FLOW ANALYSIS ON FUSIFORM ANEURYSM DURING EXERCISE CONDITION

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ABSTRACT

The dilation of fusiform aneurysm can yield unexpected predicament. The aneurysm is prone to rupture if not immediately treated. This study is focuses on investigate the flow behaviour inside the fusiform aneurysm during exercise condition under normal blood pressure (NBP) and high blood pressure (HBP). The results of this study shows the presence of the flow recirculation is observed at aneurysm region during exercise condition. The presence of the flow recirculation is proportional to the increase of flow activity at the aneurysm. The flow activity is much higher at distal end compared to proximal end region. The different of flow activity shows the different strength of the flow recirculation occurred at the aneurysm bulge. The results also show HBPE peak systole distribute the highest value of the pressure among others condition which is exhibits the high risk of the aneurysm from rupture.

KEYWORDS: *Blood flow, aneurysm, hypertension*

1.0 INTRODUCTION

Aneurysm is widening and bulging of the blood vessel due the weakening of the arteries which prone to be ruptured if not surgically treated. The physician determines that the possibility of rupture in aneurysm is at the largest diameter (Budwig *et. al.,* 1993). In clinical practice, AAA is considered the surgical treatment after the maximal diameter of aorta exceeds 5-6 cm (Lederle FA *et. al.,* 2002). The probability of the aneurysm to rupture is high if the diameter of the aneurysm exceed more than 5cm and the aneurysm will be treated using the synthetic graft (Budwig *et. al.,* 1993).

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 is around 9.5% (Darling *et. al.,* 1977).Rupture of abdominal aortic aneurysm has high morbidity and mortality rates. Many people died before entering the operating room. On that reason, the surgeon has made a difficult decision because of the uncertainty about the risk rupture of abdominal aortic aneurysm. During physiological pulsatile flow, the largest aneurysm demonstrates turbulence rather than in small aneurysm (Egelhoff *et. al.*, 1999). However, the correlation between the largest of the aneurysm and probability the aneurysm ruptures is still in question mark by many researchers. The expansion of the aneurysm segment eventually increase the risk of the aneurysm rupture (Szilagyi *et.* al, 1972) although, rupture could occur in a small aneurysm (Budwig *et. al.*, 1993). The aneurysm rupture is a major complication at the disease vessel especially in AAA which lead to 90 percent of the patients died (Khanafer *et. al.*, 2006). 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).

Pulsatile flow characteristics in AAA have been considered by many researchers (Elger *et. al.*, 1995, Finol *et. al.*, 2001) in which the flow pattern is different from that of steady flow. The hemodynamic stresses are higher in pulsatile flow rather than in steady flow (Finol *et. al.*, 2001) as illustrated in the pulsatile flow behavior which is significant to determine the development of the atherosclerosis and thrombus formation in AAAs. Peattie *et. al.*, 1994 has simulated the resting time in vivo for fusiform model for the pulsatile flow to analyze the flow behavior and shear stress distribution at aneurysm wall. As a result, the flow behavior inside the aneurysm becomes unstable proportional to the increment of the bulge aneurysm size. Egelhoff *et. al.*, 1999 has studied both numerically and experimentally, on the effect of the pulsatile flow on the hemodynamic state which may influence the growth of the aneurysm under resting and exercise time. Taylor *et. al.*, 1999 have studied the numerical modeling for physiological lumbar curvature under resting and exercise condition on rigid aneurysm wall. The lower extremity exercise may limit the progression of the AAA and resistive hemodynamic condition (Evangelos *et. al.*, 2008).

2.0 METHODOLOGY

2.1 The Geometry of the Simplified Aneurysm

The simplified 3D model of aneurysm is considered based on the real AAA geometry captured by S.K Badreddin Giuma *et. al.*, 2009. This model differs from other sinusoidal shape models in the aspect of the overall diameter of the aneurysm. Based on the actual shape, which has a more rounded shape, the current model also maintains the ratio of the diameter of the aneurysm to the ratio of the aorta. The aneurysm has a maximum diameter of; D, length between proximal and distal end of L and d for undilated aortic diameter. The current model offers the overall D/d of the aneurysm to be about 80% of the real shape.

The aneurysm bulge in this model is considered as advanced stage in AAA which may be prone to rupture.

