Transient Simulation of Blood Flow in Brain Artery

by

Maizat-ul Fatiha Binti Mohamad Nor

13112

Dissertation submitted in partial fulfillment of

the requirements for the

Bachelor of Engineering (Hons)

(Chemical Engineering)

JANUARY 2014

Universiti Teknologi PETRONAS,
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATE OF APPROVAL

Transient Simulation of Blood Flow in Brain Artery

by

Maizat-ul Fatiha Binti Mohamad Nor

A project dissertation submitted to the

Chemical Engineering Programme

Universiti Teknologi PETRONAS

In partial fulfillment of the requirement for the

BACHELOR OF ENGINEERING (Hons)

(CHEMICAL ENGINEERING)

Approved by,

____

DR. ANIS SUHAILA BINTI SHUIB

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

JANUARY 2014

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by sources or persons.

____

MAIZAT-UL FATIHA BINTI MOHAMAD NOR

ABSTRACT

Cardiovascular disease has become one of the serious killers in the world. The risk factors for the disease could be hypertension, high cholesterol content, and high glucose level in the body. One of the important risks that are being study is the high blood pressure or hypertension risk. This risk may lead to the stroke to occur. The stroke normally occurs in the middle cerebral arteries in the brain. The effect of the heart pulsatility on the person is being investigated throughout the project. As the pulsatility of every person is varies according to their health condition, it may lead to the onset of the cardiovascular disease. The study is categorized to three groups, which are the healthy person group, the hypertension group and the high cholesterol group. The different behavior of the blood flow of every group is carried by using FLUENT, Ansys software. The project also will determine the relationship of the pulsatility to the wall shear stress. From the simulation conducted, the hypertension and high cholesterol patient may have the potential to get stroke, as the wall shear stress measure is exceed the normal pressure of 1Pa.

ACKNOWLEDGEMENT

First of all, Alhamdulillah, thank to Allah for the blessing to successfully complete the Final Year Project. With His willingness, I managed to accomplish the task given within the time given even though I have faced many difficulties in order to finish this project.

Special thanks to Dr Anis Suhaila Bt Shuib, my FYP supervisor who had guided and supported while working on this project. Her guidance, supervision and supports truly help much in the progression and smoothness of the project. The cooperation given by her is indeed appreciated.

Most importantly, deepest thanks to Mr. Muhammad Yunus, Mechanical Engineering PhD student, who has given the guidance in working with FLUENT ANSYS software. This project could not be done without the guidance by him.

And not to forget, most gratitude to my friend who had willing to work together while carrying the task. The knowledge and information that are being shared really assist in many ways. All those contribution is highly treasured.

Last but not least, thanks to my parents for the keenly helped and supported until the completion this project successfully. I really appreciate all of their contribution and may God bless every one of us.

Thank you.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 Background Study

1.1.1 Cardiovascular Diseases (CVDs)

Nowadays, most of the people died because of the cardiovascular diseases (CVDs). From the data by Worlds Health Organization (WHO), CVDs are the number one cause of death globally and more people die annually because of CVDs rather than any other causes or diseases.

According to Worlds Health Organization, CVDs are the disorders or disability of the heart and blood vessel in the human systems which include: Coronary artery disease (CAD) – disease of the blood vessels supplying the heart muscle. Cerebrovascular disease is the disease of the blood vessels supplying the brain and Peripheral arterial disease is a disease of blood vessels supplying the arms and legs.

When the CVD becomes severe, it wills courage the development of heart attack and stroke to occur (Cardiovascular Disease Risk, 2005). Heart attack and strokes are the condition when the blood flow did not reach to the vital organs which are heart and brain. It can be because of blocked at the artery. Insufficient amount of blood supply to the brain or heart can lead to the damages of some part of the heart muscle and damaged the brain cells. The disruption of the normal blood flow system has the potential of paralyzing the whole body. This condition commonly is the effect of stroke.

1.1.2 Stroke

Stroke can be categorized into two types which are Ischemic and Hemorrhagic. Ischemic stroke is the common type of stroke that occurred. It happens when the blood vessels that channel to the brain is blocked. The blocked can be because of blood clot. When the blood supply to a part of brain is shut off, the brain cells will die. It is because the cells are lack of oxygen supply carried by the blood flow. The result will be lead to the inability to carry out some of the normal functions such as walking or talking (American Stroke Association, October 2012)

Hemorrhagic stroke is the rare type of stroke. It occurs when the blood vessels within the brain bursts. This is most likely cause of uncontrolled hypertension. When the pressure of blood is too high, the pressure can lead to the burst of the vessels in brain, where the vessels in brain are the smallest vessels in the human body. As the vessels in the brain burst, it leads to the bleeding in the brain. The result would be the same which is the disability to carry out some functions of the human body or in other word paralyzed (National Stroke Association, June 2012).

Some effects of the stroke could become permanent as too many brain cells die after a stroke due to the insufficient of oxygen and blood supply. These cells can never be replaced but some of them can repair themselves. They do not just simply die but they are just temporarily out of order. Over the time, they will repair themselves that can lead to the progress of the improvement of the disability occurred before (Pulsatile, 2007).

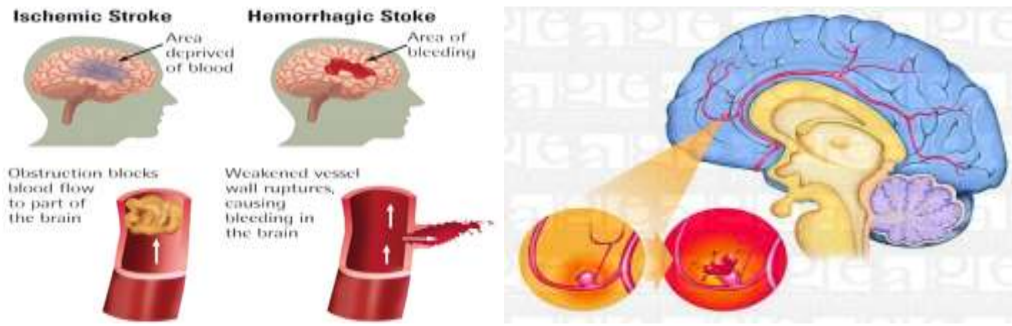


Figure 1: The type of stroke (National Stroke Association, 2012).

1.1.3 Cardiovascular Diseases (CVDs) Risk

Cardiovascular diseases risk factors can be categorized into two parts which are controlled and uncontrolled factors (Mendis et al., 2011). Majority of CVD is caused by the risk factors that can be controlled, treated or modified. However, there are also some major CVD risk factors that cannot be controlled.

The risk factors that can be controlled are hypertension (high blood pressure), cholesterol, overweight/obesity, tobacco use, lack of physical activity and diabetes. While the uncontrolled risk factors are the age, gender and family history (Mendis et al., 2011).

1.1.4 Hypertension

9 out of 10 people who have hypertension do not have apparent reason for it. However there are certain groups of people who are at higher risk. People who are overweight, smoke, eat salty and fatty regularly, drink excessively, physically inactive or suffer frequent stress are generally at a higher risk of developing high blood pressure (Hypertension, May 2012).

People who have a family history of hypertension are also more likely to develop hypertension. There are also less common causes of hypertension due to disorders of the kidney and endocrine glands. People who have hypertension, which is not treated, are at higher risk of developing cardiovascular complications such as heart attacks, heart failure, kidney damage and stroke compared to people with normal blood pressure.

