# Analysis of Hyperthermiain Aneurysm

Tunku Amrul Ilham Tunku Adaham,[a], Mohamad Ikhwan Kori,[a], Kahar Osman,[a,b,*],
Ahmad Zahran Md. Khudzari,[b], Ishkrizat Taib,[c,**]

[a)] *Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, 81310, Skudai, Johor, Malaysia.*
[b)] *Faculty of Biosciences and Medical Engineering, Universiti Teknologi Malaysia, 81310, Skudai, Johor, Malaysia.*
[c)] *Flow Analysis, Simulation and Turbulence Focus Group, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, BatuPahat, Johor, Malaysia.*

*Corresponding author: kahar@fkm.utm.my,*, iszat@uthm.edu.my,**

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## ABSTRACT

Aneurysm is one of the problems occurs in blood flow phenomena. Researchers have been interested in the flow inside the aneurysm and many numerical and experimental results have been produced. This study focuses on the effect of variable viscosity on the blood flow behavior. The study shows that as the viscosity decreased, the pressure is increased for both Newtonian and non-Newtonian conditions. Besides that, the peak pressure for low viscosity is much higher compared to the peak pressure for high viscosity which the possibility of the aneurysm to rupture valid for low viscosity blood conditions. As for the normal blood pressure and high blood pressure, the peak pressure inside the aneurysm increase as high as 90%, which become another factor of the aneurysm to rupture. Apart from all the results above, there are no significance differences for both Newtonian and non-Newtonian case. This paper predicts the possibility of aneurysm rupture in hyperthermia patient.

**KEY WORDS:** *Abdominal Aortic Aneurysm; Variable Viscosity;Computational modeling.*

## 1.0 INTRODUCTION

The developments of recirculation flow inside the aneurysm region play the significant roles of AAA growth or rupture. Nevertheless, the early detection of aneurysm is will help us to make the prediction of the AAA ruptures. The physician determines that the aneurysm possibility rupture in the largest diameter [1]. In a clinical practice, AAA is considered for the surgical treatment after the maximal diameter of aorta exceeds to 5-6 cm [2]. The probability of the aneurysm ruptures is high if the diameter of the aneurysm exceed more than 5cm and the aneurysm will be treated using the synthetic graft [1]. R.C. Darling et al reported that the rate of the aneurysm rupture between 4.1 cm and 7 cm is around 25% while the rupture of the aneurysm less than 4 cm expansion per year around 9.5% [3]. However, the correlation between the largest of the aneurysm and probability the aneurysm ruptures is still in question mark by many researchers. Nevertheless, the expansion of the aneurysm segment eventually increase the risk of the aneurysm ruptured [4] although, rupture could occur in a small aneurysm [2]. The aneurysm rupture is a major complication at the disease vessel especially in AAA which to be lead the 90 percent of patients died[5]. Moreover, the early detection of the aneurysm ruptures can be improves by using the computational modeling techniques which include the fluid wall interaction [5]. Hence, the technology will facilitate the medical doctor to make the early prediction of aneurysm rupture on the patient and directly make the decision for endovascular repair (EVAR).

Several researchers investigate the flow in AAA with the viscosity constant at a certain value. However there are also researchers that study the blood flow in the normal arteries with different viscosity.Blood viscosity increases by 50% to 300% as temperature is decreased from 37°C to 22°C [6,7]. Often, even lower blood temperatures, in the range of 8°C-12°C, are typically encountered when performing deliberate deep hypothermia for cardiac or thoracic aortic operations requiring temporary circulatory arrest [8, 9]. Because the physical characteristics of blood are complex, blood's rheology properties at temperatures commonly used for deep hypothermia cannot be reliably predicted based on measurements performed at higher temperatures.

