THE EFFECT OF STENTS STRUCTURAL PARAMETERS TO FLOW IN STENTED ANEURYSMS

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ABSTRACT

Investigation on the changes of flow patterns in a blood vessel with a fixed fusiform aneurysm resulting from placement of a different structural void area of stents. The velocity profile and pressure distribution after installing the device had been identified from the selected stent. Three different commercial stent designs were taken into consideration and these models will be referred to as type I, type II and type III. To identify the changes in local hemodynamics due to stent implantation, a stented and non stented aneurysm model was taken into considerations. The simulation of the model was studied under incompressible, Newtonian, viscous, non pulsatile condition in which we investigated computationally in a three-dimensional configuration using a fluid dynamics program. Hence, the different of stent structural pattern produces the different results of flow field around the stented aneurysm. The minimum velocity had improved after stents insertion and the type III with less void area results most optimized. However, the flow in stented fusiform aneurysms is very different from that in stented saccular aneurysms resulting lowest peak pressure 340 Pa which due to placement of stent type II. Finally, the correlations obtained from this numerical result could be used to investigate the pressure distribution around the diseased segment.

ABSTRAK

Kajian mengenai perubahan bentuk aliran didalam salur darah telah dibuat ke atas aneurism simetri dengan struktur keluasan stent yang berbeza. Profil halaju dan taburan tekanan diperolehi hasil dari implant stent yang terpilih. Tiga rekabentuk stent yang di kaji dirujuk sebagai jenis I, jenis II dan jenis III. Aneurism tanpa implant stent dan aneurism dengan implant stent diambil kira dalam kajian untuk menentukan perubahan hemodinamik darah. Simulasi model dikaji dengan parameter aliran mampat, Newtonian, bendalir likat dan keadaan tiada denyut menggunakan program dinamik bendalir tiga dimensi. Perbezaan struktur telah menghasilkan bentuk aliran yang berbeza disekitar aneurism. Halaju minimum telah di pertingkatkan selepas implant stent dibuat dan jenis III yang mempunyai keluasan stent terendah menghasilkan keputusan paling optimum. Walaubagaimanapun, aliran didalam aneurism simetri berbeza dengan aneurism berbentuk sakular menyebabkan tekanan maksimum terendah dihasilkan oleh implant stent jenis II dengan nilai tekanan 340 *Pa*. Perkaitan diperolehi dari kajian ini boleh dimanfaatkan untuk lanjutan taburan tekanan disekitar aneurism.

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CHAPTER 1

INTRODUCTION

1.1 Background

At present, stenting procedure has been widely used during the treatment of an aneurysm. An aneurysms is a vascular disease that occur when a local blood vessel ballooning greater than its nominal diameter. Normally stents are designed with tubular shape structures which inserted into the diseased region via a catheter. The installation of stents to the blood vessel is to provide mechanical support to the aneurysms to restore blood flow conditions in arteries back to normal conditions.

This project concerns particularly on aneurysm which implanted with three different types of stents. In this investigation, several parameters will be established to determine the flow behavior in stented aneurysm of selected stent. In addition, the correlations between stent structural parameters and the blood flow properties will be indentified. In order to satisfy the efficiency of a stent performance, this study will focus on blood flow behavior subjected to interaction with the presence of stent. Currently, the stent selection in surgical planning is base on statistical data; however the parameters that influence the stent suitability are not yet fully understood. The results of this fluid dynamics analysis through numerical simulations are expected to explain the local pressure distribution of blood vessel variation subjected to the change of stent void area.

1.2 Aneurysm

An aneurysm is a local undesired deformation of a blood vessel which can be due to a disease or from birth. Severe bleeding can occur if the aneurysm breaks. Aneurysms usually appear in either fusiform or saccular as shown in table 1.1. Method to detect the presence of aneurysms by using medical examination technique, such as:

- X-rays or Ultrasonography
- Angiography
- Computed Tomography (CT)
- Magnetic Resonance Imaging (MRI)

Generally, the causes of aneurysms are mainly due atherosclerosis, atheroma, syphilis, congenital defects, heart attacks, smoking, obesity, hypertension, trauma, inflammation as well as heamodynamics and other biomechanical factors (Zhonghua, 2005). However, arteriosclerosis is the most common cause of aortic aneurysms which about 80%. The reason lead to aneurysm generation and rupture is not very clear because the formation and rupture is a multi-factorial problem. Basically, there are four main types of aneurysms as summarized in Table 1.2.