This risk can be higher if a hypertensive patient has other medical conditions such as diabetes, obesity and high cholesterol.

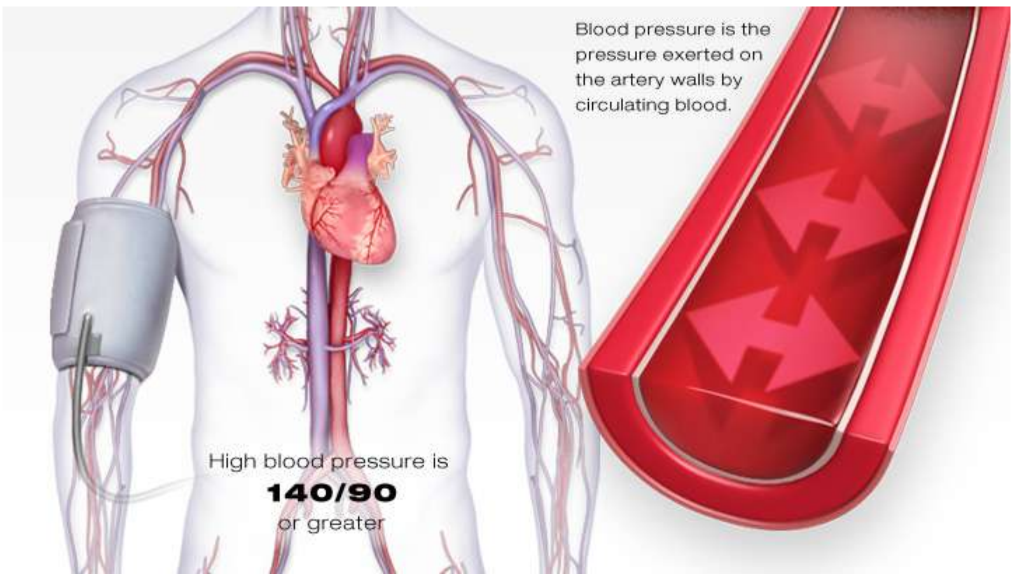


Figure 2: Illustration blood pressure in the human system (Hypertension, May 2012).

1.1.5 Cholesterol

Natural occurring fatty chemical called cholesterol is an important part of the outer lining of cells in the body. Humans need a small amount of it in order to maintain the healthy nerve cell and to produce certain hormones. It also can be used in order to maintain the body temperature (High Cholesterol, May 2012).

- Liver produced most of the cholesterol which is carried in the bloodstream to the body's cells by special proteins called lipoproteins.
- Low-density lipoprotein (LDL) and high-density lipoprotein (HDL) are the two major lipoproteins.
- You also get cholesterol in your diet mainly in foods that come from animals. These include meat, poultry, fish and dairy products. Foods of plant origin have no cholesterol.
- There is a greater chance of a blood clot forming on the surface of the fatty deposit in the artery. This may cause complete blockage of the artery, leading to death of heart muscle (heart attack) in the affected area.

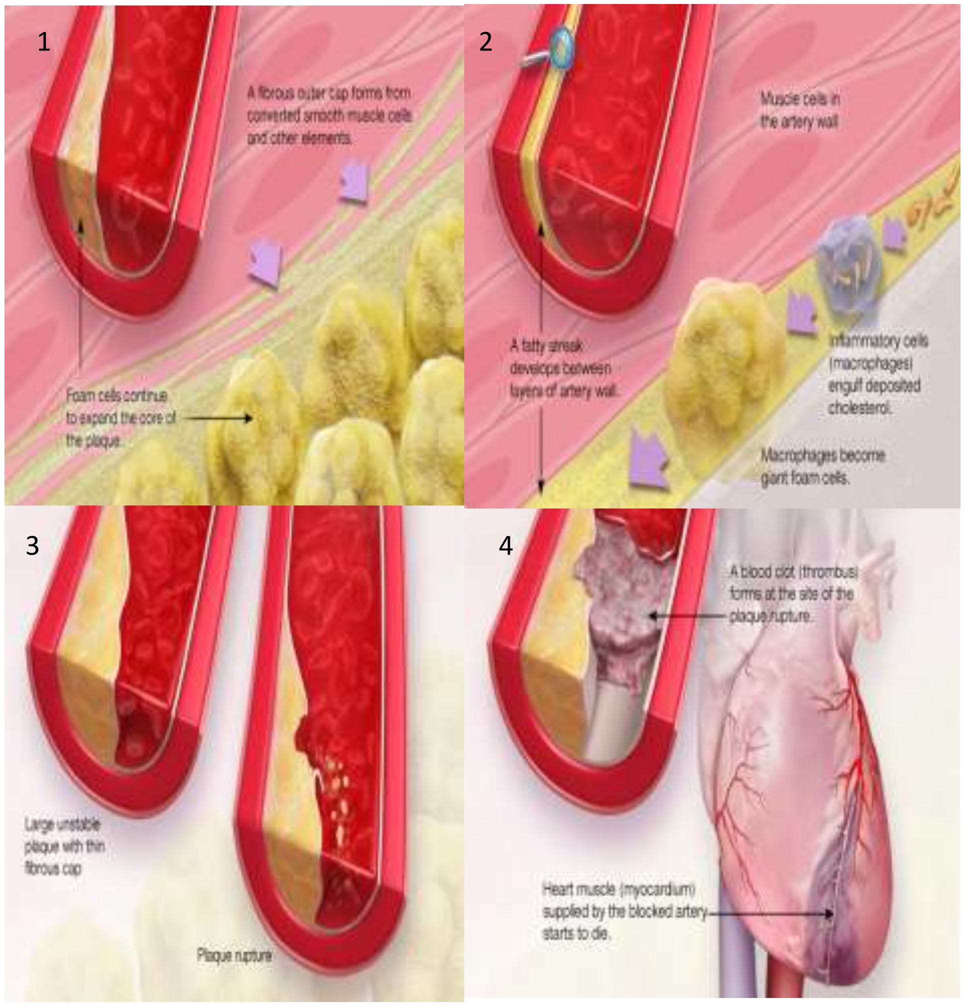


Figure 3: Illustration of formation of cholesterol in the artery wall

(High Cholesterol, June 2012).

1.2 Problem Statement

CVD risk is predicted to have the declining in the cognitive function, an increased risk of later-life dementia and also the cerebral. The focus in the study is more to the stroke cases as the day passed, where the study regarding the cardiovascular diseases risk is carried out. But it is still unclear how high CVD risks cause the cerebral pathology, for example in the case of stroke. One of the reasons is the reduction of the cerebral perfusion which is the reduction of blood flow in the brain. Hypertension is predicted to decrease the cerebral blood flow in the brain.

In the research by the Matthew P. Pase regarding the CVD risk and Cerebral blood flow velocity, it said that the higher brain pulsatile flow which is the peak systole minus end diastolic flow may contribute to the cerebral pathology and cognitive disability through the shearing of small vessels endothelium. The problem arise from the article is less attention has been paid to how the CVD risk can affects the pulsatile nature of the cerebral blood flow and it is unclear how the high CVD risk may contribute to the cerebral pathology.

