EFFECTIVENESS OF VARIABLE STENT DESIGNS FOR TREATMENT OF RENAL ARTERY ANEURYSM

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May 2018

This dissertation is submitted to

Universiti Sains Malaysia

As partial fulfillment of the requirement to graduate with honors degree in

BACHELOR OF ENGINEERING (MECHANICAL ENGINEERING)

School of Mechanical Engineering

Engineering Campus

Universiti Sains Malaysia

DECLARATION

This thesis is the result of my own investigation, except where otherwise stated and has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any other degree.

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(Signature of Student)

Date:

ACKNOWLEDGEMENTS

In the name of Allah, the most beneficent, the most merciful

To my supervisor, Dr Mohamad Aizat bin Abas, I would like to express my deepest gratefulness for his enormous guidance and advice during the research. It was fantastic opportunity for me to do the research under his supervision for his wide experience in the numerical simulation and his passion to share his knowledge with the others.

I would like to thank all the technical staff in the Aerodynamics Lab and the workshop especially Mr Ridwan for his time and technical support during the modification and fabrication work of the research.

A big gratitude to Dr Norizham bin Abdul Razak, lecturer of School of Aerospace Engineering, for his advice and help in using the particle image velocimetry method and running the experiment

I would like also to thank the School of Mechanical Engineering, Universiti Sains Malaysia for technical support for completing this project.

Last but never be the least, my best appreciation to my parents and families for all the uncountable support and prayers, their patience, understandings and for providing the perfect environment for me to focus on my study.

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ABSTRACT

This research analyzes different stent designs that are available in the market namely Honeycomb, Coronary Stent and Medical stent to reduce the probability of Renal Artery Aneurysm (RAA) from rupturing. The purpose of this research is to help reduce the fatalities that commonly happens among pregnant due to impact of RAA. Particle Image Velocimetry (PIV) is conducted experimentally and as a mean to validate using the numerical solution for Renal Artery model. Fluid-structure-interaction (FSI) simulation using Ansys is conducted to observe the velocity vector (flow pattern), pressure contour and wall shear stress to determine the best stent design to be used in the RAA treatment. From the results, it shows that Medical stent is the best stent for RAA treatment because it can control the velocity and pressure which are 0.3m/s and 16000 Pa respectively along the renal artery and especially the bulging of the aneurysm which should show velocity of zero. Medical stent also shows controlled value of wall shear to prevent hemolysis. The standard value that could lead to hemolysis is above 50 Pa. The risk of RAA rupturing also decreases with the use of medical stent.

ABSTRAK

Penyelidikan ini menganalisis reka bentuk sten yang berbeza yang berada di pasaran iaitu sten Sarang Lebah, sten Koronari dan sten Perubatan untuk mengurangkan kebarangkalian Aneurisme Arteri Buah Pinggang Aneurysm (RAA) daripada pecah. Tujuan kajian ini adalah untuk mengurangkan kematian yang kebiasaan berlaku dalam kalangan wanita hamil disebabkan impak RAA. Velocimetri Imej Zarah (PIV) telah dilakukan secara eksperimental dan telah disahkan dengan menggunakan penyelesaian berangka untuk model Arteri Buah Pinggang. Simulasi interaksi-struktur-cecair (FSI) dengan menggunakan Ansys telah dilakukan untuk memerhati vector halaju (corak aliran), kontur tekanan dan tekanan ricih dinding untuk menentukan sten yang terbaik untuk digunakan dalam rawatan RAA. Dari hasil yang telah didapati, telah menunjukkan bahawa sten Perubatan adalah yang terbaik untuk digunakan untuk rawatan RAA kerana ia boleh mengawal halaju dan tekanan iaitu 0.3m/s dan 16000 Pa sepanjang arteri buah pinggang

dan terutamanya pada bonjolan aneurisme yang sepatutnya menunjukkan halaju kosong. Sten Perubatan juga menunjukkan bahawa nilai ricih dinding dapat dikawal untuk membendung hemolisis. Nilai standard yang boleh dikira akan menyebabkan hemolisis ialah melebihi 50 Pa. Risiko RAA untuk pecah juga berkurang dengan penggunaan sten Perubatan.

CHAPTER 1

INTRODUCTION

1.1 Overview

An aneurysm is a balloon-like bulge in an artery. Arteries are blood vessels that carry oxygen-rich blood to your body Arteries have thick walls to resist traditional force per unit area. However, bound medical issues, genetic conditions, and trauma will harm or injure artery walls. The force of blood pushing against the weakened or burned walls will cause an aneurysm. It grows giant and rupture (burst) or dissect. A rupture causes dangerous bleeding within the body. A dissection may be a split in a lot of layers of the artery wall. The split causes bleeding into and along the layers of the artery wall. Each rupture and dissection usually are fatal. There are many sorts of aneurysm, like intracranial aneurysm, abdominal aortic aneurysm, renal artery aneurysm and many more. Types of bulging in aneurysm are saccular, fusiform and pseudoaneurysm(Figure 1.1).

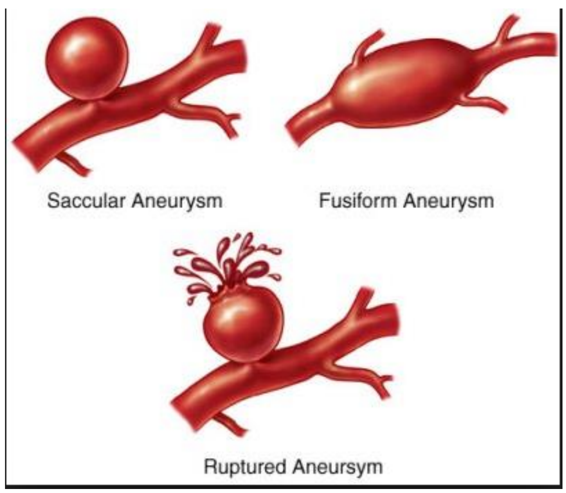


Figure 1.1: Types of Aneurysm bulging

Renal Artery Aneurysm (RAA) (Figure 1.2) is outlined as an expanded phase of renal artery that exceeds doubly the diameter of a normal renal artery. Symptomatic RAAs can cause hypertension, pain, hematuria, and renal infection. Asymptomatic RAAs could appear benign, however the potential for rupture and fistulation will increase with size. Asymptomatic patients are often referred for elective repair, but if patients are symptomatic, additional investigation with possible surgical intervention ought to be thought of. It is often diagnosed incidentally and has been detected more commonly as increased CT (computerized tomography) and MRI (magnetic resonance imaging) examinations for other non-related diseases.

