2016 as the percentage of people having the heart valve disease increase at the age of 65 years old and above (Evans, F. & Vinod H. Thourani, 2018).

Other than stenosis, aortic valve regurgitation also contributes in heart valve failure. Regurgitation is a backflow of blood during diastole (phase when heart muscles relaxes), where the blood flow backwards from the aorta to the left ventricle (Armstrong, G. P.,

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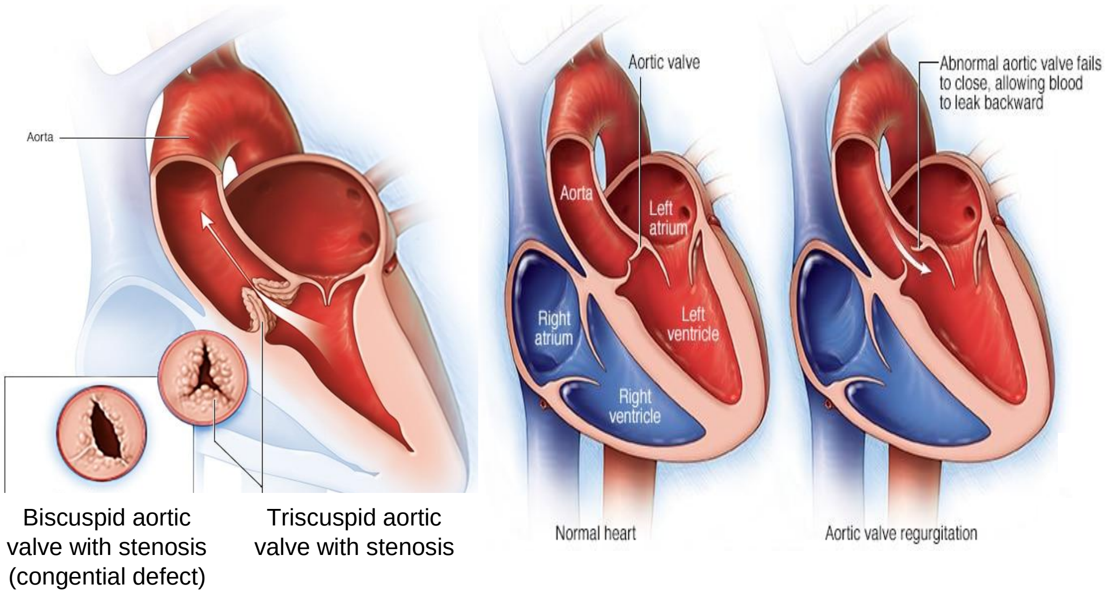
2018). Based on American Heart Association (2016), this disease can occur mostly due to aging, infection at the heart tissue and high blood pressure. It can make a person become exhausted and make them feel breathless due to the low oxygen being pumped through the heart as there are leakage occurs at the aortic valve where the blood will flow backwards from the aorta to the left ventricles.



(a) (b)

Figure 1.1 (a) Aortic valve stenosis (M. C. S, 2018). (b) Aortic valve regurgitation (M.C. S, 2017)

Due to the leakage, the aortic valve did not operate efficiently and can lead to heart failure. Figure 1.1 (b) shows how the aortic valve regurgitation can occur.

There are two types of prosthetic heart valve that can be used to treat the uncured heart valve, which are Mechanical Heart Valve (MHV) and Bio-prosthetic Heart Valve (BHV). Mechanical Heart Valve is made of pyrolytic carbon and is the most preferable prosthetic heart valve among the patients as it is last long and only need to undergo replacement surgery once in a life time (Zakaria et al., 2017). Meanwhile, Bio-prosthetic heart valve is made of animal tissues and only last long for several years as it will

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degenerate due to calcification. Therefore, another surgery needs to be done to replace the damaged valve with the new one which make this prosthetic heart valve less preferable compared to MHV. However, despite of being the most preferable prosthetic heart valve, there are few complications occur on having MHV such as thrombosis and bleeding.

Previous study found that blood clot complication is highly risk and can cause stroke or cause the valve to fail itself. If there is some vessel injury occurs at the valve, low dilution of the activated clotting factors due to low cardiac output will trigger the blood coagulation and this can occur based on different anatomical positions. Besides that, the hemodynamic flow characteristic varies with different anatomical positions. Other than that, no current or circulation of the blood flow at Bileaflet Mechanical Heart Valve (BMHV) hinges caused by the sharp geometries, can lead to thrombosis. In contrast, blunt edges at the vicinity of the vortex generator leads to low level of platelet damage (Zakaria et al., 2017).