2.2 Parameter Assumptions and Blood Properties

There are several assumptions imposed on the model in this study. The assumptions include incompressible flow, homogeneous, Newtonian flow for the rigid axisymmetric wall and the flow is predicted as a laminar flow for the Reynolds number below 2000 and Reynolds number more than 2000 is considered as turbulence flow. Besides that, the effect of Normal Blood Pressure (NBP) and High Blood Pressure (HBP) toward the aneurysm was studied in order to identify the significant of the NBP and HBP drive the AAA development. Additional to the NBP and HBP flow conditions, this study also include the exercise flow condition to investigate the effect of the combinations of the flow conditions. Resting condition is used as the basis of the comparisons.

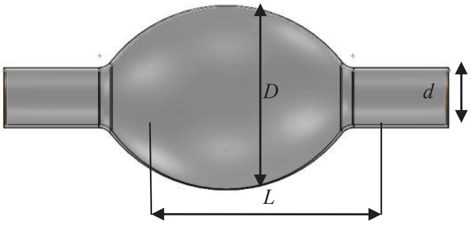

Figure 1: The simplified Abdominal Aortic Aneurysm model.

Miki Hirabayashi *et. al.*, 2004 reported that the blood exhibit as a non-Newtonian behavior. Other researchers reported that Newtonian liquid is sufficient for the case of large blood vessel. In this study, Newtonian condition is used due to the fact that the artery is large enough for the effect of non-Newtonian to be significant. There is no significant data had confirmed the difference for both non-Newtonian and Newtonian fluid (Khanafer *et. al.*, 2006) which the researcher found that the non-Newtonian effect was the minimal changes in arterial flow pattern.

2.3 Governing Equation and Boundary Conditions

In these simulations, Computational Fluid Dynamic software called Engineering Fluid Dynamic (EFD) was used. Both velocity inlet and pressure outlet are computed to solve the continuity and Navier-Stokes equations. 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:

$$\frac{\partial u_i}{\partial x_i} = 0 \qquad (1)$$

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

Where u_i = velocity in the ith direction, P = Pressure, f_i = Body force, ρ =Density, μ_i =Viscosity and ∂_{ij} = Kronecker delta. The shear stress, τ at the wall of aneurysm is calculated based on a function of velocity gradient only:

$$\tau = \mu \frac{\partial u}{\partial y} \qquad (3)$$

Where $\partial u/\partial y$ is the velocity gradient along the aneurismal wall taking into considerations the fluid viscosity. Therefore, the simple viscous fluids considered with linear relationship.

The inlet flow is considered fully developed parabolic flow, with zero radial velocity at the inlet, no slip applied at the wall and zero velocity gradient at the outlet. The inlet boundary condition setting is pulsatile velocity (Egelhoff *et. al.*, 1999) for the resting and exercise condition which whilst the outlet boundary condition setting is pulsatile pressure (Tayfun *et. al.*, 2008) for time dependent.

3.0 RESULTS AND DISCUSSION

The flow recirculation in advanced level of aneurysm yield unexpected problem. The increase of flow recirculation manages to increase the possibility of aneurysm to be ruptured. In this study, we are discusses the effect of pressure distribution at the aneurysm during physiological under exercise condition. The effect of high blood pressure which exerted along the aneurysm region is given more attention since the high possibility of wall aneurysm rupture is reported in this condition. However, NBP is also taken into consideration as comparison for those HBP results. Flows visualize the presence of vortex for HBPE and NBPE for difference stages at the aneurysm region as seen in Figure 2 and Figure 3. Figure 2 shows the flow pattern for the pressure distribution at the advanced aneurysm during exercise time under NBP.