Table 1.1: General Shape of Aneurysm

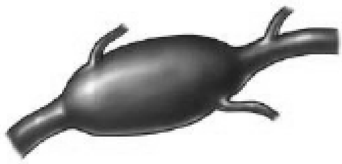
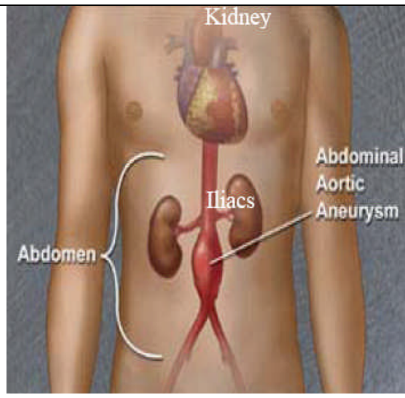
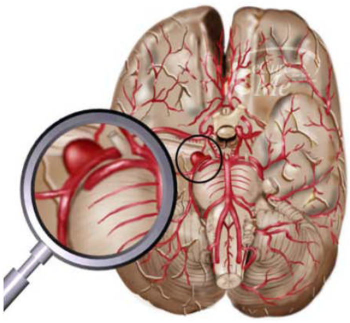
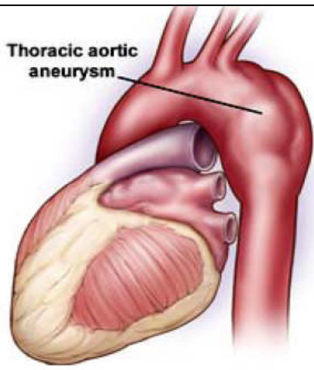
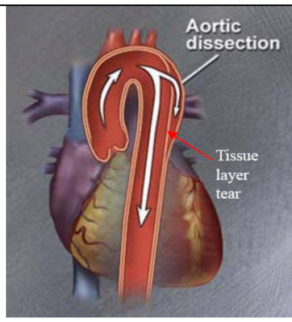
No	Shape of Aneurysm	Figure
1	Saccular	
2	Fusiform	

Table 1.2: Main type of Aneurysm

No	Type	Figure
1	Abdominal Aortic Aneurysms (AAAs). (Source: http://www.mayoclinic.org)	
2	Brain aneurysms (Source: 2001 eCureMe.com)	
3	Thoracic aortic aneurysms (Source: http://www.vascularweb.org)	
4	Dissecting aortic aneurysms (Source: http://www.mayoclinic.org)	

Currently there are two methods used 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 relatively new and being more implemented over open surgery.

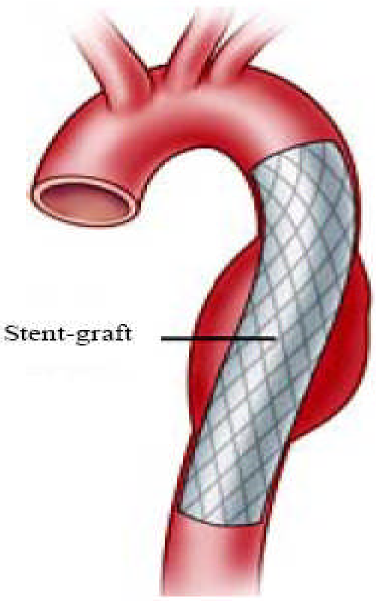
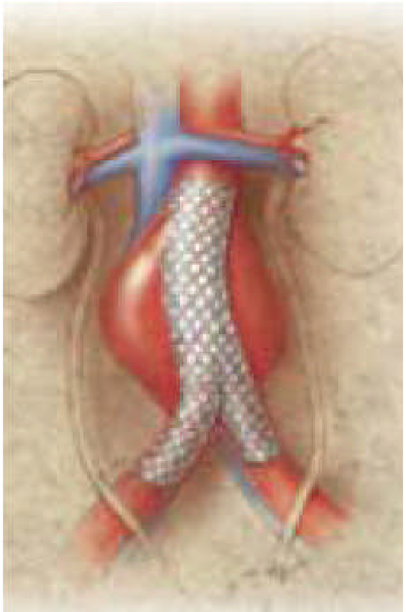