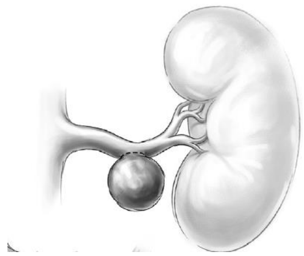
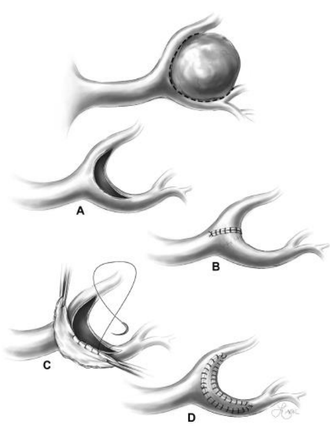


Figure 1.2: Renal Artery Aneurysm

There are two types of treatment for this type of aneurysm which are open surgical and endovascular repair (EVAR). Surgical can be done by clipping and by cutting the bulging part of the aneurysm (Figure 1.3). EVAR can be done by inserting stent coil (coil embolization) or stent grafts (Figure 1.4) to reduce the bulging of the aneurysm.



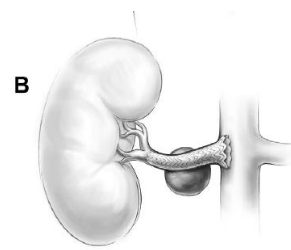


Figure 1.3: Surgical Method for Treatment of Aneurysm   Figure 1.4: Stent Graft

For now, the researchers are still finding the best method to improve the effectiveness of EVAR method. The surgical method seems to have more complications than EVAR method. The simulation and experiment need to be done on how to increase the EVAR method efficiency.

1.2 Problem Statement

The rising trend of aneurysm patients should gain more attention from the not just the medical sector but also from the engineering sector. Participation of mechanical engineers in designing and developing the aneurysm treatment methods is very helpful since they can contribute their knowledge from the perspective of stress distributions and fluid mechanics. Surgical clipping is not always the preferred choice because of the high risks involved. One of the harmful effect of surgical clipping is that it may lead to Subarachnoid Hemorrhage(SAH) after surgical treatment. Additionally, other treatment method like Endovascular coiling or Coil embolization is difficult for wide neck aneurysm. Therefore, it is best to design a wire mesh stent that can improve the flow of blood in the bifurcation aneurysm region to reduce the risk of rupture of the aneurysm.

1.3 Objective

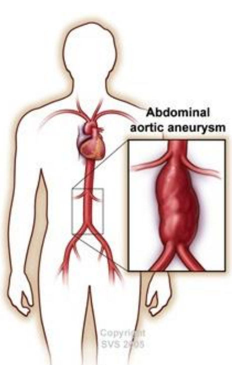
1) To create and design several stent graft treatments for RAA.
2) To simulate the blood flow on RAA after implantation of stent graft design using Ansys.
3) To validate the simulation analysis with experimental method
4) To conduct an analysis for the simulation and the experiment that has been done.

CHAPTER 2
LITERATURE REVIEW

2.1 Overview-Aneurysm

An aneurysm is a balloon-like bulge in an artery. Arteries are blood vessels that carry oxygen-rich blood to your body Arteries have thick walls to resist traditional force per unit area. However, bound medical issues, genetic conditions, and trauma will harm or injure artery walls. The force of blood pushing against the weakened or burned walls will cause an aneurysm. It grow giant and rupture (burst) or dissect. A rupture causes dangerous bleeding within the body. A dissection may be a split in a lot of layers of the artery wall. The split causes bleeding into and along the layers of the artery wall. Each rupture and dissection usually are fatal. There are many sorts of aneurysm, like intracranial aneurysm, abdominal aortic aneurysm, renal artery aneurysm and many more. Types of bulging in aneurysm are saccular, fusiform and pseudoaneurysm[1].

Abdominal aortic aneurysm(AAA) (Figure 2.1) is located between the diaphragm and the aortic bifurcation. An aneurysm is classified as suprarenal if it involves the origin or more visceral arteries, pararenal if it involves the origins of the renal arteries and infrarenal if it begins beyond the renal arteries. Ultrasonography is the primary method used for screening and highly sensitive and specific. The observations that aneurysms rupture at a smaller size in women than in men and that women have higher rupture-related mortality than men. The causes might have been of family history that has been identified having abdominal aortic aneurysm. There are two kinds of treatment, one is Endovascular repair(EVAR) using stent coil or stent grafts. Another is with open repair (Figure 2.2) using synthetic graft[2],[3], [4].



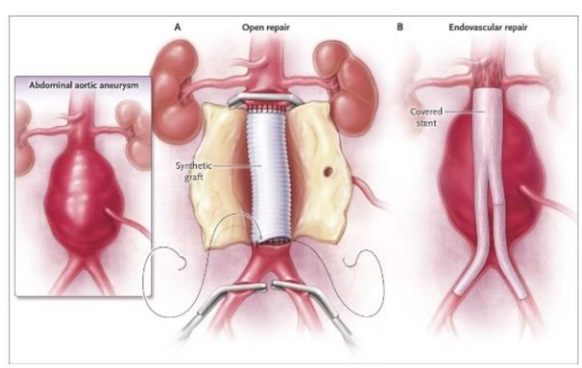


Figure 2.1: Abdominal aortic aneurysm   Figure 2.2: Techniques for repairing AAA

A brain aneurysm (Figure 2.3), conjointly mentioned as a cerebral aneurysm or intracranial aneurysm (IA), is a weak bulging spot on the wall of a brain artery greatly sort of a skinny balloon or weakness on associate tube. Over time, the blood flow inside the artery pounds against the cut portion of the wall and aneurysms type taciturnly from wear and tear on the arteries. because the artery wall becomes bit by bit dilutant from the dilation, the blood flow causes the weakened wall to swell outward. This pressure could cause the aneurysm to rupture and permit blood to flee into area aroundthe brain.A busted brain aneurysm usually needs advanced surgical procedure. There two varieties of aneurysm, saccular and fusiform (Figure 2.4). There area unit several risk factors contributory IA like smoking, high blood pressure, age over forty, tumors and others. associate cardiovascular disease is usually diagnosed employing a form of imaging instrumentality. Some strategies embrace CT Scan, CTA, tomography and MRA. Or treatment they use EVAR technique[5].