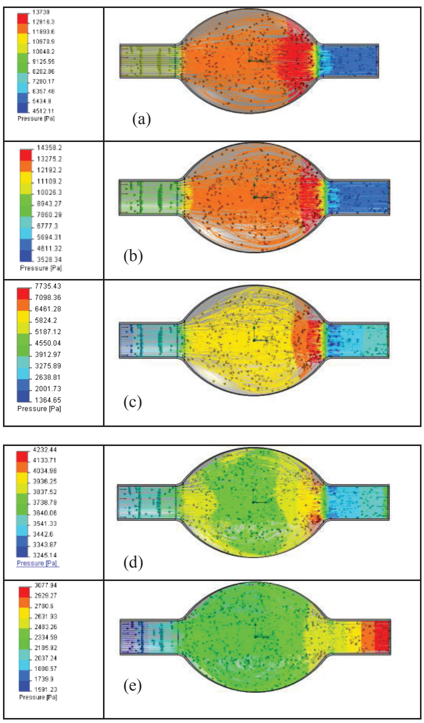

Figure 2 Flow pattern for the pressure inside the largest AAA during the exercise waveform for NBP (a) early systole shows the vortex formation at the proximal end (b) peak diastole show the vortex formation inside the AAA region (c) mid diastole shows the vortex formation occurred depicted the translation and AAA growth (d) late systole shows the vortex formation at the proximal end of aneurysm.(e) early diastole shows the dominated vortex formation inside the aneurysm.

The results of the flow visualization for advanced aneurysm model depicted five difference stages consisted early systole, peak diastole, mid diastole, late systole and early diastole. Figure 2(a) shows that formation of flow recirculation at the distal end of aneurysm at early systole time. However, during peak diastole time (Figure 2(b)), the vortex is conquered the entire bulge of the aneurysm when the blood flow travels from proximal end to distal end. By mid systole time (Figure 2(c)), there is formation of the vortex which depicted the translation and growth of the aneurysm region. However, NBPE during late systole time (Figure 2(d)) and early systole time (Figure 2(e)) flow is shown the dominated vortex which fills the entire bulge of the aneurysm wall. The high pressure distribution exerted at the aneurysm wall will weaken the aneurysm wall. The vortex strength is observed more strong at distal end rather than in proximal end of aneurysm. As summarized, the pressure distribution is shown to be highest during NBPE peak systole compared those others results.

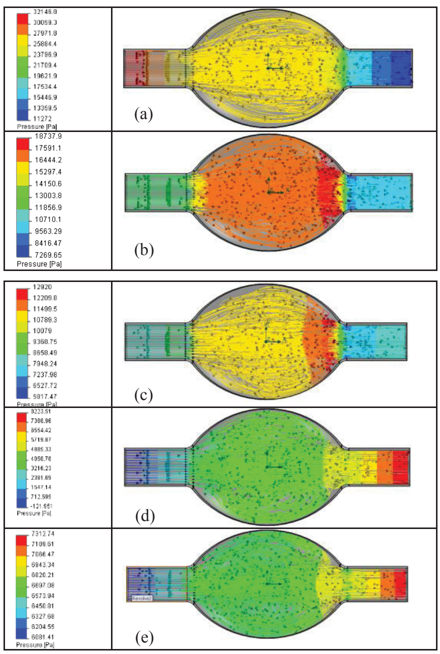

Figure 3 Flow pattern for the pressure inside the largest AAA during the exercise waveform for HBP (a) early systole shows the vortex formation at the proximal end (b) peak diastole show the vortex formation inside the AAA region (c) mid diastole shows the vortex formation occurred at distal end of aneurysm (d) late systole shows the vortex formation at the entire region of aneurysm.(e) early diastole shows the dominated vortex formation inside the aneurysm.

The investigation on the vortex formation is continued for HBP during exercis as seen in Figure 3. The presence of the vortex is seen at the aneurysm bulge which the flow is fully attached as seen in figure 3(a). The strength of the vortex is observed to be highest at distal end of aneurysm during early systole. The same phenomenon in Figure 3(a) is shown in Figure 3(b). The presence of the vortex is covering the entire bulge of aneurysm. However, the pressure distribution is higher during peak systole stage (Figure 3(b)) compared to the result at early systole stage. By mid systole (Figure 3(c)), the vortex formation is observed at distal end of aneurysm. The vortex foemation is also observed at proximal end of the bulge but the stregth of the vortex is higher at distal end of aneusym. The flow recirculation is observed at distal end of bulge during late systole stage as well as in the entrance of aneurysm. However, by early diastole, the flow becomes vortex dominated with the vortex motion filing the entire bulge of aneurysm as seen in Figure 3(e). On the other hand, the vortex is observed to be subjugated the whole area of aneurysm during HBPE at early diastole.

As summary, the pressure distribution is highest at the HBPE peak systole time which is illustrated in Figure 3(b). The vortex is observed to be form at distal end of aneurysm for all condition which explained the possibility of the aneurysm rupture is higher in this location.