However, as age is increases, the mean cerebral blood flow is declining and resulted in the cognitive decline. The pulsatile nature of blood is varies from person to person and flow of cerebral blood flow versus the cardiovascular disease risk has not been explored. Pulsatile flow may have the potential to affect to the cognitive impairment and cerebral pathology (stroke) by the shearing of the small vessel endothelium (wall shear stress).

1.3 Objectives

The objectives of the study are to:

- Fundamentally investigate the pulsatile nature of blood flow in the cerebral artery.
- Investigate the effect of pulsatility on the wall shear stress of the cerebral artery.

1.4 Scope of Work

The scope of work for this study is to run a transient stimulation of the blood flow by using the Computational Fluid Dynamics (CFD) method by using FLUENT ANSYS 14.0 software package. The software will examine the behavior of the flow.

CHAPTER 2

LITERATURE REVIEW

Blood flow under normal physiologic conditions is an important field of study. Same goes with the blood flow under disease conditions. The majority of deaths in developed countries are resulted from the cardiovascular disease. Most of it is associated with some form of abnormal blood flow in arteries. Many researchers have come out with the seminar regarding this study (Matthew et al., 2012).

2.1 Blood flow in human system

Heart is responsible to supply blood to every each of cells in the body. It also supplies blood to the lung as a medium transfer of oxygen and carbon dioxide. The blood carrying oxygen will be pump to the whole body including the brain. The failure of the heart to pump the blood sufficiently to the brain or other part will make the insufficient of oxygen to the cells. Insufficient of oxygen supply will result in the failure of the cell to function (Heart Disease, August 30).

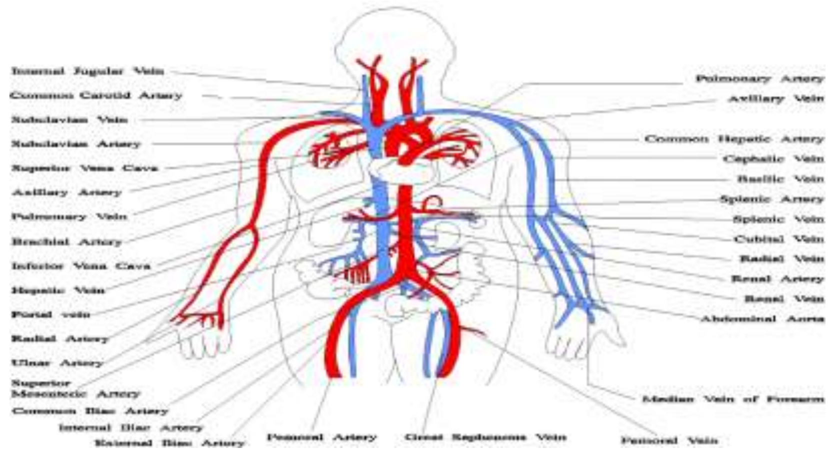


Figure 4: Illustration of blood flow system in human body (Heart Disease, August 30).

2.2 Cerebral arteries

Cerebral arteries are the arteries that supply blood to the cerebral cortex. It consists of three main pairs of arteries with their branches. The three main arteries consist of Anterior cerebral arteries, Middle cerebral arteries and Posterior cerebral arteries. The middle artery is the main focus in the study.

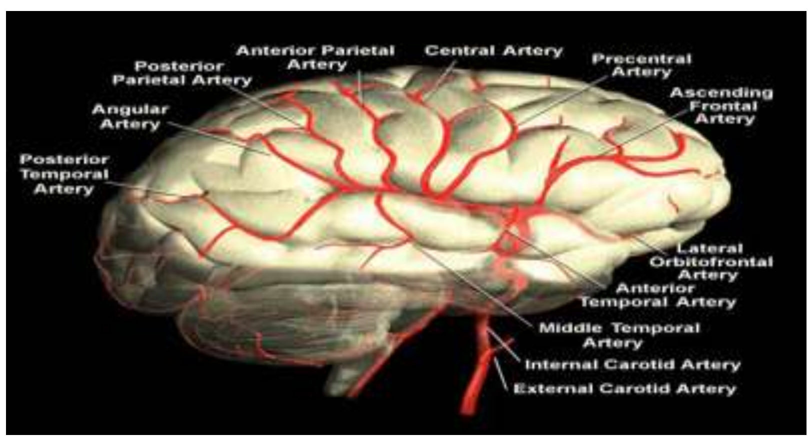


Figure 5: Illustration of cerebral arteries in the human's brain

(Heart Disease, August 30).

2.3 Middle cerebral artery

Middle cerebral artery (MCA) is the largest branch of the internal carotid. It supplies blood to the cerebrum. The artery supplies a portion of frontal lobe and the lateral surface of the temporal and parietal lobes that include the primary motor and sensory areas of the face, throat, hand and arm together with the dominant hemisphere which is the area for speech. This is where the stroke often occurs.

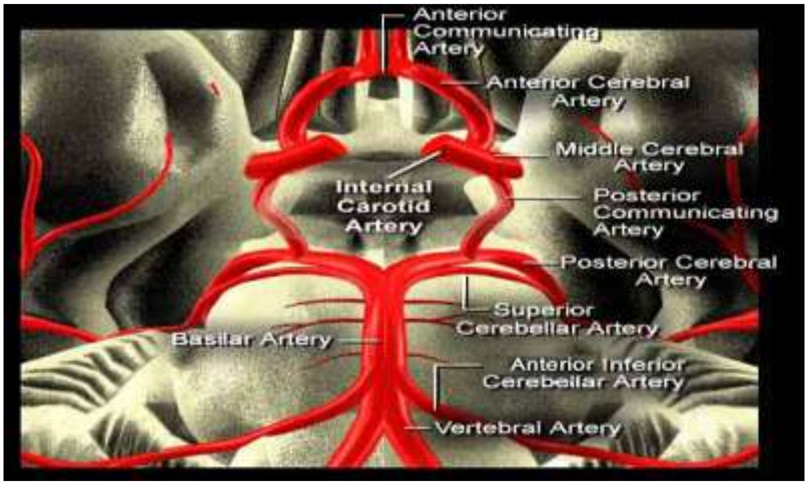


Figure 6:Illustration of middle cerebral artery (Heart Disease, August 30).

Figure 7: Illustration of the middle cerebral artery

(Corney, Johnston and Kilpatrick, 2011)

2.4 Pulsatility

The meaning of pulsatility is a measure of the variability of blood velocity in a vessel. It is equal to the difference between the peak systolic and minimum diastolic velocities divided by the mean velocity during the cardiac cycle (Pulsatile, 2007).

Generally, the blood flow and blood pressure are unsteady. The cyclic nature of the heart pump creates pulsatile conditions in all arteries. The heart will ejects and fills the blood in alternating cycles called systole and diastole. Systole is the condition where the blood is pumped out of the heart while heart is at rest during diastole and no blood is ejected. The characteristics of the pulsatile shape are varying for different part of artery system. But most of the time, the blood pressure in most arteries are pulsatile (Butany et al., 1999).

Pulsatile of person is varies according to their health condition. The person with the CVD risk may have a high pulsatility or low pulsatility compared to the healthy normal person. The pulsatility will indicate the behavior of the blood flow. Depending on that, it can determine the effects of pulsatility nature of blood flow with the CVD risk.

