The effect of blood flow past a stenotic carotid artery by using Computational Fluid Dynamics

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Abstract

This research presents the analysis of blood flow passed vessels that are clogged with fat**.** Blood flow unsteadiness is due to the heart-imposed temporal variations which occur during cardiac cycle. This study focused on the effects of the Newtonian and Non-Newtonian blood's flow behavior that computed by using both Laminar and Turbulence (k-ε model) flow. The results can show the effects from various blood's flow analyses that provide the different wall shear stresses. Consequentially, the tendency of potential risks that caused by the plaque rapture can be predicted more accurately and used as a supportive tool for the artery stenosis diagnosis as well.

Key word: Blood flow, Stroke, Stenos, CFD, Wall shear stress and Blood vessel

1. Introduction

For many years, stroke is the third leading cause of Thais' death. A plenty of patients must be suffered from a disability due to paralysis. Generally, the patients with cerebral thrombosis, particularly the lack of blood type, should be sended to a hospital within 3 hours from the onset of symtom to recover the blood circulation to the brain as soon as possible. To diagnose a stroke, physicians use a medical examination, such as image and Echo-Ultrasound of the carotid bifurcation that allows physicians to examine the abnormal blood vessels of the neck due to the fat-clogged.

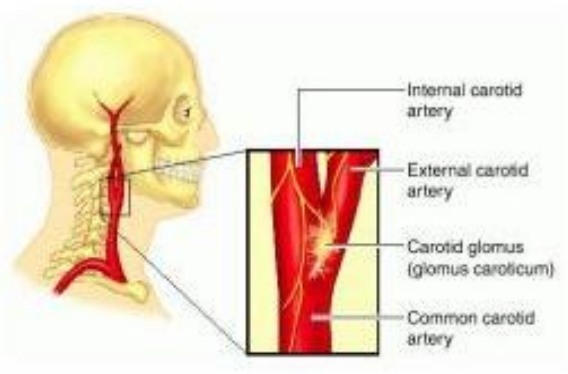


Fig. 1 carotid bifurcation

When physicians remark the abnormality of stenotic carotid artery, they can treat the patient approriately in a mean time. If the cause is the narrowing of the inner walls of blood vessels. Physicians can use a balloon or wire mesh (Stent) to stretch the inner wall of the constricted blood vessels. The efficiency of the acute stroke patients treating more relies on the availability of treatment technologies, whether equipment, techniques, medicine or the physician.

However, the use of imaging process and blood flow checking could not provide the sufficient information for physician's diagnosis. Sometimes, the treatment with a balloon or wire mesh will be used, when the symptoms of complete blockage in a blood vessel were detected. One of the major causes of patient death is plaque rupture which the fracture of fat flows passes the blood vessel and clots within the brain. This plaque rupture caused from the high wall shear stress of the artery wall was torn [1] where the wall shear stress value will be proportional to the flow characteristics of blood. [2] In the case of normal coronary flow [3], the wall shear stress is not high. Nevertheless, when the blood flows through the arteries that are clogged with fat, the wall shear stress can be higher due to the turbulent flow behavior [4].

Therefore, by employing computational fluid dynamics to simulate the blood flow through the vessels, the wall shear stress can be predicted [5]. From literature reviews, some research work analyzes the blood as a Newtonian fluid with laminar flow behavior. However, there is a research shows the fact that the behavior of blood is Non-Newtonian fluid [6]. Although, the Non-Newtonian fluid models are variety, the testing results [7] suggested that the Carreau-Yasuda Model can represent the behavior of the blood precisely.

In this research, the flow behavior of blood through the arteries with fat blockages in Stroke Patients was analyzed by using the computational fluid dynamics in order to study the effect of the wall shear stress due to the larminar and tubulence flow by considering blood as a Newtonian fluid and Non-Newtonian fluid to guideline the analysis methodology for blood flow through the arteries with fat blockages in Stroke patients.

2. Method

The 3D Model of the blood vessel was built with 80% blockage. Two constitutive equations will be employed in the simulation. One is laminar flow and the other is turbulent flow The equation governing the flow are, first conservation of mass, and second momentum conservation as the following

$$\frac{\partial \bar{u}_i}{\partial x_i} = 0 \quad (1)$$

$$\frac{\partial}{\partial x_j}\left(\overline{\rho u_i}\bar{u}_j\right) = \frac{\partial \bar{p}}{\partial x_j} + \frac{\partial}{\partial x_j}\left(\bar{\tau}_{ij} - \rho\overline{u'_i u'_j}\right) \quad (2)$$

For the blood model , the Newtonian and Non Newtonian fluid behavior are used, where the viscosity for the Newtonian is 0.00345 Pa.s and for Carreau Yasuda model, The low shear viscosity 0.00345 Pa.s, high shear viscosity 0.056 Pa.s, time constant 3.313, power law index 0.3568 and Yasuda exponent 2. Normally, the heart beat will change the flow speed and pressure within the blood vessels with time, which is called Pulse wave velocity [9] (Figure 2). Such changes affect the flow and Wall shear stress [10], hence the unsteady flow [11] analysis was applied to simulate such behavior.

