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Research Article

THE ANALYSIS OF BLOOD FLOW PAST CAROTID BIFURCATION BY USING THE ONE-WAY FLUID SOLID INTERACTION TECHNIQUE (FSI)

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ABSTRACT:
This research presents the analysis of blood flow passed carotid bifurcation that are clogged with fat. Blood flow unsteadiness is due to the heart-imposed temporal variations which occur during cardiac cycle. The effects of the Newtonian and Non-Newtonian blood's flow behavior are computed. In this study, the one way fluid–solid interaction (FSI) technique is used to calculate the flow behavior and stress distribution on blood vessel. The results can show the effects from various blood's flow analyses that provide the different wall shear stresses from computation technique. 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.

Keywords: *Blood flow, Carotid bifurcation, one-way FSI, two-way FSI*

1. INTRODUCTION

For many years, a 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, should be sent to a hospital within 3 hours from the onset of symptom 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.

When physicians remark the abnormality of stenotic carotid artery, they can treat the patient appropriately in a mean time. If the cause is the narrowing of the inner walls of blood vessels, the 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 was 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].

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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 [6-7]. Although, the Non-Newtonian fluid models are variety, the testing results [8] suggested that the Carreau-Yasuda Model can represent the behavior of the blood flow precisely.

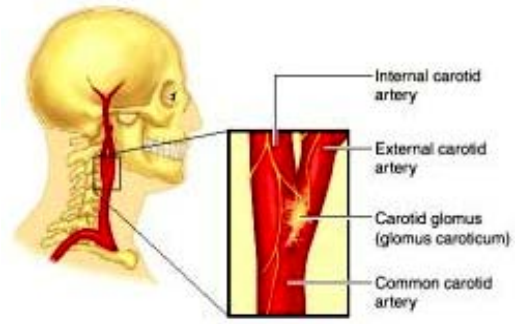


Fig. 1. Carotid bifurcation.

In this research, the flow behavior of blood through the carotid bifurcation arteries (Fig. 1) 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 and principal stress on artery with hyper–elastic behavior 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 70% blockage. For the blood model, the Newtonian and Non Newtonian fluid behaviors are used. Normally, the heart beat will change the flow speed and pressure within the blood vessels with time, which is called Pulse wave velocity [9] (Fig. 5). Such changes affect the flow and wall shear stress [10], hence the unsteady flow [11] analysis was applied to simulate such behavior.

The laminar flow will be employed in the simulation. The governing equation of flow are, first conservation of mass, and second momentum conservation as the following

$$\nabla \cdot u = 0 \tag{1}$$

$$\rho\left(\frac{\partial u}{\partial t} + u \cdot \nabla u\right) = -\nabla p + \nabla \cdot \tau \tag{2}$$

where ρ is density, u is velocity, p is the fluid pressure and τ represents the stresses on the fluid.

The nonlinear modified Mooney–Rivlin model was used to describe the material properties of the vessel wall [12-14]. The strain energy function is given by

$$W = C1(I1-3)+c2(I2-3)+D1[exp(D2(I1-3))-1] \tag{3}$$

where I1 and I2 are the first and second strain invariants, c_i and D_i are material parameters chosen to match experimental measurements and the current literature [15]. Parameter values used for the arterial vessel wall in this model were:
c_1 = 368,000 dyn/cm^2, c_2 = 0, D_1 = 144,000 dyn/cm^2 and D_2 = 2.0.

The procedure of the one-way fluid solid interaction. First, the calculation of blood flow through the arteries is show the result of velocity, wall shear stress, shear rate and pressure. From the result, pressure is used to loading condition in order to calculate strength analysis.

3. RESULT

First of all, the calculation was validated by using blood flow simulation and compared to the previous research (Anastasiou *et al.* [16]) that The experiment of blood flow through the carotid bifurcation arteries as shown in Figure 3 and using an aqueous glycerol solution substitution blood viscosity. The Local flow velocities were measured using micro Particle Image Velocimetry (μPIV).