Besides sharp geometries, thromboembolism and platelet activation are the most crucial complications of having this type of heart valve replacement surgery as it creates a high shear stress caused by the blood flow (Yun et al., 2014).

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1.2 Problem Statement

Bileaflet Mechanical Heart Valve (BMHV) is the most common design of MHV and said to be the best design during this century. However, this type of MHV cannot run from the fact of thrombosis complication that can occur in the vicinity of the leaflet due to abnormal flow (Zakaria et al., 2017). Besides that, according to Zakaria et al (2017), current design of Bileaflet MHV has a weakness as there is a gap between hinge and leaflet (150µm), where higher risk of blood clot will occur. In order to reduce the blood clot, patients need to take blood thinner known as warfarin everyday based on doctor's prescription. This could drastically affect the lifestyle of the patients for his future days and also can affect the child mortality for married women. Based on researches, the vorticity in the shear layers disperse directly soon after leave the leaflet surfaces where the fastest streamwise of the vorticity deteriorate. This phenomenon occurs during peak systole, when there is no vortex generator installed at the bileaflet heart valve (Hatoum & Dasi, 2018). Besides that, it is found that the Reynolds Shear Stress (RSS) magnitudes at the peak systole is higher when VGs are not installed compared to the absence of the VGs. In order to reduce the RSS and pressure drop, as well as the velocity of the blood flow, VGs need to be attached to the bileaflet of the valve as it leads to the slowing down of the separation of flow and reduce the unsteadiness of the free shear at the shear layers (Hatoum & Dasi, 2018). Other than that, even though VGs give big impact to reduction of RSS, pressure drop and velocity, different types of VGs will give different value and effect of those parameters. Therefore, a better geometry design of vortex generator by using the Computational Fluid Dynamic (CFD) analysis of the blood flow can help to reduce the aggregation of blood clot.

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1.3 Objectives

Bileaflet Mechanical Heart Valve (BMHV) is the most preferred prosthetic valve during this era, which is symmetrical and relatively non-turbulent in term of blood clot influence, compared to other MHV type. The most prospering material used for MHV is pyrolytic carbon as it suits the condition of the body in term of biocompatibility (Helmus, M., & Cunanan, C., 2011). This project is cognate with the geometry design of the vortex generator and the effect on the blood flow which is rigorously scrutinises the blood clot issue. There are few objectives of this study in order to achieve a better result, which are as follows;

1) To develop CFD models of blood flow in vivo at the aortic valve.
2) To improve the current vortex generator design by comparing with previous experimental studies.
3) To analyze the blood flow characteristics such as velocity, pressure drop and wall shear stress by using improved design of vortex generator attached to the real aorta.

1.4 Scope of Study

This study is focusing primarily on the effect of vortex generator on blood flow characteristic on real patient specific data. Type of prosthetic valve used in this study is Bileaflet Mechanical Heart Valve (BMHV) that resembling St. Jude Medical Regent Bileaflet Valve as it is the most thriving prosthetic valve for the heart valve replacement surgery based on the past research that gives better result compared to other type of prosthetic heart valve. Besides that, this study is also focusing on designing a new geometry of vortex generator in order to reduce the coagulation of the blood clot. Other

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than that, in this study, only the opening sequence of the leaflet will be covered. However, the effect of angle opening of the vortex generator will not be covered in this study.

General Methodology

In order to achieve the objectives and scopes of this study, there are few actions need to be carried out in a correct sequence as follows:

1) Literature review.

   Scholarly article, journal and past research thesis will be reviewed and summarized to help with the research.

2) Mimics software.

   Mimics/Slicer software will be used to create medical imaging of the real patient's data.

3) SolidWorks software.

   This software will be used to draw the mechanical heart valve with vortex generator.

4) Geomagic X software.

   This software will be used to attach the mechanical heart valve and the medical imaging of the real patient's data.

5) Simulation.

   Simulation of Computational Fluid Dynamics (CFD) models of blood flow in vivo at the aortic valve with vortex generator is simulated by using ANSYS.

6) Analysis and proposed solution.

   Analysis of the blood flow characteristics due to blood clot with the presence of vortex generator will be done in terms of wall shear stress (WSS).

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