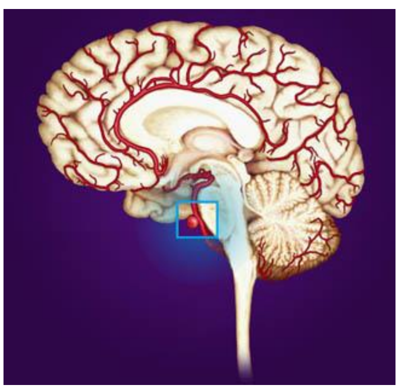


Figure 2.3: Brain aneurysm

Figure 2.4: Types of brain aneurysm

Renal Artery aneurysm (RAA) is kind of aneurysm that happens in renal artery (Figure 2.5). RAA happens in 0.1% among general population. This aneurysm is discovered throughout gross autopsy. Every kind of Aneurysms are often detected by angiography and computed tomography. Refer to Table 2.1 for features of RAA. RAA is absolutely a large deal for pregnant girls. Pregnancy is assumed to be related to the next rate of rupture secondary to accrued vascular flow and secretion changes, leading to weakening of the vessel wall elastic tissue. Ruptures usually occur within the trimester with solely several case reports of rupture post-delivery. Rupture throughout physiological condition has been delineated in aneurysms as tiny as one cm. Historic reports imply dismal consequences (56%-92% maternal mortality and 82%-100% fetal mortality). up to date outcomes for each mother and craniate is also up, as there are anecdotal reports of physiological condition rupture leading to each maternal and fetal survival.[6], [7]

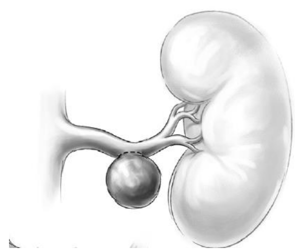


Figure 2.5: Aneurysm in Renal Artery

Table I. Features of renal artery aneurysms (RAAs)

Incidence	• Autopsy rates, <0.01%-0.09%[1] • Arteriogram rates, 0.3%-2.5% (up to 9.7%)[2-5] • CT rates, 0.7%[6]
Natural history	• Large autopsy series demonstrate no rupture[3,4] • Most report no rupture during surveillance out to 270 months[1,2,4,5,7-11] • Growth rate 0.06-0.6 mm/y[9-11] • Rupture rate 3%-5% with nongestational mortality <10%[2,5,12-15]
Clinical presentation and risk factors	• Sixth decade of life (range, 46-62 years of life)[2,4,7,9-11,13,15,16] • Female predominance up to 72%[1,7,9-13,15,17] • Association with FMD up to 68%[1,7,9-13,15,17] • Symptoms rare (4%-23%): abdominal and/or flank pain, hematuria • Clinical exam may identify: HTN, renal bruit, and palpable abdominal mass • Majority of patients are hypertensive • Chronic renal insufficiency has been identified in 4-14% of patients[1,12,15,16] • Alternate arterial aneurysms (ie, aortic, iliac, visceral) in 7%-30% of cases
Anatomy and radiographic features	• Most saccular • Two-thirds affect arterial bifurcations • Often multiple, 10%-20% bilateral, non-renal arterial aneurysms (7%-30%)[1,2,7,9,11,12,15-17] • 18%-68% calcified • 8%-11% demonstrate thromboembolism

CT, Computed tomography; *FMD,* fibromuscular dysplasia; *HTN,* hypertension.

Table 2.1: Features of RAA

However, there are two treatments that are discovered up to now, that is by surgical and endovascular treatment (EVAR). Surgical are often done by clipping and by cutting the bulging a part of the aneurysm (Figure 2.6). EVAR are often doing by inserting stent coil (coil embolization) or stent grafts (Figure 2.67 so as to scale back the bulging of the aneurysm.The most purpose of this project is to simulate the flow of blood through aneurysm with and while not EVAR treatment and conjointly to hold out by experimentation. apart from that, planning an acceptable quite stent graft conjointly vital to grasp that one is feasible to be used for treatment for RAA.[8], [9]

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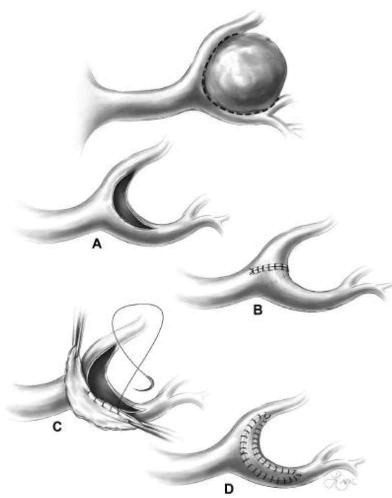


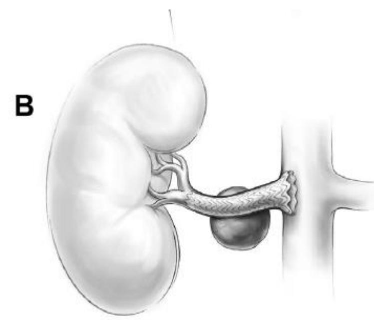


Figure 2.6: Surgical Method for Treatment of Aneurysm   Figure 2.7: Stent Graft

In a nutshell, there are such a big number of sorts of aneurysm existed within the world. Primarily all aneurysm factors occur once being too hypertense or being the age of forty. Supported the outline of all aneurysms, it is seen that there are two reasonably treatments to be used, that are surgical methodology and EVAR. During this project, RAA is kind of aneurysm that must be done through an experiment and simulationally as a result of it is seldom happens and extremely harmful for ladies particularly throughout maternity.[10]

2.2 Stent Classifications

A stent may be a tube-like device that may be inserted into a narrowed passageway or vessel to carry it open. A stent thus acts as a scaffold that holds bodily tubes open.[11]

The part of the center muscle empty blood becomes necrotic or dies and then cannot operate. The narrowing of the coronary blood vessel is typically caused by induration of the arteries or the build of fatty deposits that eventually kind a plaque. As blood flow becomes reduced, angina or pain could occur. Stents are placed inside the narrowed arteries to carry them open and restore blood flow.