Figure 1.1: Stented Thoracic



Figures 1.2: Stented AAA

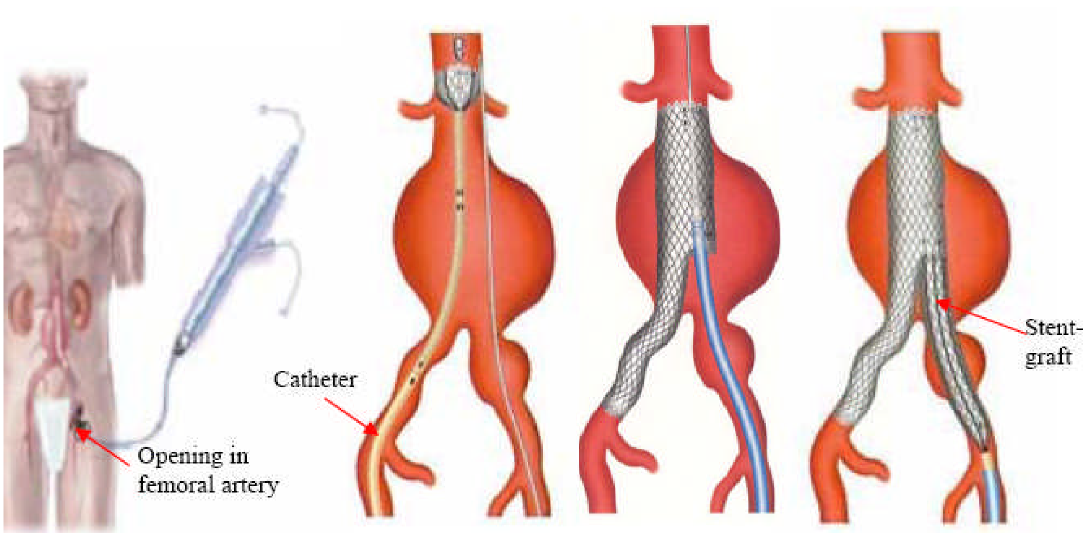


Figure 1.3: Process for endovascular repair (Source: http://www.hpcbd.com)

For saccular shape aneurysm, the treatment starts with the placing of delivery system. The stent deployment begins by pulling the catheter back over the stabilizer catheter, which pushes the stent out as shown in below process.

