Study On The Effect Of Stenting to Aneurysms Deformation

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ABSTRACT

Aneurysm has a tendency to enlarge over the years, depending on several factors. One of the treatments for aneurysm is by inserting stent in the blood vessel to reduce the pressure in the area. In this study, growth of the aneurysm is investigated using numerical approach. Both cases were considered, with and without the insertion of stent. The growth of the non stented aneurysm was compared with the actual measurement and good agreement was obtained. The same method was used to predict the growth of stented aneurysm. The result show promising reduction in the possibility to rupture for the aneurysm.

Keyword: Aneurysm, Stents, Numerical, Blood flow

1. INTRODUCTION

The numerical method is applied to model blood flow in aneurysms to study the effect of stenting to the growth rate of aneurysms. The objective of this study is to develop numerical models to analyze the wall deformation due to various type of stent. Computational Fluid Dynamics is known as a powerful alternative approach in solving various fluid flow phenomena. This provides us the opportunity for to go deeper into the blood flow and understand how the interaction between them would affect the macroscopic parameters of blood flow.

Aneurysm is a degenerative disease which abnormality appears in the form of dilation of a blood vessel due to weakening of its wall. The vessel may rupture and cause life threatening bleeding if not surgically treated. Currently, two methods are available for treatment of aneurysm – open surgery or endovascular aneurysm repair. The first treatment uses synthetic polymeric graft to replace the diseased site, whilst the second involves strengthening the blood vessel wall with an expandable metallic stent. Endovascular aneurysm repair is gaining popularity over open surgery, but the technique is relatively new without long-term follow-up outcome. Pre-clinical evaluations are therefore crucial to minimise possible complications such as endoleaks, stent migration, stent failure and other complications. The analysis of stented aneurysms model using numerical methods to study the interactions between the stent and the blood vessel wall have been conducted both in two and three dimensions [1, 2, 3, and 4]. These studies investigate among other things the stresses and strains exerted on the blood vessel wall, strut strength of the stent, and the degree of stent flexibility. Predictions from finite element analyses confirmed the altered haemodynamics of stented vessel found experimentally and actual complications found after surgery.

Generally, there are two shapes of aneurysms; fusiform and saccular. The existing treatment procedures do not provide suitability for fusiform aneurysms [5] and therefore, stenting becomes an experimental alternative for these aneurysms. Many successful clinical cases have been reported [5,6] due to stent implantation that works effectively. Currently, few studies focused on stenting of fusiform aneurysms compared to saccular aneurysms in from of experimental and theoretical studies [7].

In surgical treatment, a stent graft is guided to the affected area of the blood vessel and then expanded by ballooning to create a new sleeve through which the blood can flow. The new sleeve will protect the weak wall of the blood vessel from the pulsatile blood pressure that could lead to rupture [9]. The technique has shown significant success for the treatment of aneurysm, however, many post-operative complications such as stent migration, stent failure, and blood leakage may still occur. The metallic stent is normally made of surgical grade balloon expandable 316L stainless steel mesh tubes with diameter ranging from 2-4mm and length ranging from 8-38mm [2]. The open mesh comes in various configurations with two of the most common designs are the diamond-shape

[1] and the tubular rings with bridging links [2]. Once introduced at the aneurysm site, the stent is expanded by inflating an angioplasty balloon with an inflating pressure between 12 to 18 atmospheres [3]. The stent will eventually fuse with the blood vessel wall with tissue ingrowths surrounds the open mesh.

The changes of local velocity and pressure inside the aneurysm lead to vortex formation and complex flow structure exist in blood vessel around the aneurysm. These phenomena become a common finding from previous numerical study. The fluid phenomena found by previous work revealed almost similar flow pattern. The vortex formation could be explained due to the pressure imbalance that leads to the swirl in aneurysm. But, the strength of the swirl is not yet investigates by any researcher to relate with either the size of aneurysm or specific location of detected diseased.

Another aim of this study is to determine the correlation between deformed wall and the peak pressure produce of each part of the aneurysm segment. Three different types of stents were used in the simulation, Type I, Type II and type III. The plot of deformation profile was presented along the wall of aneurysm dome.

2. METHODOLOGY

2.1 General Assumptions and Blood Properties

In general, computational fluid dynamic (CFD) techniques have the advantage of a greater flexibility with respect to the experimental or *in vivo* methods [8]. For the CFD simulations carried out in this study, it is assumed that blood is an incompressible, Newtonian fluid and that the flow is laminar and isothermal. Blood exhibits non-Newtonian behaviors [9]. However, in many cases for large enough vessels and fast enough flows, a Newtonian approximation is sufficient. However it still depend on the situation, which blood behaves as a non-Newtonian fluid when shear rate increases, the blood viscosity decreases. But, this feature is prominent for small arteries, whereas Newtonian features are characteristic for large arteries. Therefore, there is no significant difference for Newtonian and non-Newtonian flow within an aneurysm, which was confirmed in others who found minimal changes in arterial flow patterns when non-Newtonian effects were included. Thus, the Newtonian blood model was assumed in this study.