Some medical researcher reported that fever also couldcause aneurysm rupture [10,11,12]. Mizuno et al had confirmed that when a person is having a fever, there are also possibilities of the aneurysm to rupture. From his case study, a 58-yearold woman with preceding aortic regurgitation was admitted to his hospital because of high grade fever. Within weeks her symptoms worsened. She was diagnosed as aortic regurgitation and had been treated with diuretic. In quite a few cases many of the internal carotid aneurysms have been noticed initially because of the hemorrhage from the pharynx, which can be massive and lead to suffocation and result death [13]. Meanwhile, according to one of the Barlow et al [14] study case, a 55-year-old man with an abdominal aortic aneurysm presented with fever and abdominal pain. The abdominal pain worsened and further investigation including CT scan demonstrated a leaking aortic aneurysm. Based on the report, the behavior of the aneurysm due on the flow in condition, in which the patient is in hyperthermia or fever need to be analyzed. The highest temperature thatare taken into account is at 41°C as there are people survived with 41°C of body temperature according to report by Kosaka et al [15]. According to his report, biological functions are dependent on the thermosensitive characteristics of the protein and fatty substances composing the body structure [15]. He added that in a stressful environment, the extremely high human body temperature detected by computer screening in his laboratory are in the range of 41°C – 46.5°C.

Mover et al reported that stress at wall play the significant role for the vessel ruptures due to exceed the tensile strength at the aortic wall when the mechanical stress acting on the inner wall, the failure of material occur and tissues separate at the wall[16]. In order to evaluate the aneurysm ruptured, the critical evaluation in how to understanding the hemodynamic stress exerted at the aortic wall and the factor which may influence the deformation of aneurysm [17].The investigation on the experimental for thesteady flow and the digital particles image velocity in hemodynamic aortic aneurysm could be validate with the numerical simulations for the propensity for platelet deposition [18] and the Doppler velocimetry laser (LDV) will visualize the flow to investigate the critical Reynolds number [19]. Peattie et al reported that the spatial distribution of turbulence was investigated in steady flow [20]. Budwig et al.summarize the steady flow behavior in his study [1].In this study, the aneurysm model is considered as a simplified model. This study concentrates on Newtonian steady flow.

## 2.0 METHODOLOGY

### 2.1 The geometry of the simplified aneurysm

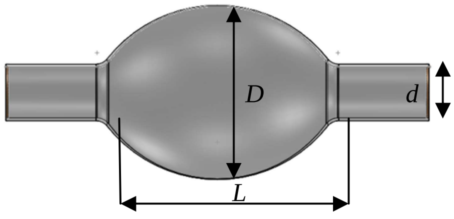


Figure 1: The simplified model of Abdominal Aortic Aneurysm.

The simplified 3D model of aneurysm is considered based on the real AAA geometry modelled by Giumaet al [21]. The aneurysm has a maximum diameter of*D*, length between proximal and distal end of *L* and *d* for un-dilated aortic diameter.

### 2.2 Parameter assumptions and blood properties

Blood is considered as an incompressible, homogeneous, Newtonian fluid while the AAA wall is considered as rigidwall.The flow with Reynolds number (Re) in the region of $2000 \leq Re \leq 4000$,which is turbulent flow, is considered. Besides that, both normal blood pressure (NBP) and high blood pressure (HBP) are simulated to predict the significance of NBP and HBP to the growth of AAA.

The viscosity of the blood in AAA is set to be varied with respect to different temperature. Figure 2showsthe correlation between blood temperature and viscosity. Furthermore, density, thermal conductivity and specific heat are based on the normal blood properties. All of the data used were assumed to be constant along the blood vessel during the simulation.

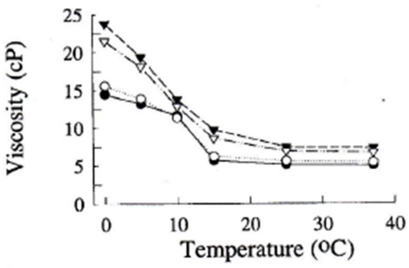


Figure2: Viscosity versus Temperature [22]

### 2.3 Governing equation and Boundary condition

In this simulation, Computational Fluid Dynamic software called Engineering Fluid Dynamic (EFD) was used in this simulation. Both velocity inlet and pressure outlet are computed to solve the continuity and Navier-Stokes equation. Hence, the physical laws describing the problem of AAA are the conservation of mass and the conservation of momentum. For such a fluid, the continuity and Navier–Stokes equations are as follows:

$$\frac{\partial u_i}{\partial x_i} = 0 \tag{1}$$

$$\rho\left(\frac{\partial u_i}{\partial t} + u_j\frac{\partial u_i}{\partial x_j}\right) = -\frac{\partial P}{\partial x_j} + \mu\frac{\partial^2 u_i}{\partial x_j \partial x_j} + f_i \tag{2}$$