2.5 Wall shear stress

Comparisons between various arteries and blood viscosity models are presented in terms of wall shear stress distribution. It is believed that wall shear stress is a significant factor in the onset of CVD (Johnson, Corney and Kilpatrick, 2004).

Wall shear stress is the force cause by the fluid flow to the wall. For example, the wall shear stress in blood flow, it indicates the pressure cause by the flow of blood to wall of the arteries. Wall shear stress can be indicated from the CFD analysis. It can also being calculate through the mathematical formula. As the pulsatility of blood flow is different of every each of person considering many factor such as age, gender and type of patient, is there any relation between the wall shear stress with the pulsatile effect in the arteries (Shear Stress, 2008).

Fully developed pulsatile flow in straight or tapered tube can be expressed analytically. The Womersley solution for velocity profile can be used to generate excellent approximation for shear stress (Shear Stress, 2008).

$$\alpha = R\sqrt{\frac{\omega}{\nu}}, \quad (1)$$

Where;

R is the tube radius, ω is the angular frequency and ν is the kinematic viscosity.

From the article by Ku N.D, the wall shear stress is proportional to the velocity gradient at the wall and fluid viscosity (Ku, 1997).

$$\tau = \mu\, du/dr. \quad (2)$$

Shear stress for laminar steady flow in a straight tube is expressed as equation below and it is reasonable estimate for the mean wall shear stress in arteries. Shear stress is not easily measured by the pulsatile flows, therefore the velocity gradient and time varying must be measured closed to the wall. It is technically quite difficult to measure. An alternative method is to use the shear stress sensor that measure the heat or mass transfer between the two adjacent points on the wall. This will give the velocity gradient.

$$\tau_{wall} = \frac{32\mu Q}{\pi D^3} \qquad (3)$$

It is worth noting that the various non-Newtonian blood models are obtained by parameter fitting to experimental viscosity data obtained at certain shear rates under steady state conditions (Walburn and Schnneck, 1976). It is assumed that these models can be used under pulsatile flow conditions. This assumption is a possible limitation to this work because the formation of red blood cell is different under steady and pulsatile condition.

It was found that in the case of steady flow in a given artery, the pattern of wall shear stress is consistent across the all models. However the magnitude of wall shear stress is influenced by the used of the model.

The simulation of the pulsatility of blood flow of the different person with different type of the CVD risk. The computer simulation results will demonstrates relationship between the effects of pulsatility of the blood flow to the wall shear stress distributions (Liu and Bang, 2010).

CHAPTER 3

METHODOLOGY

3.1 Transient Simulation

Transient simulation is a time dependent simulation. It is a study of the condition at certain time intervals. The simulations presented are representative of a cyclic phenomenon in time, it is expected that the solution at the beginning of the cycle should be identical to the solution at the end of the cycle. To achieve this, the model was initially configured with the flow data from a steady state simulation with inlet velocity of 0.1m/s. It was then run over number of cycles until the data was converging and the solution at the start of the cycle was identical to the end of the cycle. Typically, transient simulation was run over five cycles which were sufficient to satisfy the condition (Johnson, Corney and Kilpatrick, 2004).

In term of transient simulations, there is significant variation between the different arteries in term of wall shear stress distribution and these different are maintained for most of cardiac cycle. In most cases, regions of low wall shear stress predominate at the proximal end of the artery with further areas of low shear stress decreasing in size and frequency as the artery is traversed (Kirpani et al., 1999). It is probably related to the fact that most of the arteries taper towards the distal end.

3.2 Computational Fluid Dynamics (CFD)

CFD is the knowledge of predicting the unknown value of related phenomena by solving numerically the set of governing equation. It is a computer based mathematical modeling tool that incorporates the solution of the fundamental equations of fluid flow, the Navier-Stokes equation and other allied equations. CFD will integrate empirical models for modeling turbulence based on experimentation, as well as the solution of heat, mass and other transport and field equations (Matsuo et al., 1988).

In performing CFD simulation, Navier Strokes Equations need to be understood since the equation is the fundamental to CFD problems. The general form of Navier Strokes equation is as equation below.

$$\rho\left(\frac{\partial \mathrm{v}}{\partial t}+\mathrm{v}.\nabla \mathrm{v}\right)= -\nabla p+ \nabla.\mathbf{T}+\mathbf{f} \tag{4}$$

Where, v is the flow velocity, ρ is the fluid density, p is the pressure, **T** is the (deviatoric) stress tensor, **f** represents body forces (per unit volume) acting on the fluid, ∇ is the del operator.

The left side of the equation is the term for acceleration and composed of time dependent (as well as the effects of non-inertial coordinates) while the right side of the equation describes as the summation of body forces and divergence of stress.

3.3 FLUENT ANSYS

FLUENT ANSYS 14.0 software is one of the sciencetific tools in the computational fluid dynamics (CFD) software package. It can be used to model turbulence, heat transfer, flow model and reaction for industrial applications. The physical models allow the accurate CFD analysis for wide range of fluids problem for example from the blood flow to the semiconductor manufacturing (Ansys Fluent, 2013).

CFD FLUENT ANSYS uses the finite volume method for solving the governing equations of a fluid. The uses of different physical models such as incompressible or compressible, laminar or turbulence are capable in the ANSYS. Normally, the CFD ANSYS comes with the GAMBIT which is the preprocessor that bundle with ANSYS. GAMBIT will deal with the geometry and generation step (Akram and Andre, June 2000).

The results obtained from the CFD ANSYS analysis are relevant for the conceptual studies of new design, redesign and troubleshooting. By using CFD ANSYS software, one does not have to carried out and perform laboratory experiment that really take more time with the data or result that are sometimes inappropriate. It also helps to reduce the time constraint and work effort as compared to the experimental procedures.

3.4 CFD Methodology

There are three basic steps in solving the problem by using the CFD modeling. The first step is problem identification and preprocessing. In this step, the modeling goal is defined by identify the domain of the model. Then it is followed by the design and creation of grid by GAMBIT. The second phase is the solver execution. This step will solve for the equation by the finite volumes. To solve this, the numerical method is used. The last phase is post processing. This is where the visualization of the CFD code predictions can be observed and it will require the further evaluation and revision by the user.

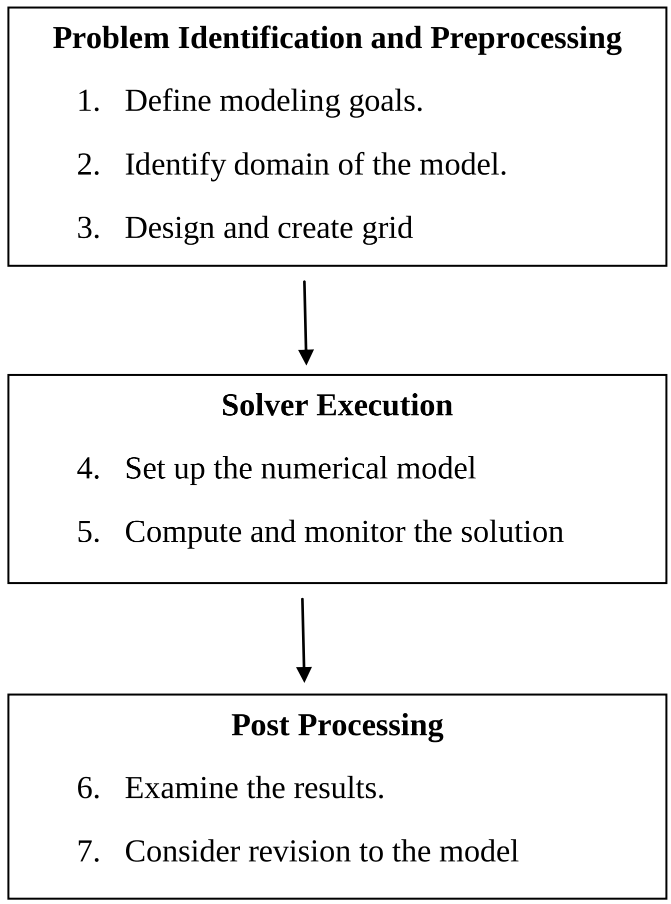


Figure 8: Flow chart of the CFD simulation

(McGarry et al., 2004).