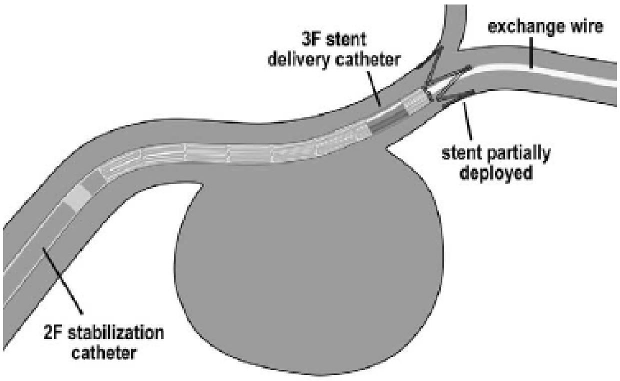


Figure 1 .4: Delivery system placement

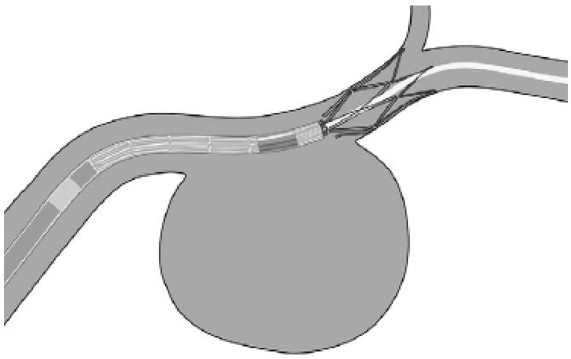


Figure 1.5: Further stent expansion

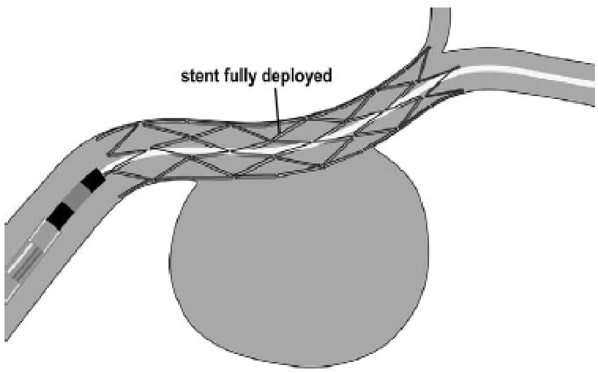


Figure 1.6: The stent fully deployed

1.3 Stent Technology

A stent is a wire mesh tube that is expanded by a balloon into an artery to return blood flow to normal (Holzapfel et. al., 2006). In normal case, stent widely use as treatment of stenosis, aneurysm or dissection which applied to the coronary, brain, renal, thoracic, abdominal and peripheral arteries. The most frequent usage of stents is to prop open the constricted lumen of the atherosclerotic artery. But they are used also for treatment of obstructions in the urethral, biliary and gastrointestinal.

There are currently over 100 different types of stents in the market and laboratories in the world (Stoeckel D et. al., 2002). Stents can be classified as slotted tube, coil and mesh types based on their original cell patterns. The geometric cells can be in closed or open patterns to balance the strength and flexibility requirements. Before deployment, the stent is collapsed to a small diameter and put over a balloon catheter. It is then moved into the area of the blockage in a blood vessel and expanded by the inflation of the balloon. The expanded stent permanently locks in the place of stenosis and forms a scaffold that holds the artery opens so that blood flow is improved (Zahora et. al., 2007). The stent category with the example of currently available in the market is summarized in table 1.3 below. The figure of linkage example shows in Figure 1.7.

Table 1.3: Category of stent

Type of Unit Cell	Type of Link Structure	Example
Closed	No Connector	Palmaz-Schatz PS153
	Bar	Tenax
Opened	Bend Shape	MAC Q23, MAC Standard
	Straight Line	RX Ultra Multi-link