A stent is planted using a procedure referred to as percutaneous coronary intervention (PCI) or coronary angioplasty. For this procedure, a long, skinny referred to as a catheter with an expansive balloon at the tip is inserted into an artery (usually a large artery in the patient's groin) and is threaded through to the guts underneath the steering of X-ray imaging.

Once the tip of the catheter reaches the narrowed part of the artery, the tip is inflated to push the artery walls open. Once the artery is widened, the balloon is deflated and removed, whereas the stent is bolted in place, holding open the vessel even once the balloon is deflated.

Around one third of patients who have had their coronary blood vessels dilated with a balloon but have not had stents inserted, have found the vessel narrows again after a few months of balloon angioplasty. This re-narrowing is called restenosis. Stenting helps prevent restenosis.

Nowadays, a more recent type of stent called the drug-eluting stent is available. These stents are embedded with drugs that slowly elute into the coronary artery to prevent the closing of the vessel on a long-term basis. Stents that do not contain drugs are called bare metal stents.[12]

After a stenting procedure, antiplatelet and anticoagulant drugs such as aspirin and clopidogrel can be used to prevent clot formation around the stent and restenosis.

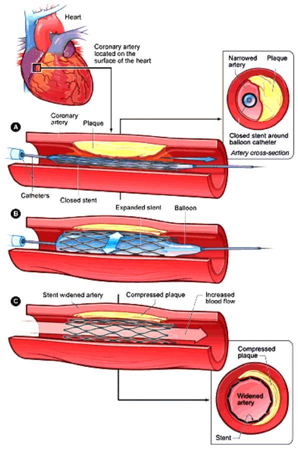
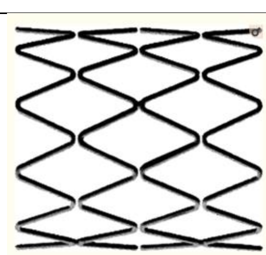
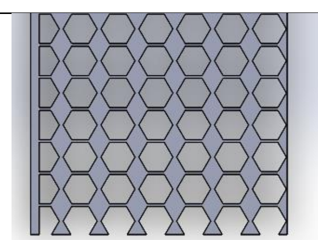
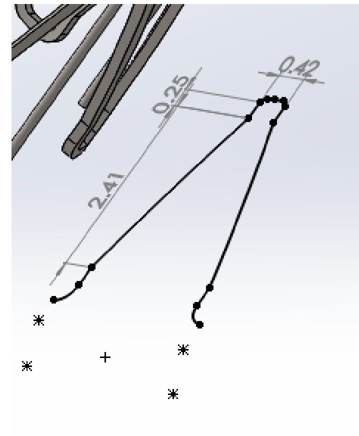


Figure 2.8: Placement of Coronary Stent

There are many consideration have been taken when designing many types of stent. Designers must select and optimize among numerous interrelated parameters, such as strut length and width, wire diameter and pitch, bridge configuration, material selection, and processing conditions to achieve optimal performance. Consider radial force as an example of the difficulty of assessing a performance attribute in stent design. The radial force required will be dependent on lesion characteristics and location. Aorto-ostial lesions may require more force than internal carotid artery stenoses. The radial strength of a carotid stent should provide adequate apposition and enough resistive force to prevent vessel wall recoil. Excessive force or rigid closed-cell designs might result in plaque disruption in a vulnerable unstable lesion. Most nitinol stents can be adjusted for cell size and still maintain satisfactory radial force. [13]

Type of Stent Design and Characteristics :

Name of Stent	Driver Stent (Coronary Stent)	Hexagonal Honeycomb Stent	Bare Metal Stent(medical stent)
Design			

Size range	Length, 9–30 mm; diameter, 2.8–4.0 mm; maximum expansion, 4.4 mm.	Length, 30mm; Circumference,13.55mm; θ= 30 degree	Length, 30mm; 
Physical characteristics	The smooth, edgeless, modular design consists of 10 crown sinusoidal rings linked via 1.0 mm elements	The Hexagonal stent is similar to the Diamond stent, except that the circumferentially running connector strut is extended axially to the same nominal length as the bending struts	It is a mesh-like tube of thin wire
Stent material	Cobalt alloy finished with a chrome rich oxide	Polytetrafluoroethylene (***PTFE***)	Cobalt Chromium L605

The advantages of Driver Stent are it is Ultrathin, round struts offer smoother delivery and less stress on tissue. The cobalt alloy, which conforms to ASTM F562, is stronger than stainless steel, making possible thinner struts without decreasing radial strength. Driver struts are an average of 0.0036 in., approximately 20 percent thinner than the S7 struts. Thinner struts, in turn, contribute to a lower profile. The alloy is also denser than 316L stainless steel, such that good radiopacity is maintained despite the thinner strut dimensions.[14]