Where $u_i =$ velocity in the $i^{th}$direction, $P$ = Pressure, $f_i$ = Body force, $\rho$ = Density, $\mu_i$ = Viscosity and $\partial_{ij}$ = Kronecker delta. The shear stress, $\tau$ at the wall of aneurysm calculated based on a function of velocity gradient only:

$$\tau = \mu\frac{\partial u}{\partial y} \tag{3}$$

Where $\partial u/\partial y$ is the velocity gradient along the aneurismal wall taking considerations of fluid viscosity. Therefore, the simple viscous fluids considered with linear relationship. The equation of motion in terms of vorticity, ω as follows:

$$\frac{\partial \omega}{\partial t} - \nabla X (V X \omega) = \frac{\mu}{\rho} \nabla^2 \omega \qquad (4)$$

Where ω is the vorticity, $\rho$ =Density and μ= viscosity with vector $\nabla^2 V$ evaluated as well. Solution of these equations in their finite volume form is accomplished through a commercial software package EFD Lab. The solver solves the governing equations with the finite volume (FV) method on a spatially rectangular computational mesh designed in the Cartesian coordinate system with the planes orthogonal to its axes and refined locally at the solid and fluid interface. Additional refining was done for specified blood regions, at the arterial and aneurysm surfaces during calculation. Values of all the physical variables are stored at the mesh cell centers and due to the Finite Volume method, the governing equations are discretized in a conservative form and the spatial derivatives are approximated with implicit difference operators of second-order accuracy. The time derivatives are approximated with an implicit first-order Euler scheme. The geometric dimensionof the side-wall aneurysm, the parent artery harboring the aneurysm was modeled using computer aided design software.

The boundary conditions are considered fully developed parabolic flow, zero radial velocity at the inlet, no slip applied at the wall and zero velocity gradient at the outlet. In this study, the viscosity for each casevaries with different temperature.

## 3.0 RESULTS AND DISCUSSION

### 3.1 Pressure Distribution

Three different viscosity values with effect of temperature were investigated in order to see the influences of the temperature on the aneurysm wall. Figure 3shows pressure distribution along the aneurysm wall for all the case studies. As expected, the pressure distribution for the high blood pressure with high blood temperature is way much higher compared to the other cases. From the same figure also shows that the increment of the pressure is not linearly increase. The increase of the pressure between 37°C and 39°C is not the same as the increase of pressure between 39°C and 41°C. From that, it is predicted that the possibilities of the aneurysm to rupture is higher when the person is in fever or in other words hyperthermia. As for the cross sectional analysis, the pressure at the distal neck of the aneurysm is the highest compared to the proximal and the center. With this results, the possibilities of the aneurysm to ruptured is most likely located between the center and the distal end of the aneurysm. However, there are also other considerations that should be taken in order to predict the location of the aneurysm to ruptured. Peak pressure inside the aneurysm is the most important factor that could lead to the explanation of the aneurysm to rupture. Figure 4 is the peak pressure in the aneurysm for normal human blood pressure and also high blood pressure with the changes of viscosity due to temperature difference. It is seen to be that the pressure distribution pattern increase gradually due to the temperature increase. The pressure distribution at all location of the aneurysm for normal blood pressure and high blood pressure is also different. In which that the peak pressure for high blood pressure is way much higher than the normal blood pressure whereby at high blood pressure conditions, the possibilities of the aneurysm to ruptured lies down there compared to the normal blood pressure. For futher investigation of the possibilities of the aneurysm to ruptured, higher temperature should be analysed in order to predict it to ruptured. When all the prediction that made, the aneurysm should be treated in order to save a human's live.