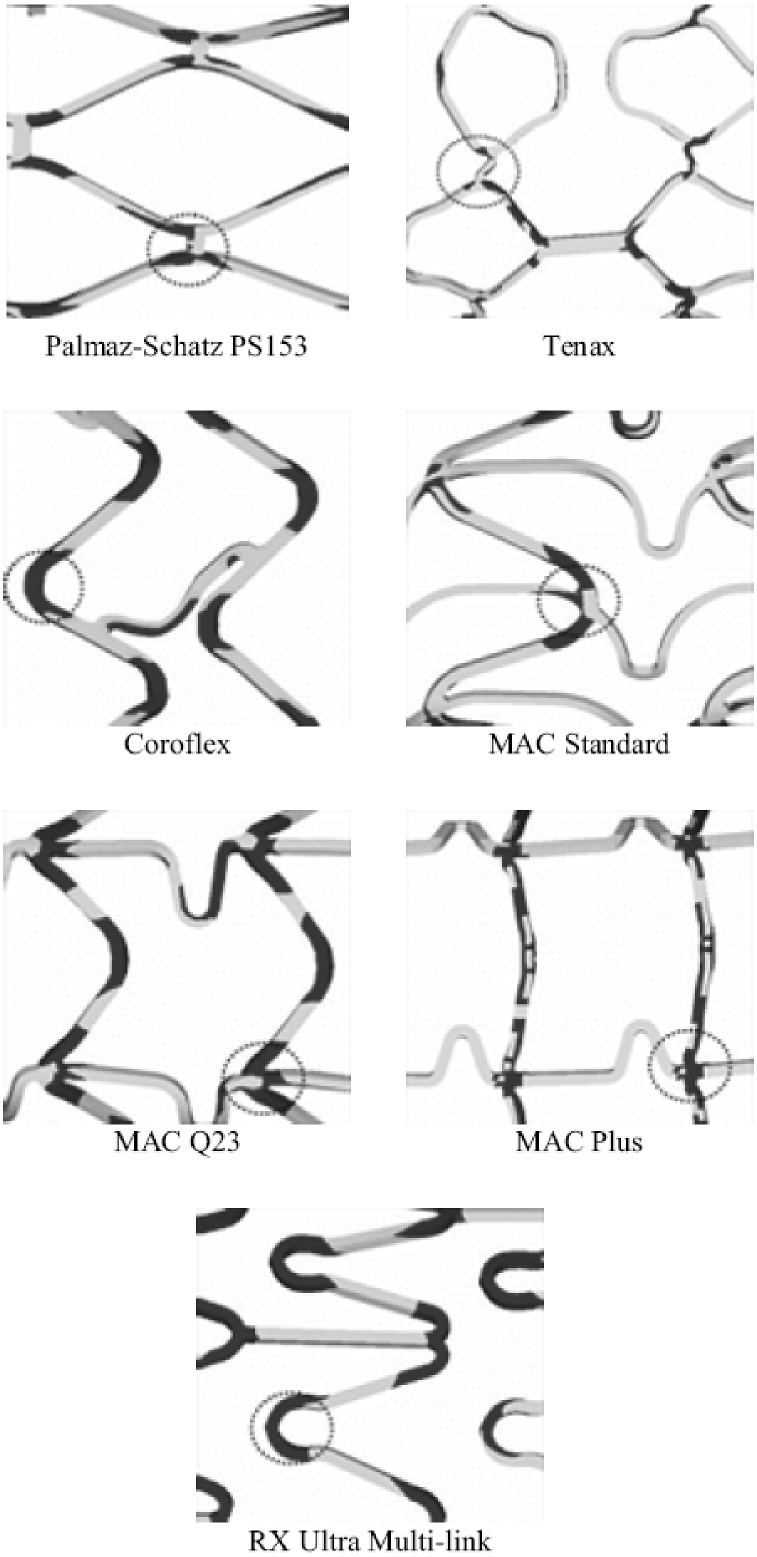


Figure 1.7: Examples of type of stent link

The pattern of the transient non-uniform balloon-stent expansion at four different instants during the expansion process is shown in Fig. 1.8. Only the expansion pattern for Palmaz-Schatz PS153 stent is shown because all stents had similar expansion patterns. (Won-Pil Park et. al., 2007)