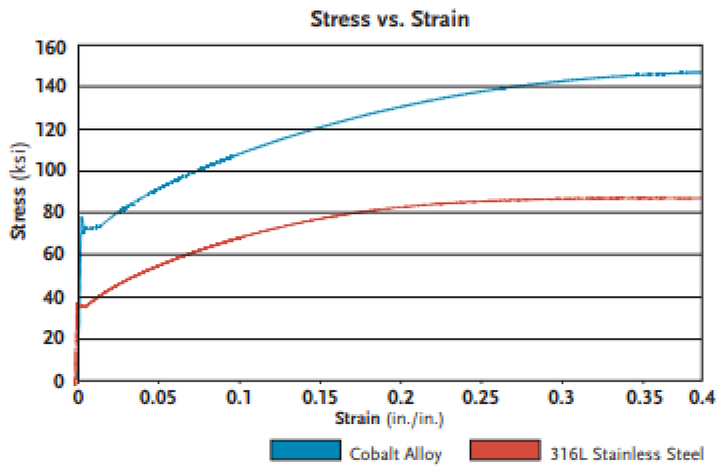


Figure 2.9: Stress VS Strain graph of Cobalt ally and 316L Stainless Steel

The cobalt alloy has higher strength than stainless steel—allowing thinner struts while maintaining radial strength. Figure 2.9 illustrates "stress-strain" curves for both the Driver cobalt alloy and 316L stainless steel. These curves are generated using samples of each material fabricated with the same cross-sectional area. The cobalt alloy is denser than 316L stainless steel (see Table 2.2). This higher density makes it possible to design a thin-strut stent with radiopacity as good as or better than a stainless-steel stent.[15]

Material	Pounds per $Inch^3$
Cobalt alloy	0.304
316L stainless steel	0.287

Table 2.2: Density value of Cobalt Alloy and 316L stainless steel

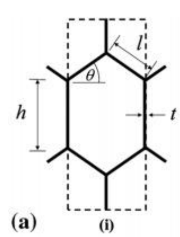


Figure 2.10: Geometrical of Hexagonal Honeycomb Stent

For Hexagonal Honeycomb Stent, From Fig. 2.11, it is evident that systems having a ratio of h/l > 0.25 in the cases of the non-re-entrant honeycombs and the hybrid honeycombs were able to sustain the 200% elongation

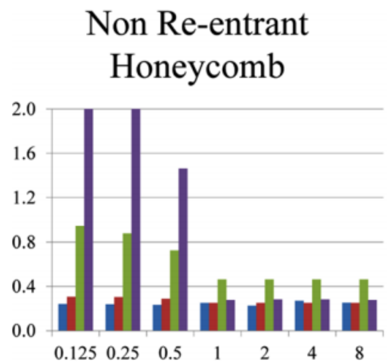


Figure 2.11: Plots of breaking strain versus h/l ratios for various u values for the non-re-entrant honeycomb

The non-re-entrant honeycomb stent, however is much better suited to adapt to curvatures. Nonetheless, it is still not ideal. The ribs in the non re-entrant honeycomb stents experience some bending in the radial direction, which would ultimately lead to a higher loss of shape.[16]

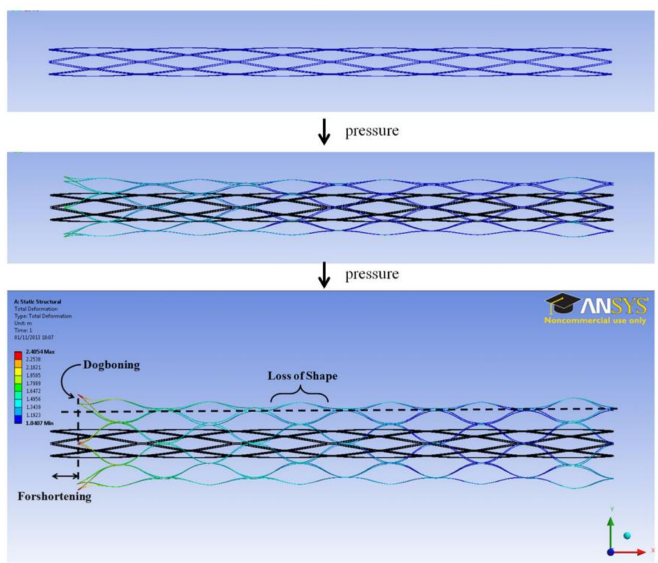


Figure 2.12: Deformation occurring in the non re-entrant stent upon subjecting it to a pressure on the inside surface to simulate its inflation

Figure 2.12 illustrating the different degrees of displacement at each point of the stent. It is evident that upon inflation, the circumferential surface loses shape. Moreover, there is also a high degree of non-uniformity along the stent indicating dogboning effects, which are clearly evident at the edge of the stent (left hand side). It should also be noted that inflation is also accompanied by a foreshortening effect.

Bare metal stent has one advantage which is devices show vascular healing after 4-6 months with reendothelialization at almost 100%. These stents are easy to produce and cheap, and are easy to implant with a small profile and good trackability. Major disadvantage of this type of stent is that it is associated with restenosis rates from 15-20% and require re-intervention in 5-10%5. However, dual antiplatelet therapy is needed only for 1-2 months. Nevertheless, bare metal stents are a valid alternative to drug eluting stents but are no longer considered as a “state of the art” device.[12], [17]

So for this review can be said that bare metal stent and coronary stent still new to this kind of aneurysm so still need to be figured out but for Hexagonal Stent it have been proven. The effectiveness will be proved by simulation.

CHAPTER 3

METHODOLOGY

3.1 Overview

To prove the efficiency of using stent in Endovascular (EVAR) method, experimental and simulation data needs to be collected. Experiments are conducted in Aerodynamics Lab in Aerospace School of Engineering while the simulation will be conducted using Ansys software. Particle Image Velocimetry (PIV) is an optical method of flow visualization used in education and research. It is used to obtain instantaneous velocity measurements and related properties in fluids. The fluid is seeded with tracer particles which, for sufficiently small particles, are assumed to faithfully follow the flow dynamics (the degree to which the particles faithfully follow the flow is represented by the Stokes number). The fluid with entrained particles is illuminated so that particles are visible. The motion of the seeding particles is used to calculate speed and direction (the velocity field) of the flow being studied. [18]

3.2 Establishment of CAD model

A model of Renal Artery Aneurysm (RAA) is created using solidworks. The size of the Aorta (point A) is 2.5cm in diameter while the renal artery (point B) is 4.50mm in diameter. The bulging part is 1.5cm diameter (Figure 3.1)

. The length of the renal artery is 30mm.