3.4.1 Imaging data

In ANSYS software, the idealized model is constructed in the Design Modeler. The geometry used is straight cylinder pipe.

3.4.2 Simulation model

It will assume that the flow of the blood in the cerebral artery is governed by the Navier-Stokes equations;

$$\rho\left(\frac{\partial \mathrm{v}}{\partial t} + \mathrm{v}.\nabla\mathrm{v}\right) = -\nabla p + \nabla.\mathbf{T} + \mathbf{f} \tag{5}$$

The continuity equation for an incompressible fluid

$$\nabla.\mathrm{v} = 0 \tag{6}$$

From the equation 5, v is the three dimensional velocity vector, t the time, P the pressure, ρ the density and τ the stress tensor.

3.4.3 Mesh

The artery was constructed from the biplane angiograms, from which the centerline and radius of the artery along the centerline were extracted. The mesh is completed by creating a mesh entrance plane and extruding this mesh along the centerline (Cornel, Johnson and Kilpatrick, 2001). The higher the number of nodes shows that the mesh is fine. To get the more accurate result, meshing is very important stages.

Table 1: Number of nodes for different type of mesh.

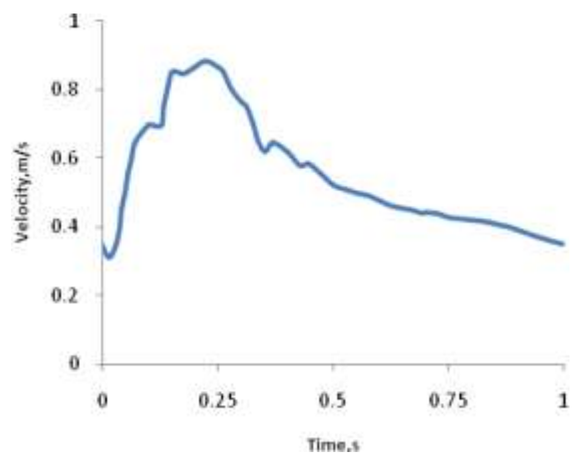
Meshing without refinement	Number of nodes : 11 000
Meshing with refinement of scale 1	Number of nodes : 70 000
Meshing with refinement of scale 2	Number of nodes : 158 000
Meshing with refinement of scale 3	Number of nodes : 280 000

3.4.4 Boundary condition

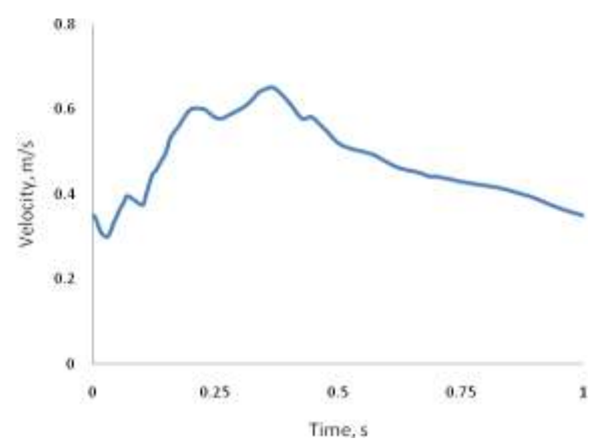
Blood is assumed as Newtonian and incompressible fluid with the density of ρ=1080kg/m^3 and μ=0.0041 kg/m-s (McGarry et al., 2004). The vascular wall is treated as rigid. Each model will use the inlet velocity which in the form of pulse following the 9th order polynomial equation (Sendstad et al., 2011). The pulse is set to 1s.

3.5 Variable for CFD

By using the CFD ANSYS, the variable that being manipulated here is the value of velocity of the peaks. The peaks represent the Vmax of the blood flow. The pulsatile variation are varies to three peaks, Vmax=0.85m/s and Vmax=0.65m/s. These peak values or the Vmax value may vary to every person. The type of person with CVD risk being observed are the hypertension patient with the peak velocity of 0.85m/s and high cholesterol person with peak velocity of 0.65m/s (Fagard et al., 1993).



Graph 1: Vmax of 0.85m/s for hypertension patient (Sendstad et al., 2011).



Graph 2: Vmax of 0.65m/s for high cholesterol patient (Sendstad et al., 2011).

3.6 Geometry Models

The geometry used for the simulation is divided into 2 types which is the idealized model and real brain artery. The idealized model is a straight artery blood or the straight tube. The tube is set to vertically as the control basis. The diameter of model is set to 4.5mm with length of 88mm. The dimension of the straight cylinder pipe model is equal with the real artery model dimension.

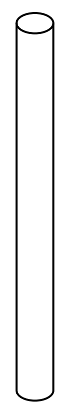


Figure 9: Illustration of straight artery blood.

The real artery model is the model that have branch represent the path of the blood in the brain. However, in this study the part that being stimulated only the straight part of the artery, neglecting the branches of the artery.

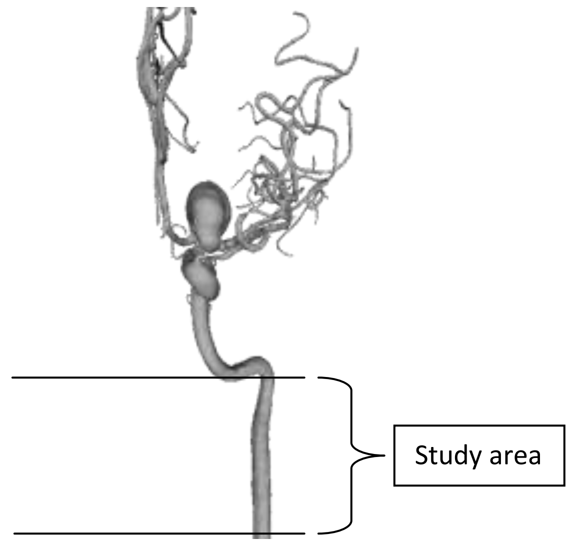


Figure 10: Illustration of the brain artery (Corney, Johnston and Kilpatrick, 2011).