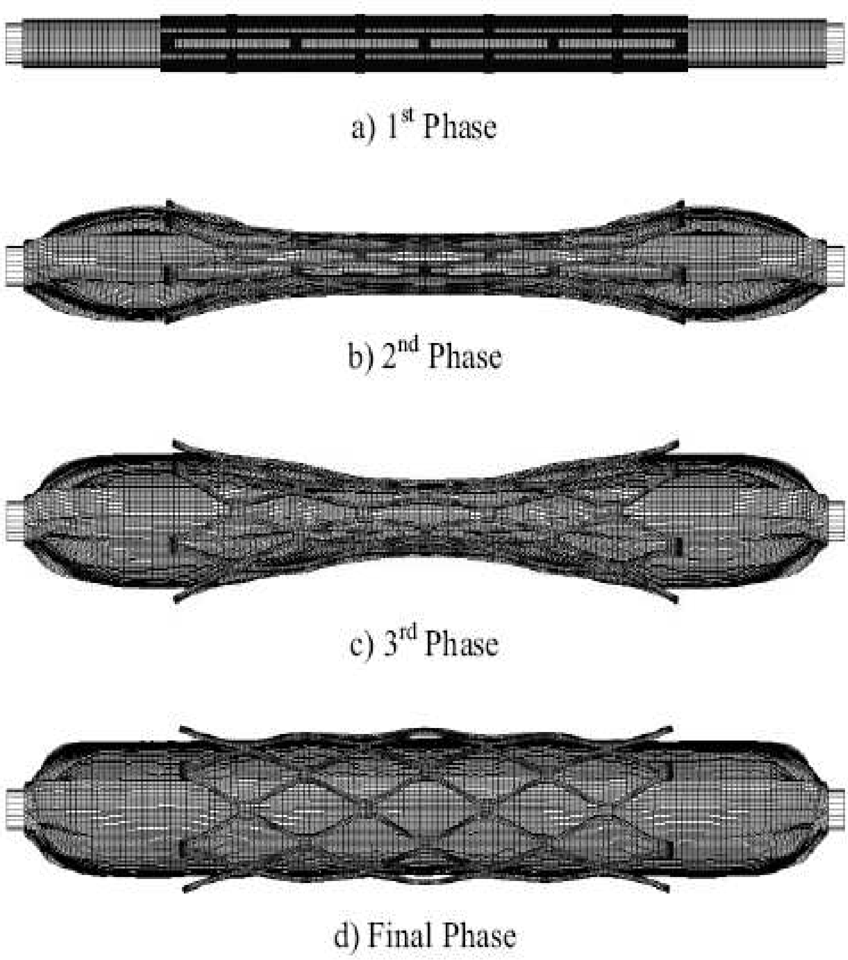


Figure 1.8: The balloons expansion phase for Palmaz stent (Won-Pil Park et. al., 2007)

1.4 Effect of Stent Design

The design of stents with different struts, mesh and porosity are currently available in the market. However, in term of technical performance, there is still a general lack of quantitative understanding about how specific design features of stents affect the hemodynamic in aneurysms. In an attempt to reveal this issue, Kim et al (Kim et. al., 2008) studied two commercial high-porosity stents (Tristar stent^{TM} and Wallstent^{TM}) in aneurysm models of varying vessel curvature using Computational Fluid Dynamics.

They investigated how these stents modify hemodynamic parameters such as aneurysmal inflow rate, stasis, and wall shear stress, and how such changes are related to the specific designs. They found that the flow damping effect of stents resulting aneurysmal stasis and wall shear stress are strongly influenced by stent porosity, strut design, and mesh hole shape. Their results also confirmed that the damping effect is significantly reduced at higher vessel curvatures, which indicates limited usefulness of high-porosity stents as a stand-alone treatment.

Additionally, they showed that the stasis-inducing performance of stents in 3D geometries can be predicted from the hydraulic resistance of their flat mesh screens. From this, they proposed a methodology to cost-effectively compare different stent designs before running a full 3D simulation.

In order to evaluate the fundamental effects of stent design damping aneurysmal inflow, it is required to develop the characteristics of flow passing through; for example in Kim experiment, they use infinitely large flat screens of various porosities and strut patterns shows in Figure 1.9. For both stent mesh patterns (Tristarstent^{TM} and Wallstent^{TM}), their original meshes as flat screen models (Screen T and screen W) being reproduced as shown in Figure 1.10. From these two basic screens, additional screen models of various hypothetical porosities (50–80%) created by varying the distance of the struts while keeping strut angles and hydraulic strut diameters (0.1 mm for both stents) constant. Figure 1.10 shows the resulting mesh patterns of the Screen T and Screen W models (Kim et. al., 2008).

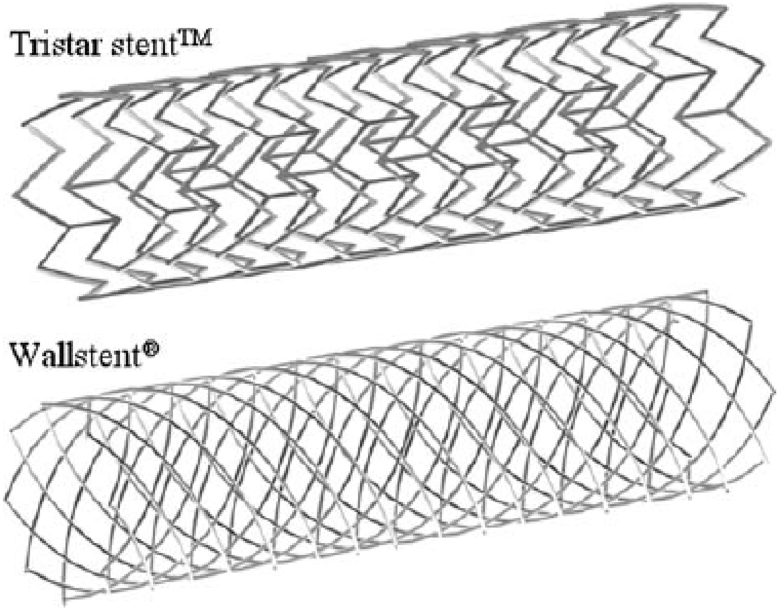


Figure 1.9: Geometry of the Tristarstent^{TM} and Wallstent^{TM} (Kim et. al., 2008)