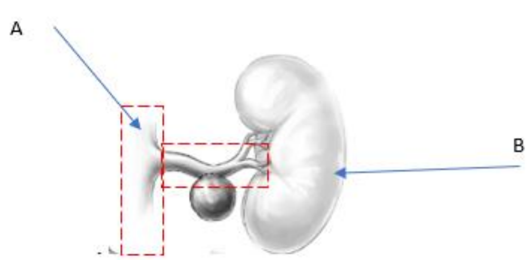


Figure 3.1: Model of RAA

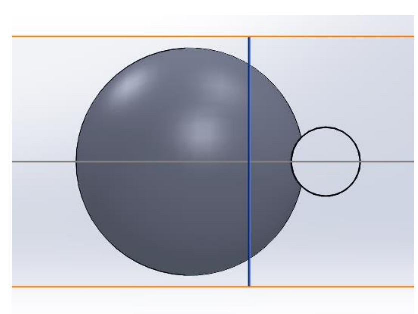


Figure 3.2: Side view of RAA

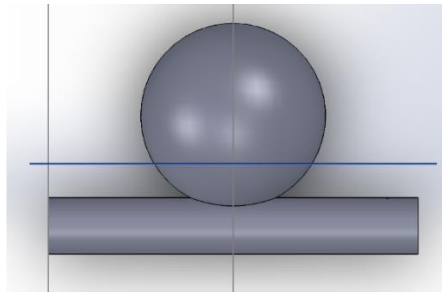


Figure 3.3: Front side of RA

So, in order to run experimental data using PIV, the model of RAA is to be created to help gain information that is needed. So, by using blocks in Solidworks, the Perspex like model is created . After then it is sent to be done in Computer Numerical Control (CNC) machining.

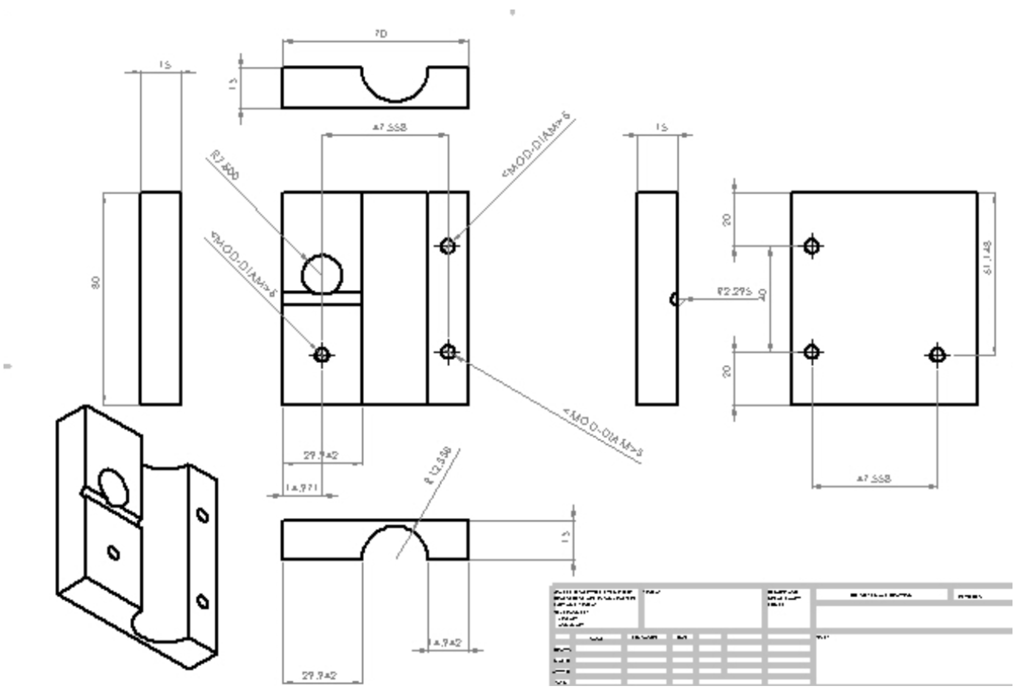


Figure 3.4: Drawing of Solidworks of Perspex model of RAA

3.3 Particle Image Velocimetry(PIV)

It was done using Particle Image Velocimetry (PIV) which use 2-Dimensional(2d) to observe the particle moving in the RAA model. The set-up is shown below.