In the simulation, Carreau Yasuda blood model was employed for computational fluid dynamics. After fitting curve (Fig. 2), the results show that the low shear viscosity is 0.03 Pa.s, high shear viscosity is 0.005 Pa.s, time constant is 0.6967, power law index is 0.6971 and Yasuda exponent is 2.0.

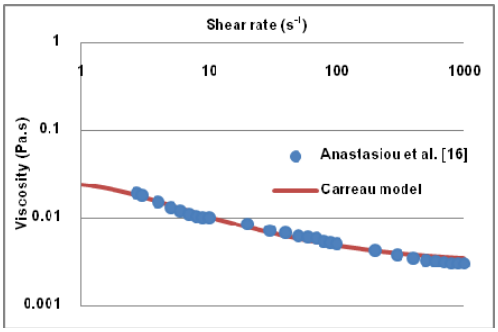


Fig. 2. Blood viscosity at shear rate.

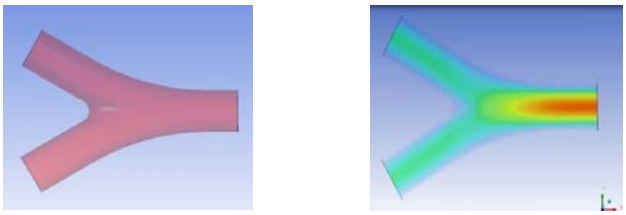


Fig. 3. carotid bifurcation for validation.

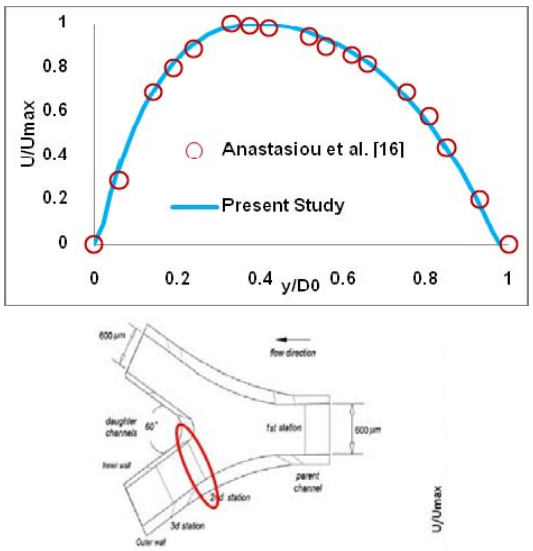


Fig. 4. The comparison Velocity at 2 stations between present study and Anastasiou *et al.* [16].

The calculation results agree well with the testing as shown in Figure. 4. With the validity of analysis above, the blood flow passed carotid bifurcation is investigated, which the heart beat will change the flow speed and pressure within the blood vessels with time, which is called Pulse wave velocity.

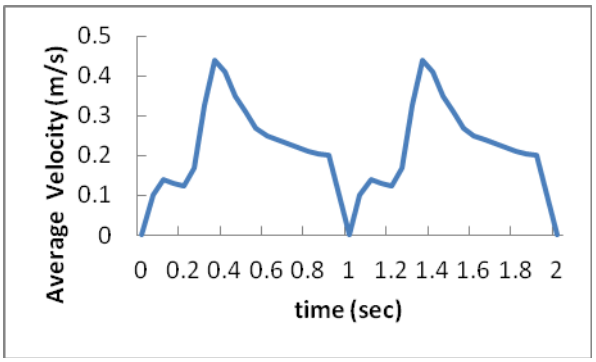


Fig. 5. Pulse wave velocity.

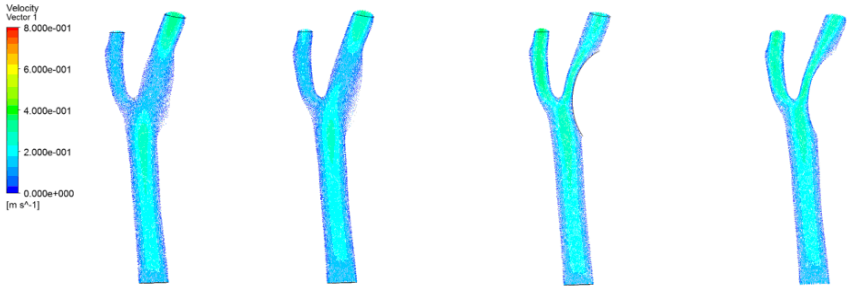
In this study, the normal carotid and carotid with plaque are analyzed with Newtonian and Non-Newtonian blood property follow Table 1.