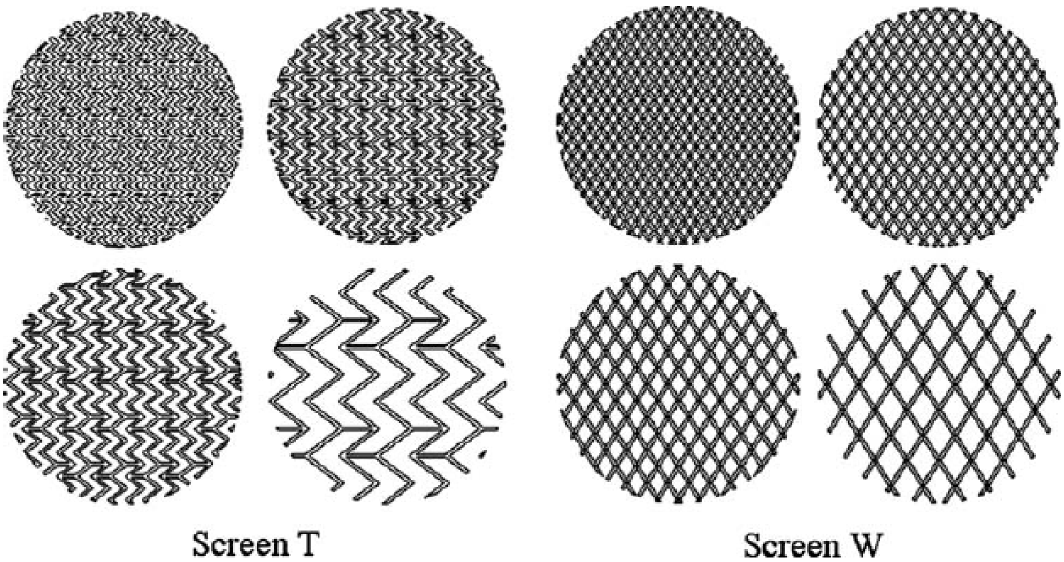


Figure 1.10: Mesh patterns of Screen T and Screen W for various porosities 50, 60, 70, and 80%. (Kim et. al., 2008)

To compare the hydraulic resistances induced by such mesh patterns, each screen was placed in a computational model of an infinitely large wind tunnel with uniform steady flow entering far enough upstream that disturbances due to the screen became negligible at the inlet. The wind tunnel model was created by placing a unit section of the screen into a finite-sized computational domain with side-wall boundaries defined as ‘‘cyclic boundaries’’ to simulate an infinitely large extension of the domain in the screen plane, as shown in Figure 1.11.