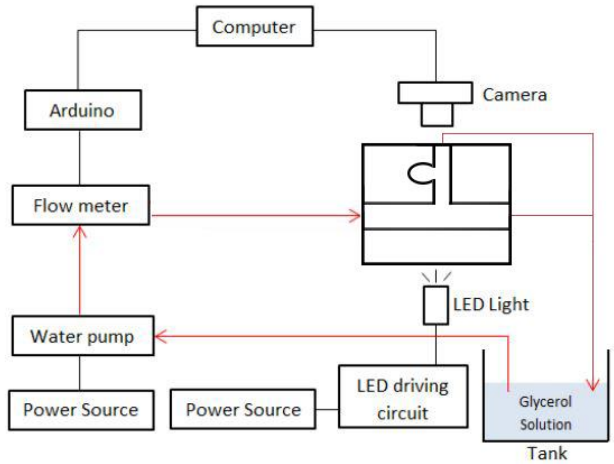
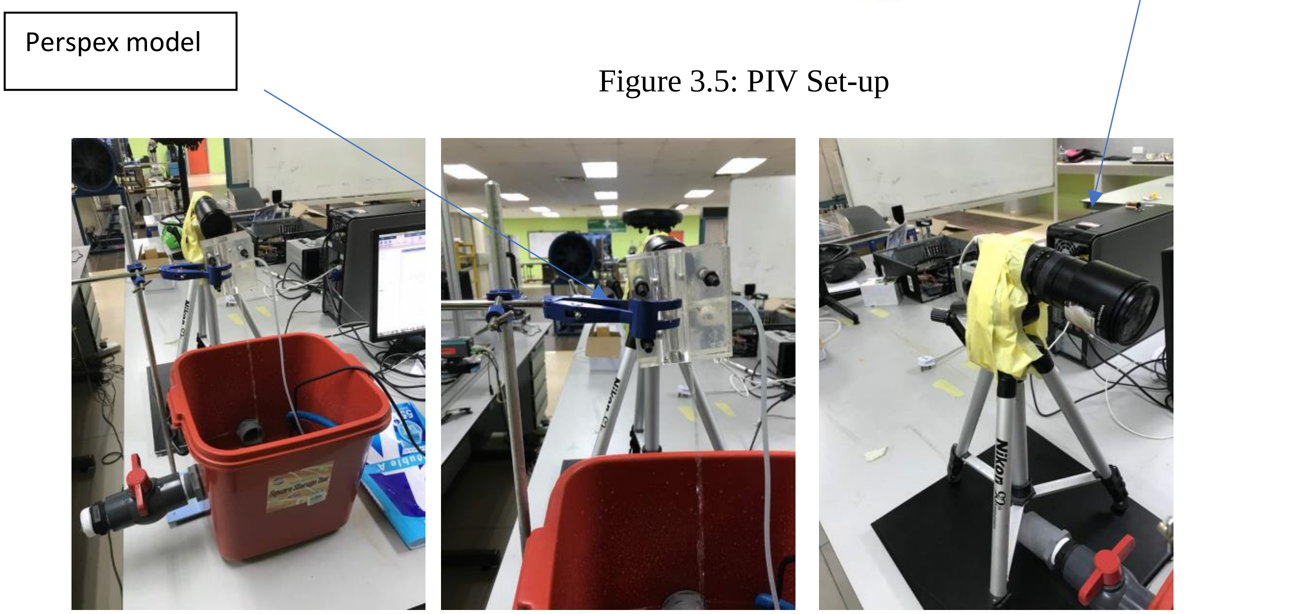
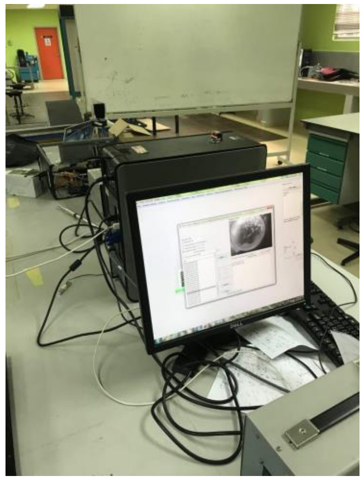


Figure 3.5: PIV Set-up



(i) (ii) (iii)



(iv)

Figure 3.6: The experimental setup PIV done, (i) and (ii) The Perspex of the RAA model and the water tank, (iii) Camera used to capture the movement of Particle in the perspex and (iv) The PIV software used to gain information

The pump used is 2000L/h but in this experiment we need only 1.1L/min[19]. Therefore, we used flow valve to control the flow meter. The glycerol solution in the tank is pumped through the system by a 12V DC water pump. The fluid is first pass through a flow meter which has the flow rate range of 0.2-30L/min. The instantaneous flow rate and fluid velocity is measured by an Arduino Uno R3 board and the data is display on a computer. The voltage supply to the water pump determines the velocity of the fluid. Higher voltage results in higher velocity. The inlet velocity is kept constant at 0.06m/s. Fluid passing through the flow meter is then flow into the inlet of the Perspex model, fill up the artery and then flow out from the two outlets back into the tank.

The camera used to record the video of the flow is TSI C49, a PIV camera which has the maximum frame rate of 60fps. It is fix on a retort stand and connected to the computer. The software used to control the camera is IC Capture 2.4. To capture the PIV seeding particles clearly, a LED light is installed at the bottom of the Perspex model to illuminate the particles. The LED light is connected to a LED driving circuit which functions as a driver to regulate the power to the LED and prevent it from becoming too hot and unstable.

The procedure of the experiment is rather simple. First, the bolts and nuts of the Perspex model are tightened up to prevent leakage. The pipes are connected, and the water pump is switched on by turning up the voltage of the power source. The LED light is turned on as well. As the fluid is flowing, the velocity is observed and controlled by manipulating the voltage. When the velocity reaches the required velocity of 0.06m/s, the camera is used to record videos of the flowing fluids at the bifurcation region. The operator is advised not to touch anything in the setup during the video is being captured because it will cause vibration to the camera. After the recording is done, the water pump is switched off. Pipes connecting the Perspex model are removed. The Perspex model is opened and clean using water to remove sticking particles on the wall of the artery. Stent is placed into the artery and the Perspex model is tightened up again. The procedures are repeated for all four sets of stents configuration. The frames of the videos are extracted using VLC player. Finally, the frames are imported to PIV lab to be analyzed.

3.4 Simulation

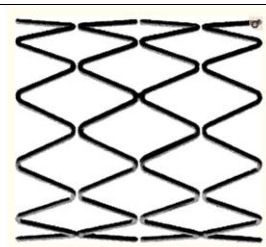
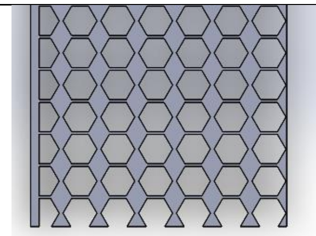
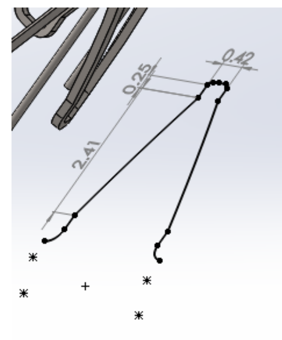
The simulation is done in Ansys using one-way Fluid-Structure-Interaction (FSI). Fluid-structure interaction (FSI) is a Multiphysics coupling between the laws that describe fluid dynamics and structural mechanics. This phenomenon is characterized by interactions –which can be stable or oscillatory between a deformable or moving structure and a surrounding or internal fluid flow.[20]

When a fluid flow encounters a structure, stresses and strains are exerted on the solid object forces that can lead to deformations. These deformations can be quite large or very small, depending on the pressure and velocity of the flow and the material properties of the actual structure. The usage of Navier-Stokes equation is used in this simulation.

$$\underbrace{\rho\left(\frac{\partial \mathbf{u}}{\partial t} + \mathbf{u}\cdot\nabla\mathbf{u}\right)}_{1} = \underbrace{-\nabla p}_{2} + \underbrace{\nabla\cdot\left(\mu(\nabla\mathbf{u} + (\nabla\mathbf{u})^T) - \frac{2}{3}\mu(\nabla\cdot\mathbf{u})\mathbf{I}\right)}_{3} + \underbrace{\mathbf{F}}_{4}$$

` Equation 3.1: The Navier-Stokes equations represent the conservation of momentum.