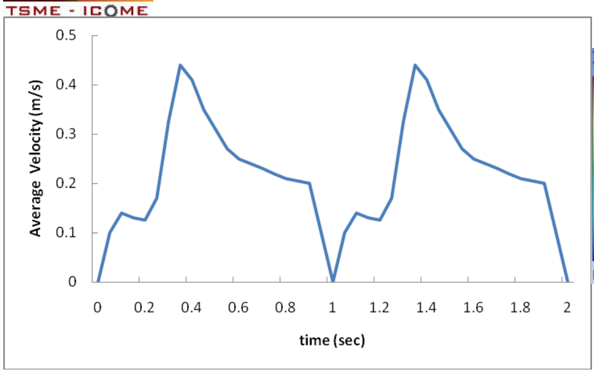
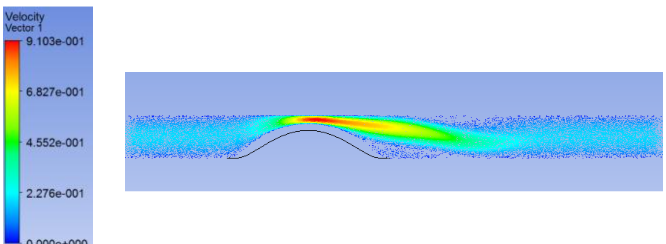


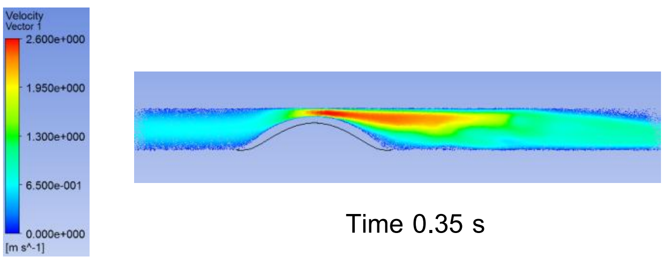
Fig. 2 Pulse wave velocity

3. Result

According to the results, the maximum wall shear stress in each simulation case occurs when the heart compress at 0.35 sec. Figure 4 shows the wall shear stress at 0.1, 0.35, and 0.9 sec for predicting the plaque rupture. After that, the average wall shear stress at the given interval were plotted as shown in figure 5. From the graph, the wall shear stress in laminar newtonian case is higher than the other 3 cases which agrees well with the average dynamics viscosity plot as shown in figure 6. The results shows that the average dynamics viscosity of the laminar newtonian case is highest as well. This suggested that the dynamics viscosity affect to the wall shear stress.



Time 0.1 s



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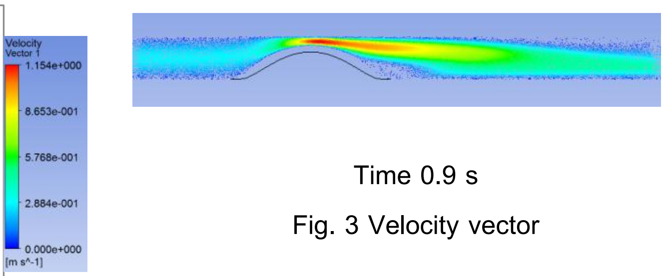

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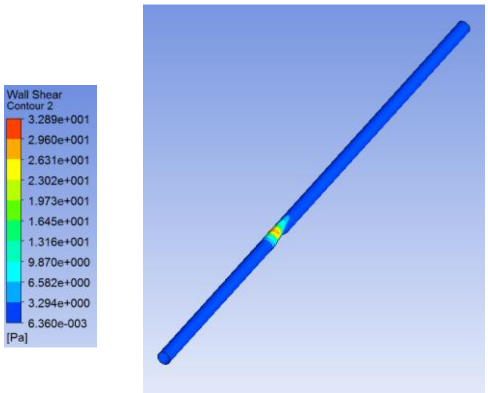
Fig. 3 Velocity vector