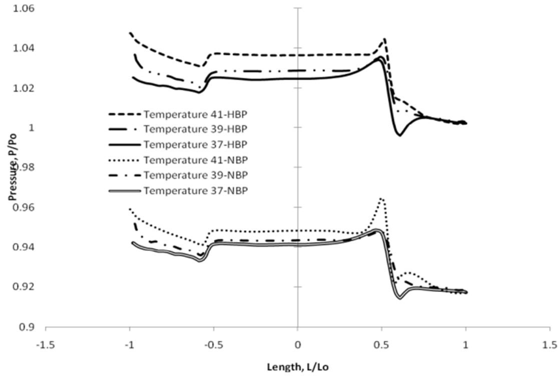


Figure3: Pressure distribution at aneurysm wall for 3 different viscosity for normal blood pressure and high blood pressure

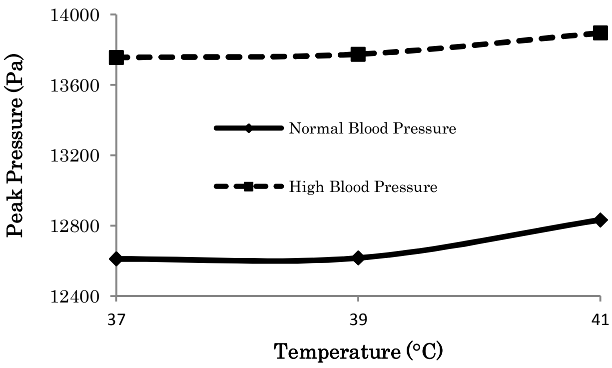


Figure4: Peak pressure at aneurysm wall for 3 different viscosity

### 3.2 Velocity Profile

Figure 5 shows the velocity bandwidth with different temperature. As the temperature increases, its velocity also increases. At high blood pressure condition, it is seen that the velocity distribution is much higher than the normal blood pressure due to the higher movements of the blood for the high blood pressure conditions. From the figure also shows that higher values of velocity bandwidth when a person is in fever and also having high blood pressure compared to the other conditions. It means that there are higher vortex occur during that condition in which it can lead the aneurysm to rupture. Figure 6 shows the profile for x-velocity along the center of the cross-sectional aneurysm. The result is obseved that a very weak recirculation or vortex is present at distal area. It is also seen that the velocity decreased as the blood travels from proximal nect to distal end due to the increases of aneurysm diameter, inline with basic flow theory. From figure above also it can be seen that for temperature 41°C at high blood pressure conditions, the formations of vortex is the highest among all in which it explained to the high pressure distributions in aneurysm for this conditions. The negative values in the profile depict the reverse flow of blood travels in distal end.

When a person is in fever and also high blood conditions, the values of the velocity bandwidth is high as well as the discrepancy of the x-velocity activity inside the aneurysm. In short, there are high possibility of the aneurysm to rupture when a person with fever and also high blood pressure due to the high vortex activity as well as the pressure inside it.