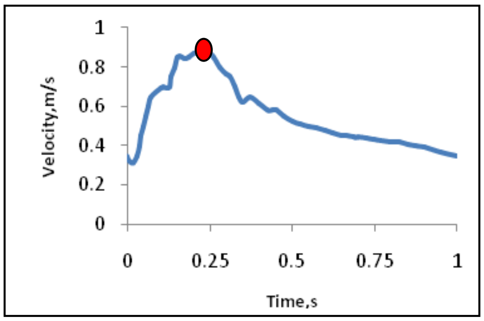
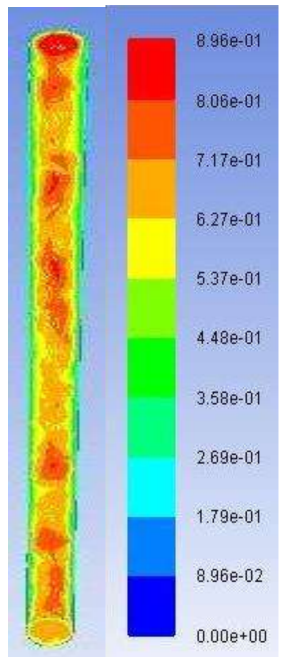
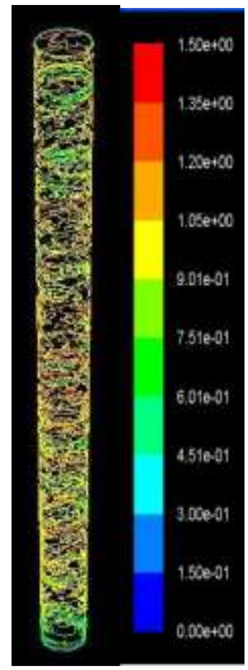
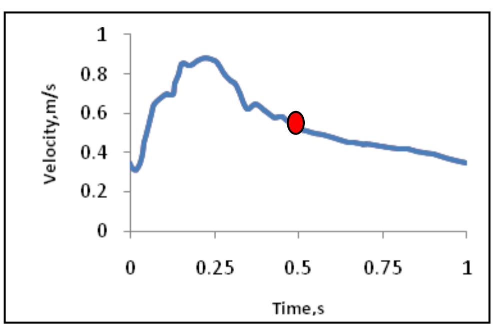
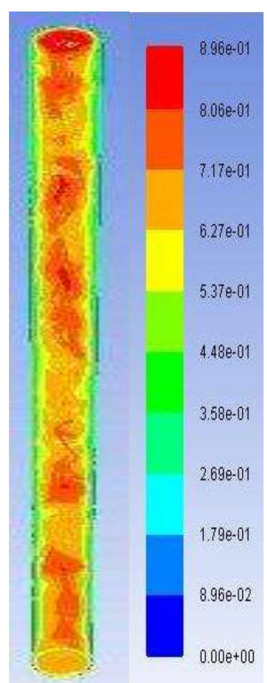
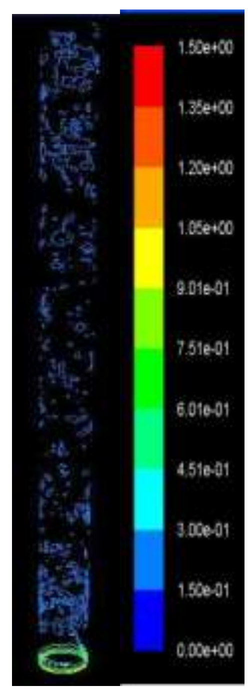
CHAPTER 4

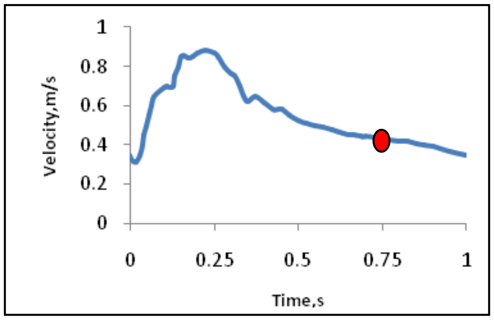
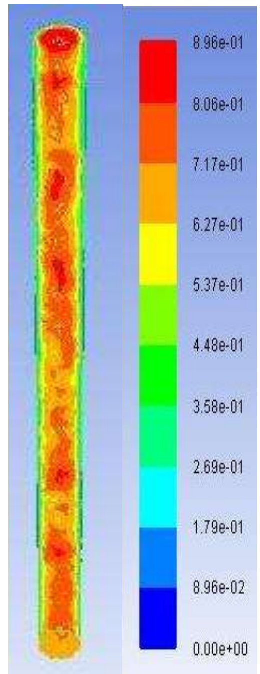
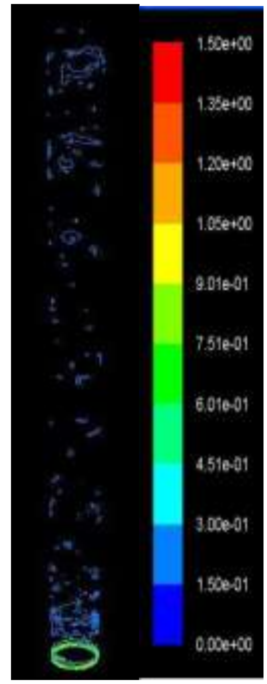
RESULT AND DISCUSSION

4.1 Hypertension patient group

In order to get the wall shear stress, velocity is an important parameter being plotted in several timing (Yunus, Shuib and Fawad). For hypertension patient group, the wall shear stress is captured at 0.25s, 0.5s, 0.75s and 1.0s. It is because the peak velocity of 0.85m/s occurred at 0.25s.

Table 2: Result for Hypertension patient with pulsatility flow of 0.85m/s.

Time instant (s)	Velocity Streamlines (m/s)	Wall Shear Stress (Pa)
At t =0.25s 		
At t=0.5s 		

At t =0.75s 		

From the velocity contour of the hypertension group, the maximum velocity of 0.85m/s is indicating by the red colour. While the velocity at the wall of the artery is represented by the green colour shows that the velocity is 0.269 m/s. The velocity is high in the middle of the artery and decreasing toward the wall of the artery. The flow inside the tube is significant based on the fluid mechanics theory where, the fluid typically enters the pipe with a nearly uniform velocity profile. The region where the fluid enters the pipe is term as inlet region. As the fluid is moving through the pipe, the viscosity affects it to stick to wall of the pipe. This is the condition of no-slip boundary (Yh, 2007).

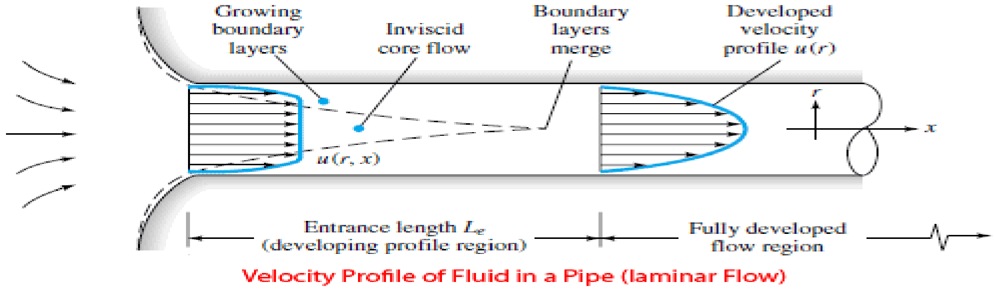


Figure 11: Velocity Profile of fluid in a Pipe for Laminar flow (Yh, 2007).