Table 1: Case for calculation

Case	Type of carotid	Blood property
1	Normal Carotid	Newtonian
2	Normal Carotid	Non-Newtonian
3	Carotid with plaque	Newtonian
4	Carotid with plaque	Non-Newtonian

Normal carotid Carotid with plaque

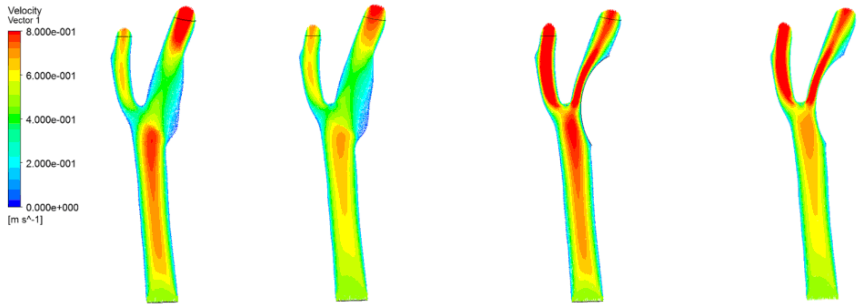
Fig. 6. Normal carotid and carotid with plaque.



Case 1 Case 2 Case 3 Case 4

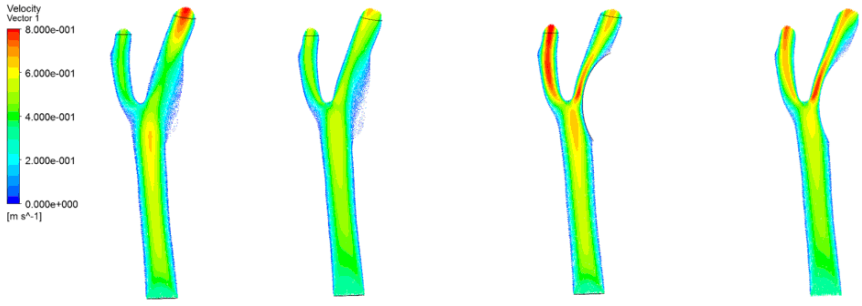
(a) time 1.2 sec

Fig. 7. Velocity vector case 1, 2, 3 and 4.