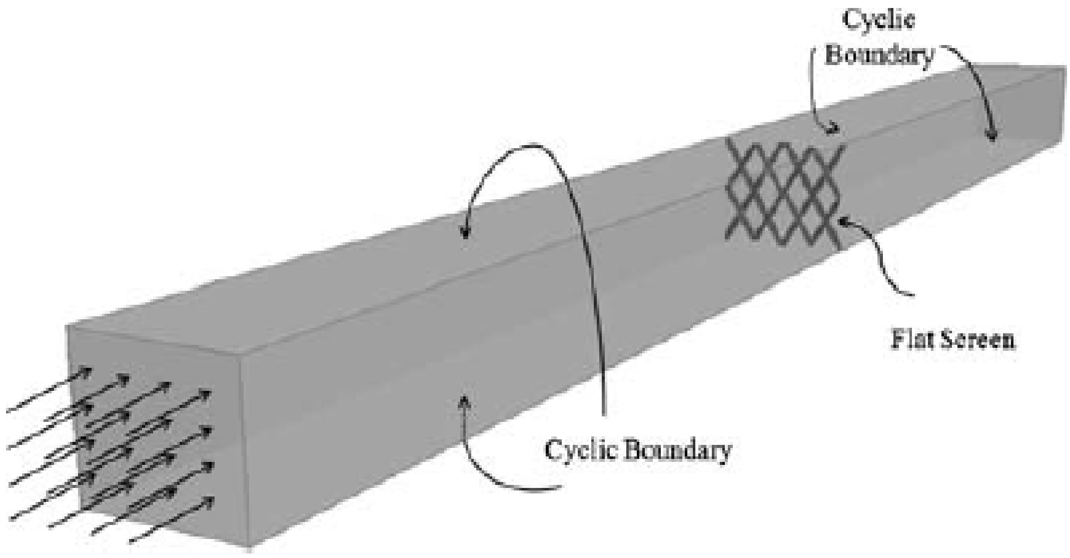


Figure 1.11: Wind tunnel model for flat screen resistance (Kim et. al., 2008)

Stent design affect the stent performance in diminishing aneurismal inflow. There are studies that investigated the effect of the stent strut size on the intra-aneurysmal flow in a sidewall aneurysm model using particle image velocimetry (PIV). They found that the stent reduces the aneurysmal vorticity and that the reduction of mean flow circulation varies depending on the strut diameter. The effect of stent shapes (helix stent vs. mesh stent) on intra-aneurysmal flow investigated by Liou et. al. using particle tracking velocimetry measurements and flow visualization. They concluded that the stented aneurysmal flow varies markedly with the shape of the stent and that the helix stent is more favorable compared to the (rectangular hole) mesh for endovascular treatment.

However, these experimental studies only provide us the information on two dimensional cross-sections of highly three-dimensional aneurysmal flow. More quantitative studies examining stent effects on three-dimensional aneurysm hemodynamics have been carried out using Computational Fluid Dynamics (CFD). For example, Aenis et. al. used a ‘‘square mesh’’ stent with a porosity of 85% and found significantly diminished flow in the stented aneurysm.

The mesh convergence analysis using more realistic stent geometry (helical wires with a porosity of 82%) and reported high wall shear stress (WSS) on the stent wire surface and reduced WSS on the aneurismal wall. Utilization of a stent composed of circular rings with a porosity of 60% results the average wall shear rate in the majority of the stented aneurysm was less than 100/s.

On the other hand, a simulation of flow passing complex endovascular devices such as coils and stents using a hybrid mesh (body conforming mesh and adaptive embedding mesh) technique also have been done. In addition to idealized aneurysm models, a basic requirement is simulations of patient-specific aneurysm models. However, many computational studies were limited to the mere demonstration of hypothetical stents in aneurysm flow alteration. This happens due to lack of comparative or systematic study of realistic stents for aneurysm treatment in scientific literature.

It is expected that the porosity of a stent is the most important parameter that affects its ability to modify the aneurysmal flow. The hypothesis here, the lower porosity results in more flow blockage, but if the porosity is too low, the stent might inadvertently block perforating vessels or become too rigid for deployment. Because of these constraints, the neurovascular stents currently in use are high-porosity stents and, in fact, current FDA-approved endovascular stents for cerebral applications have only slight variations, with porosities between 80% and 90%. On the other hand, these stents do differ widely in the mesh shape, size, and the strut shape and size.

In this project, evaluation will be made on the influence of void area design, focusing on three commercial porosity stents as examples to establish the methodology for studying any practical stent designs. Hopefully, the findings from this study will shed light on how the void area design can differentially influence the hemodynamics in aneurysms.

1.5 Objectives and scopes

The first objective of this project is to determine the flow behaviour in stented aneurysm using numerical approach. This project also includes the aim to determine the correlations between stents structural parameters and blood flow. The structural parameters in particular is the void area design from three commercial porosity stents as case study to establish the methodology for studying any practical stent designs.

In order to achieve these objectives, some limitations were decided to range the whole study. Therefore, the main concerned is to analyze selected stents based upon different structural parameters. Furthermore, the application of stent will be on fixed aneurysm and non pulsatile blood flow will be used in the simulation. All the solutions of the problem presented in this study will be based on numerical approach only. The results of these analyses through numerical simulations are expected to explain the local pressure distribution of blood vessel variation subjected to the change of stent void area as the fixed parameters.

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