As the velocity is unsteady (not uniform) across the pipe, the initial flat end of cylinder is distorted by time when the fluid has moved along the pipe. This is why the velocity in the middle of the artery is high as compared to the wall of the artery.

From the contour of wall shear stress, at the t=0.25s, the wall shear stress measured is 1.2Pa. The wall shear stress contour at that time shows the high reading of stress, Pa as compared to other time interval. The typical value of wall shear stress should be less than 1Pa (Matthew et al., 2013). Therefore, the hypertension patient may have the high potential of getting stroke.

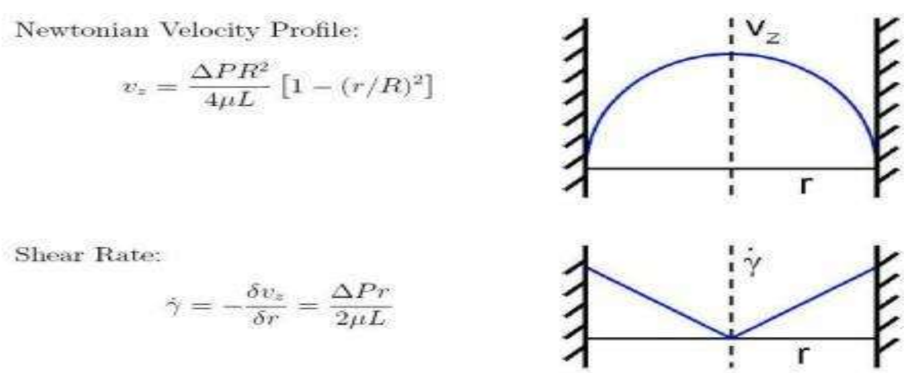


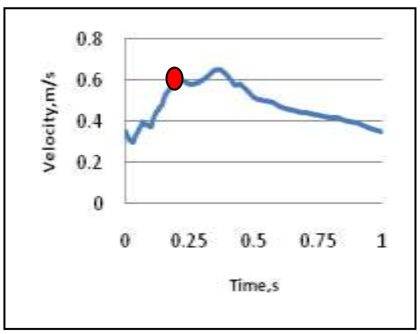
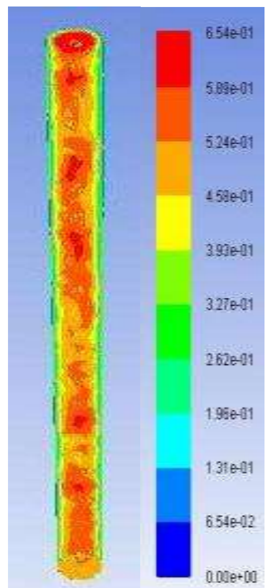
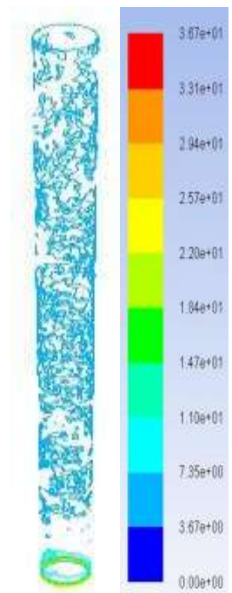
Figure 12: Shear stress Profile (Yh, 2007).

The distributions of shear stress in pipe flow indicate that the shear stress is maximum at the wall of the pipe. The concept also can be applied for blood flow in the artery. The wall shear stress of the artery should be high at the wall as compared to the middle of the artery. The molecules dart across the wall of the artery. The area of forces is greater at the wall because the velocity area is small at that position. Therefore, more forces is exerting on the wall.

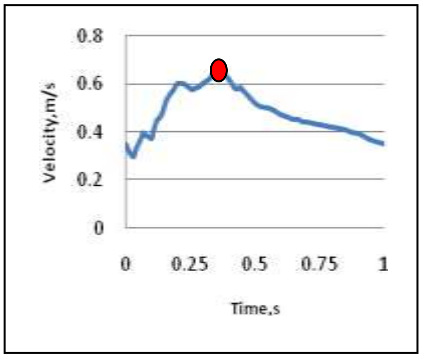
4.2 High Cholesterol patient group

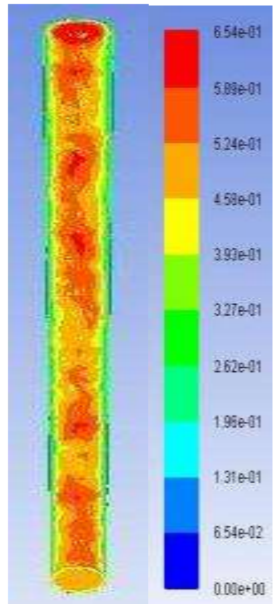
For the high cholesterol group of patient, the wall shear stress is captured at every 0.2s interval. It is because the peak velocity of 0.65m/s occurred at 0.4s.

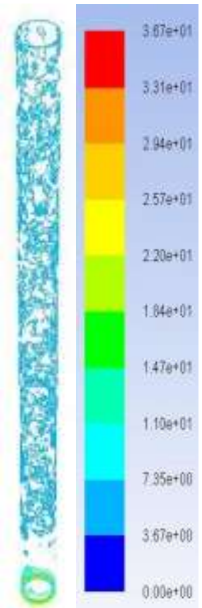
Table 3: Result for High Cholesterol patient with pulsatility flow of 0.65m/s