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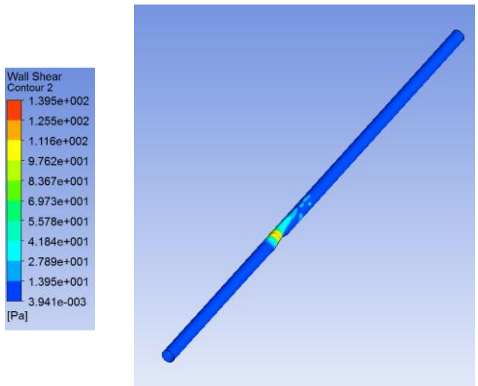

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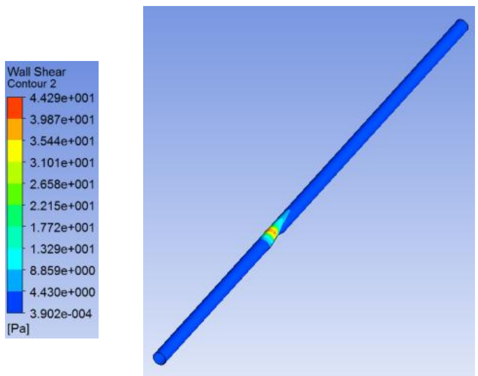

Time 0.9 s

Fig. 4 Wall shear stress at Laminar Newtonian

For Non Newtonian model, the dynamics viscosity is higher than the one of newtonian model and proportional to the shear strain rate. In figure 7, the shear strain rate at 0.1, 0.35, and 0.9 sec show that the laminar flow pattern gives the higher shear strain rate comparing to the Time 0.35 s turbulent flow.

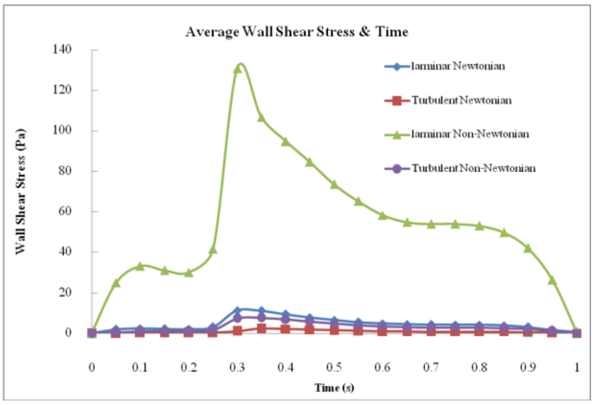

Fig. 5 Average wall shear stress with time

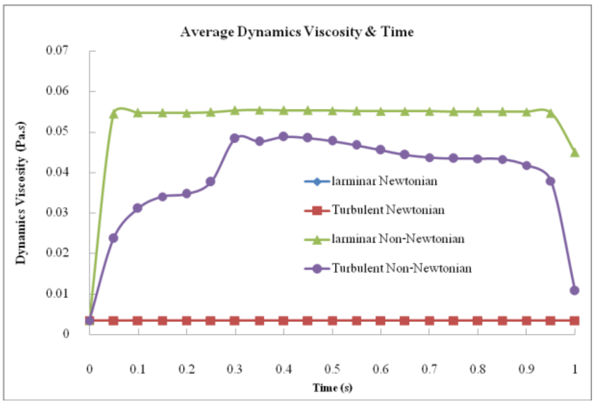

Fig. 6 Average dynamics viscosity with time

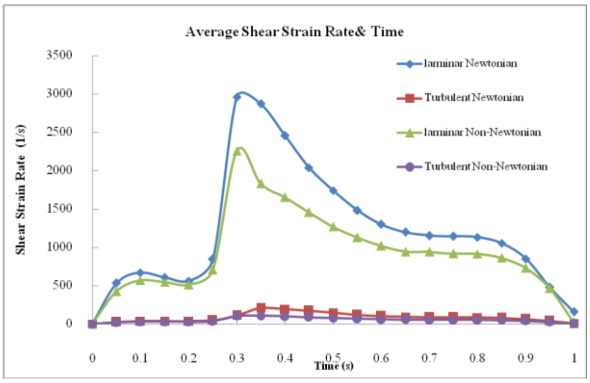

Fig. 7 Average shear strain rate with time

4. Conclusion

As shown by the computational results above, the analysis of blood flow past a stenotic carotid artery by using Newtonian model gives the different wall shear stress value from the Non Newtonian model which quite agree with the research work [3] on Non Newtonian Carrue-Yasuda Model. Moreover, the laminar and turbulent flow pattern also affect to the wall shear stress calculation. Consequentially, to obtain the accurate calculation in blood flow past a stenotic carotid artery, the blood model and flow pattern must be should appropriately.

5. Acknowledgement

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