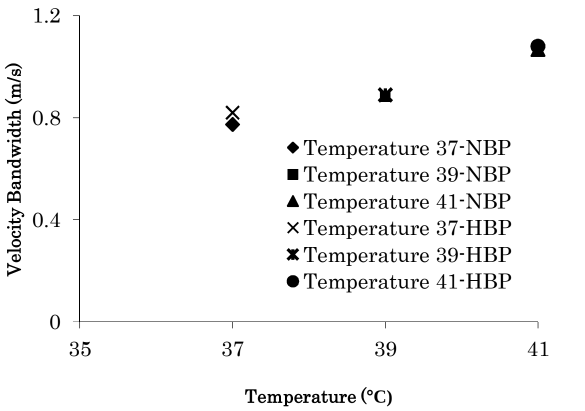


Figure5:Velocity bandwidth of the aneurysm versus temperature

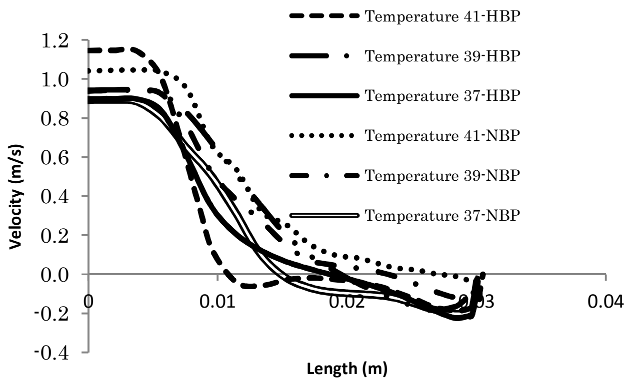


Figure6: X-velocity profile inside the aneurysm

### 3.3 Shear Stress Distribution

Shear stress distribution can also be said as the highly critical factor in predicting the rupture of aneurysm. Figure 7 is the effect of fluid shear stress along the arterial wall proportional to the temperature rise. Fluid shear stress is a tangential force per unit area generated by the flow stream at the aneurysm wall. The fluid shear stress explained the deformation of the vortex induces the higher of the fluid shear stress at the distal end rather than the proximal neck. The exchangeble of curvature pattern shows the effect of different temperature inside the aortic wall. Normally, shear rate is identified by the velocity gradient of blood and the sizing of the aortic wall. The high shear rate can be present with high velocity at the large arteries whilst the low shear rate can be present in the microcirculation in the lower viscosity inside the blood vessel. The aneurysm may be ruptured because of the normal and tangential stress that involved in the local dilation. Thus , the increase of shear stress will point to decreased thrombus deposition. Figure 8 show the shear stress distributions along aneurysm in two blood conditions; normal blood pressure and also high blood pressure, for temperature 37°C, 39°C and also 41°C. The negative values in this distributions shows the vorticity occurs inside the aneurysm. The vortex occurred in aneurysm contributed the energy losses of the fluid and unable to recover after the flow entering back to the normal artery. The discrepancy of the shear stress relates with the risks of the aneurysm to rupture. At high blood pressure and also hyperthermia, the discrepancy of the graph below shows that at that conditions, the possibility of the aneurysm to rupture is much higher compared to other conditions. At the distal end is the most critical part where as it can be seen that higher negative values at that part in which can be said that the vortex activity is the highest at the distal end and can be relates to the rupture of the aneurysm. In short, the most critical part of the aneurysm that could possibly rupture locates at the distal end. At that location, the pressure distribution at the wall is the highest. Besides that, the vortex activity also high at the distal end which relates to the shear stress inside the aneurysm that can lead to the rupture of the aneurysm. Apart from all that, high possibility of the aneurysm to rupture occur when a person is having a fever and also high blood conditions which can be clearly seen at all the three profiles.

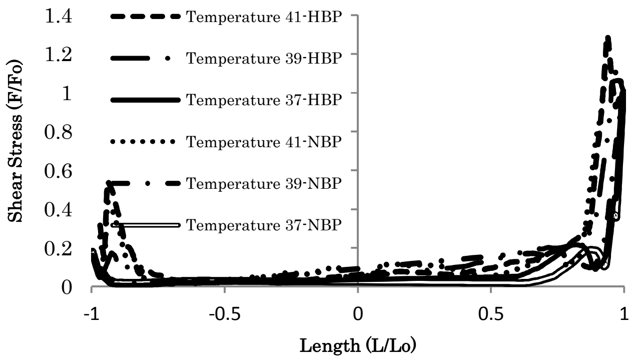


Figure 7: Fluid shear stress distributions at the aneurysm wall

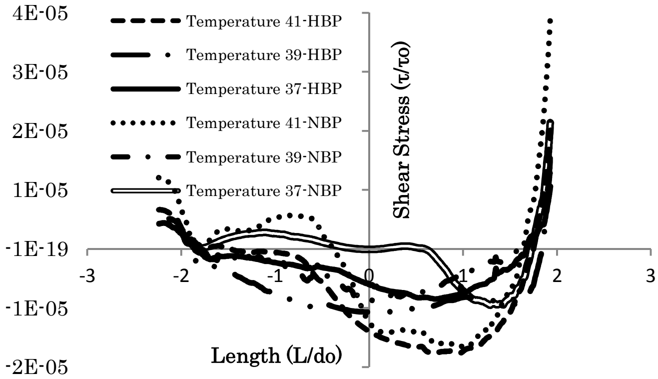


Figure 8: Shear Stress in the aneurysm

## 4.0 CONCLUSIONS

From all the results obtained, it is seen that the peak pressure for low viscosity is much higher compared to the peak pressure for high viscosity.The results also show thathigh possibilities of aneurysmto rupture withlow viscosity blood. Apart from that, the results also show that at high blood pressure condition, the possibility of the aneurysm to rupture is higher compared to the normal blood pressure condition. It is about 90% increment of the peak pressure inside the aneurysm for high blood pressure compared to the normal blood pressure. Thus the possibilities of the aneurysm to rupture also high when a person is in high blood pressure conditions.

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