Time instant (s)	Velocity Streamlines (m/s)	Wall Shear Stress (Pa)
At t =0.2s 		

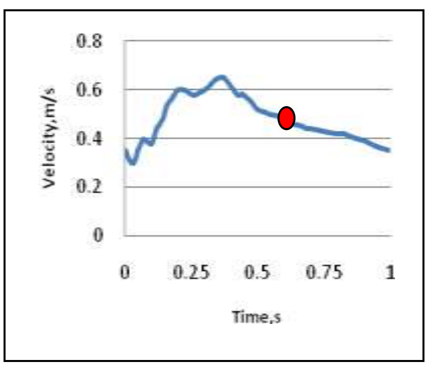
<table>
<tr>
<td>
At t =0.4s

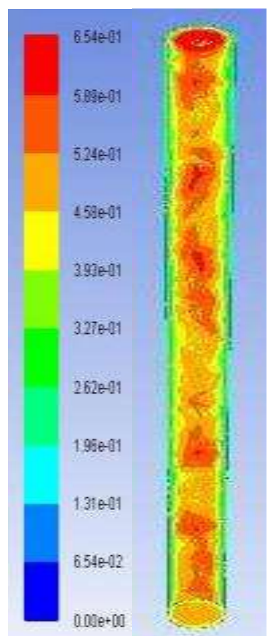


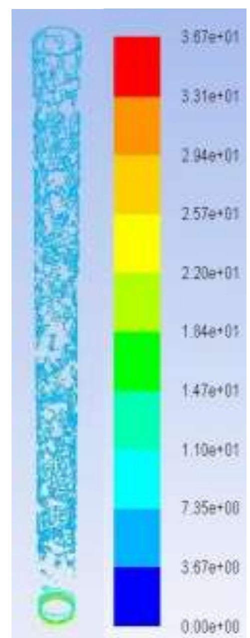
</td>
<td>


</td>
<td>


</td>
</tr>
<tr>
<td>
At t =0.6s

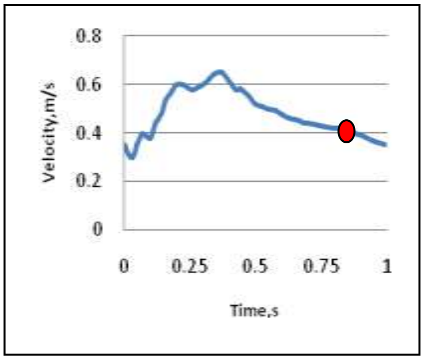


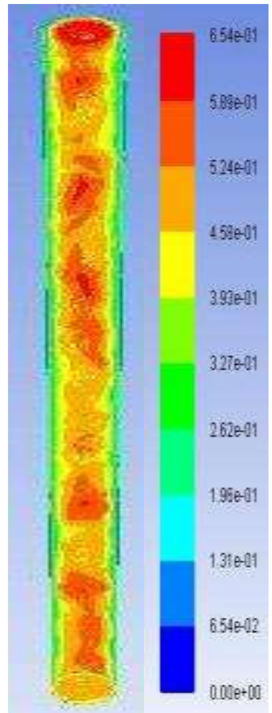
</td>
<td>


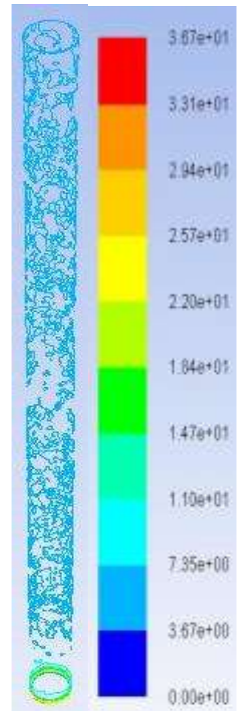
</td>
<td>


</td>
</tr>
</table>

At t =0.8s







For the high cholesterol group of patient, the peak velocity of 0.65m/s occurred at 0.4s. At this stage, the wall shear stress reading is above 1Pa for every time interval. It nearly approaches 3Pa. It indicates that the wall shear stress of the artery is very high and the chance of getting stroke is much higher as compared to the hypertension patient. The same concept of fluid mechanics was applied for these two simulations. The different is only for the inlet pulse velocity for different group of patient.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

As a conclusion, the simulation will result in the flow pattern and forces on the artery wall for those three different group of patient. The result will show the value of force exerted to the wall of cerebral artery (wall shear stress) according to their group pulsatile (inlet velocity). Simulation is used to predict the consequences of the pulsatility effect of the blood flow with CVD risk to the wall shear stress of the cerebral arteries. We did not and cannot perform the experimental procedure to the real human brain because we can simply install a stress sensor in the living human brain. It may violate the humanity value. Therefore, simulation can be the best way to study the case.

As a recommendation, the simulation for the real blood artery should be carried out in order to get the accurate result. The real geometry of blood will give the better output to study the wall shear stress in the brain artery. The pulsatile also can be varies to more type of patient group.

REFERENCES

Akram, M.S., Andre, J.D., (2000, June). Wall Shear Stress and Early Atherosclerosis. American Journal of Roetgenology, 174(6), 1657-1665.

American Heart Association, (2013, August 30). Heart Disease. Retrieved from the American Heart Association website : http://www.heart.org/HEARTORG/Caregiver/Resources/WhatisCardiovascularDise ase/What-is-Cardiovascular-Disease

American Stroke Association, (2012, October 23). About Stroke. Retrieved from the American Stroke Association website : http://www.strokeassociation.org/STROKEORG/AboutStroke/About-Stroke

Ansys Fluent. (2011). Fluid Dynamics Solutions. [Brochure]. USA.

B. Wiwatanapataphee., Y.-H. Wu., S. Amornsamankul and B. Novaprateep (2008). Simulation of Transient Blood Flow in the Artery with an Asymmetric Stenosis.

Corney, S., Johnston, P.R.,Kilpatrick, D., 2001. Construction of realistic branched,three dimensional arteries suitable for computational modeling of flow. Medical and Biological Engineering and Computing 42, 660-668.

Fagard, R., Bielen, E., Lijnen, P., Amery, A. Cardiac variables and blood pressure as determinants of left ventricular inflow velocities. Journal of Human Hypertension, 1993 7(1): p. 7-12.

Johnston, B. M., P. R., Corney, S., and Kilpatrick, D. (2004). Non-Newtonian blood flow in human right coronary arteries: Transient simulations. Journal of Biomechanics 39, 1116-1128.

Johnston, B. M., P. R., Corney, S., and Kilpatrick, D. (2008). Non-Newtonian blood flow in human right coronary arteries: Steady-state simulations. Journal of Biomechanics 37(5), 709-720.

Kirpani, A., Park, H., Butany, J., Johnston, K.W., Ojha, M., 1999. Velocity and wall shear stress patterns in the human coronary artery. Journal Biomechanical Engineering 121, 370-375.

Ku, N.D., (1997). Blood Flow in Arteries. Annu. Rev Fluid Mech. 29:399-434.

Liu, B., and Tang, D., 2010. Computer simulation of atherosclerotic plaque growth in coronary arteries. Journal of Biomechanics 7(4), 193-202.

Matsuo, S., Tsuruta, M., Hayano, M., Immamura, Y., Eguchi, Y., Tokushima, T., Tsuji, S., 1988. Phasic coronary artery flow velocity determined by Doppler flowmeter catheter in aortic stenosis and aortic regurgitation. The American Journal of Cardiology 62(1), 917-922.

Matthew, P.P., et al., (2012). Cardiovascular Disease Risk and Cerebral Blood Flow Velocity.

McGarry, J.P., O'Dennell, B.P., McHugh, P.E., and McGarry, J.G. Analysis of the Mechanical Performance of a Cardiovascular Stent Design Based on Micromechanical Modelling. Computational Materials Science Elsevier, 2004. 44: p. 421-438.

Mendis, S. Puspa, P., Norrving, B. (2011). Cardiovascular Disease Risk Factors. Cardiovascular Disease Prevention and Control. Geneva.

Merrill, F.E., et al., 2011, Norms and reference values for pulse wave velocity: one size does not fit all. Journal of Bioscience and Medicine 1,4.

National Stroke Association , (2012, June 17). Type of Stroke. Retrived from the National Stroke Association website : http://www.stroke.org/site/PageServer?pagename=stroke

National Stroke Association , (2012, June 17). What is Stroke. Retrived from the National Stroke Association website : http://www.stroke.org/site/PageServer?pagename=stroke

Pulsatile, (2007). The American Heritage Medical Dictionary . Boston, MA : Houghton Mifflin.

Sendstad, K. V, et al. Direct Numerical Simulation of Transitional Flow in a Patient Specific Intracranial Aneurysm. Journal of Biomechanics Elsevier, 2011. 44:p. 2826-2832.

Walburn, F.J., Schneck, D.J., 1976. A constitutive equation for whole human blood. Biorheology 13, 201-210.

Yh, C.S., 2007. Fundamental of Fluid Mechanics, Department of Bio-Industrial Mechatronics Engineering, National Taiwan University.

Yunus, M., Shuib, A.S, and Fawad, H. Numerical Simulation of Blood Flow on Wall Shear Stress in Aneurysm Artery, Universiti Teknologi PETRONAS.