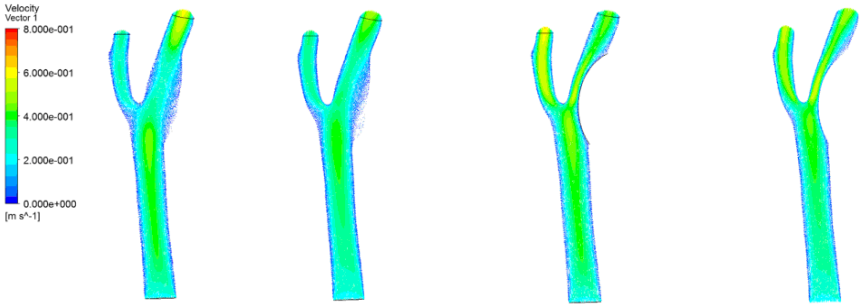
Case 1 Case 2 Case 3 Case 4

(b) time 1.3 sec



Case 1 Case 2 Case 3 Case 4

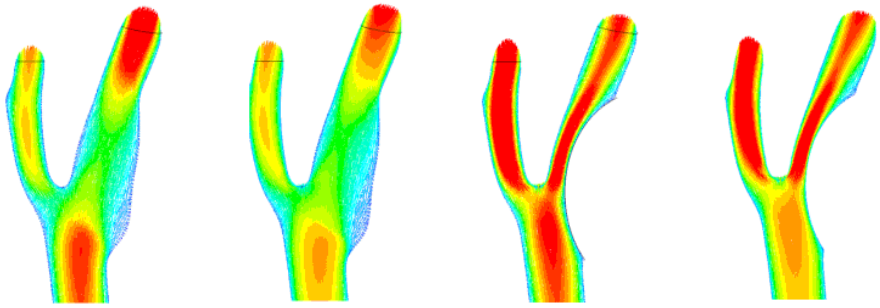
(c) time 1.5 sec



Case 1 Case 2 Case 3 Case 4

(d) time 1.8 sec

Fig. 7. Velocity vector case 1, 2, 3 and 4 (cont.).



Case 1 Case 2 Case 3 Case 4

Fig. 8. Velocity vector case 1, 2, 3 and 4 at time 1.3 sec.

The blood flow passed carotid is transient analysis due to heart beating. Therefore, the calculation will be done for two consecutive heart compression cycles. The calculation result of the second compression cycle is used in order to get rid of the problems that caused by initial flow in the first compression cycle. When comparing the results between Newtonian and Non-Newtonian as shown in Figure. 7, The Newtonian blood has more velocity than Non-

Newtonian blood in the area with less shear strain rate due to the high viscosity of that area. Beside, in the case of carotid with plaque, the Newtonian and Non-Newtonian blood also presents the similar behavior as normal carotid illustrated in Figure. 8. As can be seen, at time 1.3 sec, the highest velocity occurs during the compressive cycle.

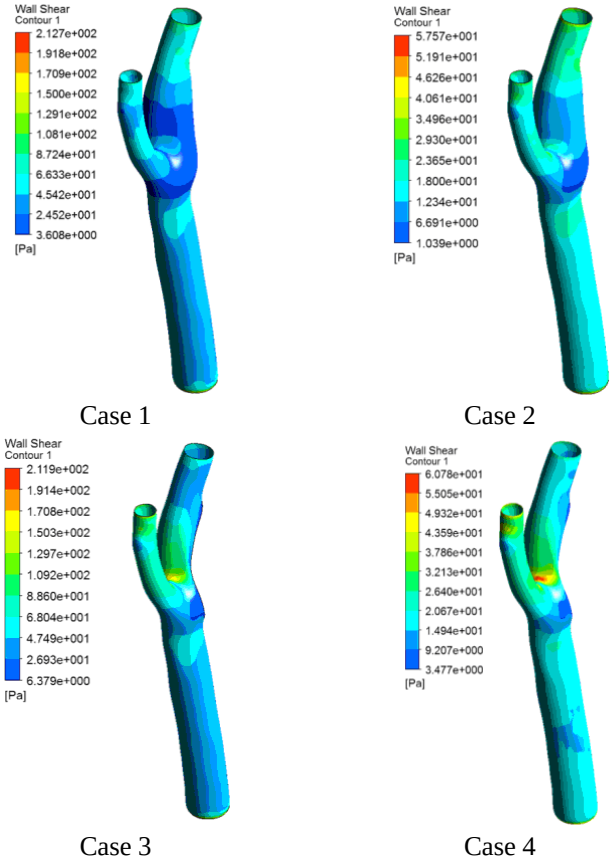


Fig. 9. Wall shear stress distribution on carotid bifurcation case 1, 2, 3 and 4 at time 1.3 sec.

Table 2: Average wall shear stress and average pressure on carotid bifurcation wall at time 1.3 sec

Case	Average wall shear stress (Pa)	Average pressure (Pa)
1	39.15	2,946.54
2	15.09	2,416.91
3	51.33	4,089.16
4	18.73	3,155.63

In the case that the carotid bifurcation wall was considered as non-deformable wall, the wall shear stress is used as an indicator for the failure of bifurcation wall. As shown in Figure. 9, the Newtonian blood has higher wall shear stress than Non-Newtonian due to the drastically change in shear strain rate nearby the bifurcation wall, owing to the low viscosity of Non-Newtonian blood.