4.0 CONCLUSION

This study shows the presence of the vortex is observed at aneurysm region for both physical under exercise condition. The presence of the vortex is proportional to the increase of flow activity at the aneurysm. The flow activity is much higher at distal end compared proximal end region. The different of flow activity shown the different strength of the vortex occurred at the aneurysm bulge. The results also shows HBPE peak systole distributed the highest value of the pressure among others condition which is exhibits the high risk of the aneurysm from ruptured.

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6.0 REFERENCES

Badreddin Giuma S.K[1], Kahar Osman[1] and Mohamed Rafiq Abdul Kadir[1,2], "Numerical Modeling of Fusiform Aneurysm with High and Normal Blood Pressure".2009

C.J. Egelhoff, R.S. Budwig, D.F. Elger, T.A. Khraishi and K.H. Johansen, Model studies of the flow in abdominal aortic aneurysms during resting and exercise conditions, *J. Biomech*. 32 (1999), 1319–1329.

D.F. Elger, J.B. Slippy, R.S. Budwig, T.A. Kraishi and K.H. Johansen, A numerical study of the hemodynamics in a model AAA, *Bio-Med. Fluids Eng*. 212 (1995), 15–22.

E.A. Finol and C.H. Amon, Blood flow in abdominal aortic aneurysms: Pulsatile flow hemodynamics, *ASME J. Biomech*.*Eng*. 123 (2001), 474–484.

Evangelos Boutsianis, Michele Guala, Ufuk Olgac, Simon Wildermuth, Klaus Hoyer, Yiannis Ventikos, Dimos Poulikakos," CFD and PTV Steady Flow Investigation in an Anatomically Accurate Abdominal Aortic Aneurysm",*Journal of Biomedical Engineering*.131(2008),2406-2414.

K.M. Khanafer et al."Modeling pulsatile flow in aortic aneurysms:Effect of non-Newtonian properties of blood", *IOS Press, Biorheology* 43 (2006) 661–679.

Khalil M. Khanafer a, Prateek Gadhoke a, Ramon Berguer a,b and Joseph L. Bull a. Modeling pulsatile flow in aortic aneurysms: Effect of non-Newtonian properties of blood. Biorheology 43 (2006) 661–679.

Lederle FA, Wilson SE, Johnson GR, Reinke DB, Littooy FN, Acher CW, et al. Immediate repair compared with surveillance of small abdominal aortic aneurysms. N Engl J Med 2002;346(19):1437–44.

Miki Hirabayashi *et. al.*, "A lattice Boltzmann study of blood flow in stented aneurism", *Future Generation Computer Systems*, Elsevier B.V, 20 (2004) 925–934.

Peattie, R.A., Schrader, T., Bluth, E.I., Comstock, C.E., 1994. Development of turbulence in steady flow through models of abdominal aortic aneurysms. Journal of Ultrasound Medicine 13, 467-472.

R. Budwig, D. Elger, H. Hooper and J. Slippy, Steady flow in abdominal aortic aneurysm models, *ASME J. Biomech. Eng*.115 (1993), 419–423.

R.A. Peattie, T.J. Riehle and E.I. Bluth, Pulstaile flow in fusiform models of abdominal aortic aneurysms: flow fields,velocity patterns and flow-induced wall stresses, *ASME J. Biomech. Eng*. 126 (2004), 438–446.

R.C. Darling, C.R. Messina, D.C. Brewste and L.W. Ottinger, Autopsy study of unoperated abdominal aortic aneurysms: The case for early detection, *Circulation* 56 (1977), 161–164.

Szilagyi DE, Elliott JP, Smith RF. Clinical fate of the patient with asymptomatic abdominal aortic aneurysm and unfit for surgical treatment. Arch Surg 1972;104(4):600–6.

Tayfun E. Tezduyar1, Sunil Sathe, Matthew Schwaab and Brian S. Conklin1, "Arterial fluid mechanics modeling with the stabilized space-time fluid-structure interaction technique," *International Journal for Numerical Methods in Fluids*, vol. 57, (no. 5), pp. 601-629, 2008.

Taylor, T.W., Yamaguchi, T., 1994. Three-dimensional simulation of blood flow in an abdominal aortic aneurysm- steady and unsteady fow cases. ASME Journal of Biomechnical Engineering 116, 88-97.