Since arteries are viscoelastic structure, the interactions between artery walls and blood cause that endothelial cells are under continuous pressure. Measurement of artery wall properties may be very hard task as properties of healthy and diseased vessels are varied. On the other hand, healthy arteries are highly deformable complex structures, characterized by a nonlinear strain–stress curve with exponential rigidity in the higher strain ranges. This rigidity effect, characteristic for all biological tissues, is the result of rough collagen fibers which show typical anisotropic behavior [10]. Other parameters such as density, dynamic viscosity, thermal conductivity and specific heat are according to normal blood flow conditions. These values were assumed to be constant along the blood vessels during the simulations. The physical problem discussed is based in the configuration of figure 1 in directing the flow through the aneurysms.

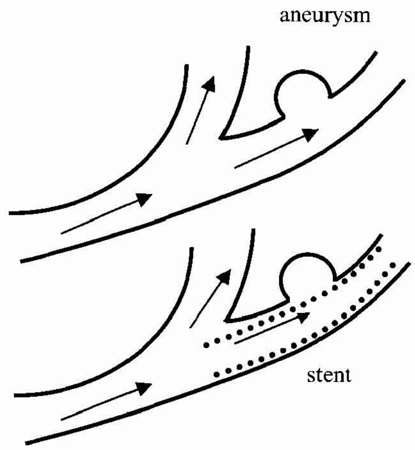

Figure 1: (Top) Blood flow through branching with aneurysm. (Bottom) The stented aneurysm to improve blood flow.

2.2 Governing Equations

The physical laws describing the problem investigated here 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, ρ =Density, μ_i =Viscosity and δ_{ij} = Kronecker delta.

3. SIMULATIONS PARAMETER

In the modeling stage, selected fixed artery dimension is considered 8mm in diameter and aneurysm size is 20mm diameter with 40mm length. Velocity magnitude without the stent is lower than 1 m/s and the Reynolds number within the aneurism is varies from 100 to 400. The average wall thickness of the aneurysm is set to 1.5 mm based on measurements by using experimental study. The three model of stents design with inner diameter 8mm during expanded conditions inside the artery are shown in Figure 2. The expanded stent length for all type is set to be the same dimension, 50mm and thickness 1.0mm. Figure 3 shows the configurations of axisymmetric rigid wall aneurysm and stent implanted at location extended 5mm from the proximal neck and similarly 5mm for the distal neck of aneurysm. The inlet pressure is 463 Pa at the initial length of artery and average velocity for inlet is as normal conditions of blood flow from actual aneurysmal boundary.

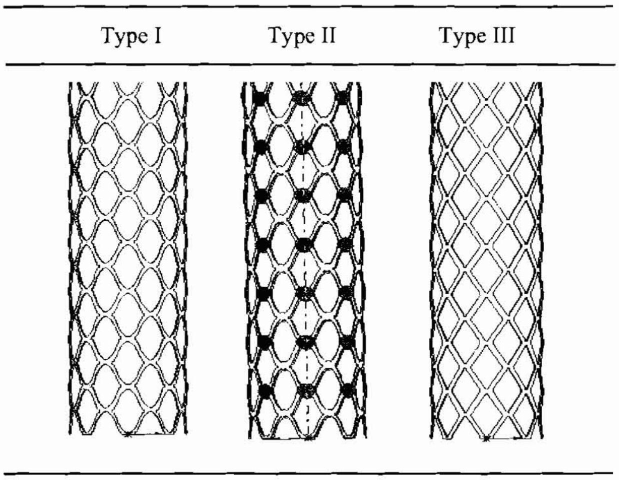

Figure 2: Stents used in the simulations

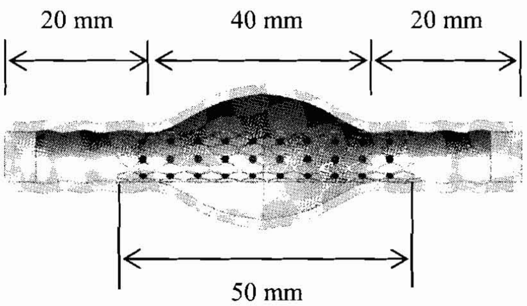

Figure 3: Stented Aneurysm model

4. RESULTS AND DISCUSSIONS

4.1 The effect of Reynolds Number

Velocity profile inside the aneurysm region for a different Reynolds number is presented in Figure 4. According to the velocity pattern presented here, the lowest minimum velocity refers to the simulations results of non stented blood flow behavior for initial condition before stent placement.

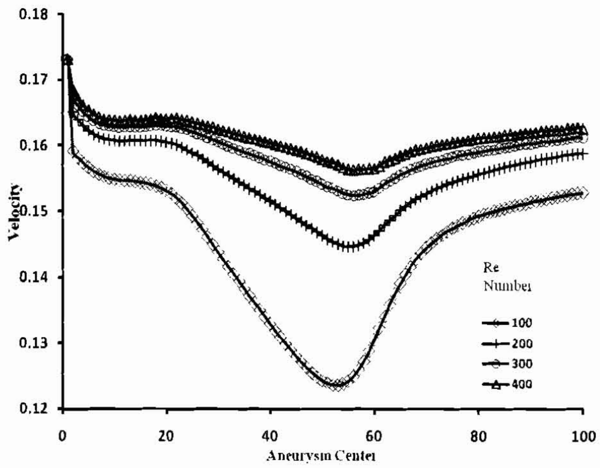

Figure 4: The effect of Reynolds number

4.2 Pressure distributions

The result of pressure distribution from numerical simulation is shown in Figure 5. The pressure for non stented aneurysm is the highest compared to the other stented aneurysm according to the plotted pressure. Therefore, the stenting effect could be seen clearly to reduce the pressure in the region that being studied.

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