Table 2 shows the average wall shear stress and average pressure on carotid bifurcation wall at time 1.3 sec. Then both of average wall shear stress and average pressure in the case Newtonian has higher value than the case Non-Newtonian because of the shear strain rate of blood flow that comes from viscosity.

In the other hand, if the bifurcation wall was consider as deformable wall and the one-way interaction methodology was employed by using the pressure on the wall as input loads for stress analysis, as a result, the failure behavior of bifurcation wall can be improved and better represented the real behavior during compressive cycle. As presented in Figures. 10-13, the carotid with plaque has the higher stress than normal carotid, whereas the Newtonian blood causes the higher stress than Non-Newtonian blood.

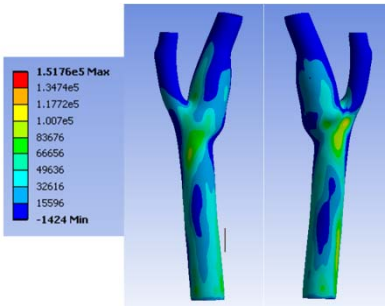


Fig. 10. Principal stress distribution on carotid bifurcation case 1 at time 1.3 sec.

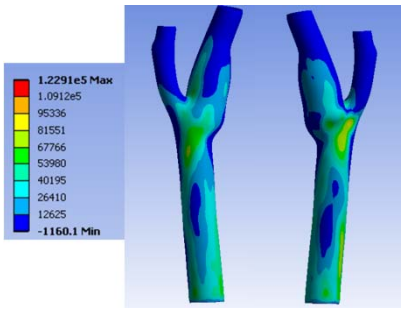


Fig. 11. Principal stress distribution on carotid bifurcation case 2 at time 1.3 sec.

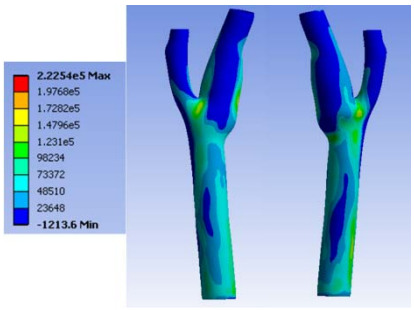


Fig. 12. Principal stress distribution on carotid bifurcation case 3 at time 1.3 sec.

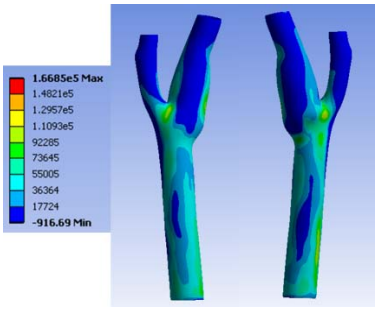


Fig. 13. Principal stress distribution on carotid bifurcation case 4 at time 1.3 sec.

4. CONCLUSIONS

In this paper, the computational fluid dynamics analysis of blood flow in normal carotid and carotid with plaque are presented. According to the simulation results, the Newtonian and Non Newtonian blood property is directly affected to the flow pattern, pressure, wall shear stress and principal stress. For the Newtonian blood, the velocity, pressure, wall shear stress and principal stress are higher than those of Non-Newtonian blood due to the constant viscosity and the viscosity change from shear strain rate.

As known that, the Non-Newtonian blood substitutes and the Carreau Yasuda model is quite accurate [8] for blood flow analysis. Contrary to the Newtonian behavior of the blood that makes the wall shear stress and principal stress is higher than the physical testing value.

Furthermore, the analysis of the vessel wall without collapsing just uses the wall shear stress to predict the damage that may occur to the vessel wall, but not the real stress on the wall. Thus, the one-way FSI analysis which considers both the collapse of the walls of blood vessels and the pressure inside the blood vessels, could improve the accuracy for damage analysis of the artery wall.

Future work, the simulation will calculate two-way fluid solid interaction due to the behavior of blood flow and cross section area of carotid always are changing. For these reason, the result form simulation will be nearby the real behavior of blood flow in human. The advantage of these research can predict the plaque rapture and plan how to treat the stroke patient.

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