Stent done for this simulation is shown below (Coronary stent,Honeycomb stent and Medical Stent):-

Name of Stent	Driver Stent (Coronary Stent)	Hexagonal Honeycomb Stent	Bare Metal Stent
Design			
Size range	Length, 9–30 mm; diameter, 2.8–4.0 mm; maximum expansion, 4.4 mm.	Length, 30mm; Circumference,13.55mm; θ= 30 degree	Length, 30mm; 
Physical characteristics	The smooth, edgeless, modular design consists of 10 crown sinusoidal rings linked via 1.0 mm elements	The Hexagonal stent is similar to the Diamond stent, except that the circumferentially running connector strut is extended axially to the same nominal length as the bending struts	It is a mesh-like tube of thin wire
Stent material	Cobalt alloy finished with a chrome rich oxide	Polytetrafluoroethylene (***PTFE***)	Cobalt Chromium L605

3.5 Parameters of Blood

Table 3 shows the parameters used for Ansys setup

Table 3.1: Parameter setting in Ansys Software

Inlet diameter	4.50mm
Average inlet velocity	0.3m/s [21]
Kinematic viscosity	1.561e-06 m^2/s [22]
Density	1060 kg/m^3 [22]
Volume	3.283151e-13 (artery only)
Reynold Number (Re)	409

3.6 Meshing

For renal artery only, minimum size for meshing used is 1.8845e-2 mm. Minimum size meshing for renal artery aneurysm plus honeycomb stent is 5.5227e-6 m. For coronary stent, minimum size of 0.20mm is used and for medical stent, 8e-5 m.

Sizing	
Size Function	Curvature
Relevance Center	Coarse
Transition	Slow
Span Angle Center	Fine
Curvature Nor...	Default (18.0 °)
Min Size	Default (1.8845e-002 mm)
Max Face Size	Default (1.88450 mm)
Max Tet Size	Default (3.76910 mm)
Growth Rate	Default (1.20)
Automatic Mesh ...	On
Defeature Size	Default (9.4227e-003 mm)
Minimum Edge L...	11.2410 mm

Figure 3.7: Mesh Sizing for Renal Artery

Sizing	
Use Advanced Si...	On: Curvature
Relevance Center	Fine
Initial Size Seed	Active Assembly
Smoothing	High
Transition	Slow
Span Angle Center	Coarse
Curvature Nor...	Default (70.3950 °)
Min Size	Default (5.5227e-006 m)
Max Face Size	Default (5.5227e-004 m)
Max Size	Default (1.1045e-003 m)
Growth Rate	Default (1.20)
Minimum Edge L...	3.765e-006 m

Figure 3.8: Mesh Sizing for Honeycomb stent

Sizing	
Use Advanced Si...	On: Curvature
Relevance Center	Coarse
Initial Size Seed	Active Assembly
Smoothing	Low
Transition	Slow
Span Angle Center	Coarse
Curvature Nor...	Default (70.3950 °)
Min Size	0.20 mm
Max Face Size	Default (1.88560 mm)
Max Size	Default (3.77120 mm)
Growth Rate	Default (1.20)
Minimum Edge L...	1.9698e-004 mm

Figure 3.9: Mesh sizing for Coronary stent

Sizing	
Use Advanced Si...	On: Curvature
Relevance Center	Coarse
Initial Size Seed	Active Assembly
Smoothing	Low
Transition	Slow
Span Angle Center	Coarse
Curvature Nor...	Default (70.3950 °)
Min Size	8.e-005 m
Max Face Size	Default (1.8856e-003 m)
Max Size	Default (3.7712e-003 m)
Growth Rate	Default (1.20)
Minimum Edge L...	4.6492e-007 m

Figure 3.10: Mesh sizing for Medical stent

The mesh statistics(elements) for each model is shown below respectively:

i) Renal Artery = 21775

ii) Honeycomb stent = 127997

iii) Coronary stent = 233788

iv) Medical stent = 409725

Statistics	
Nodes	5644
Elements	21775

(i)

Statistics	
Nodes	25738
Elements	127997
Mesh Metric	None

(ii)

Statistics	
Nodes	44385
Elements	233788
Mesh Metric	None

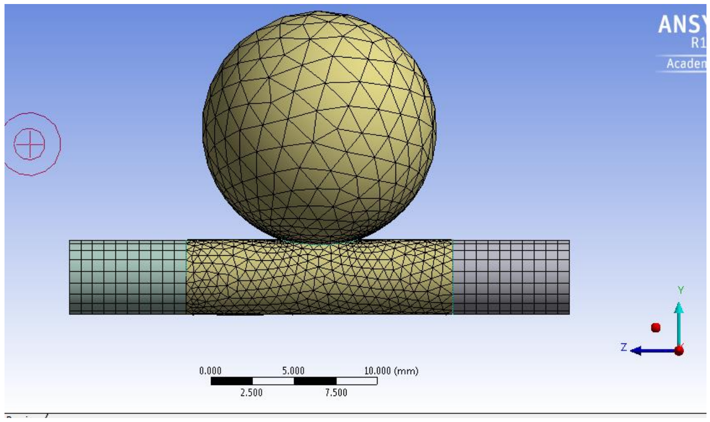
(iii)

Statistics	
Nodes	80401
Elements	409725
Mesh Metric	None

(iv)

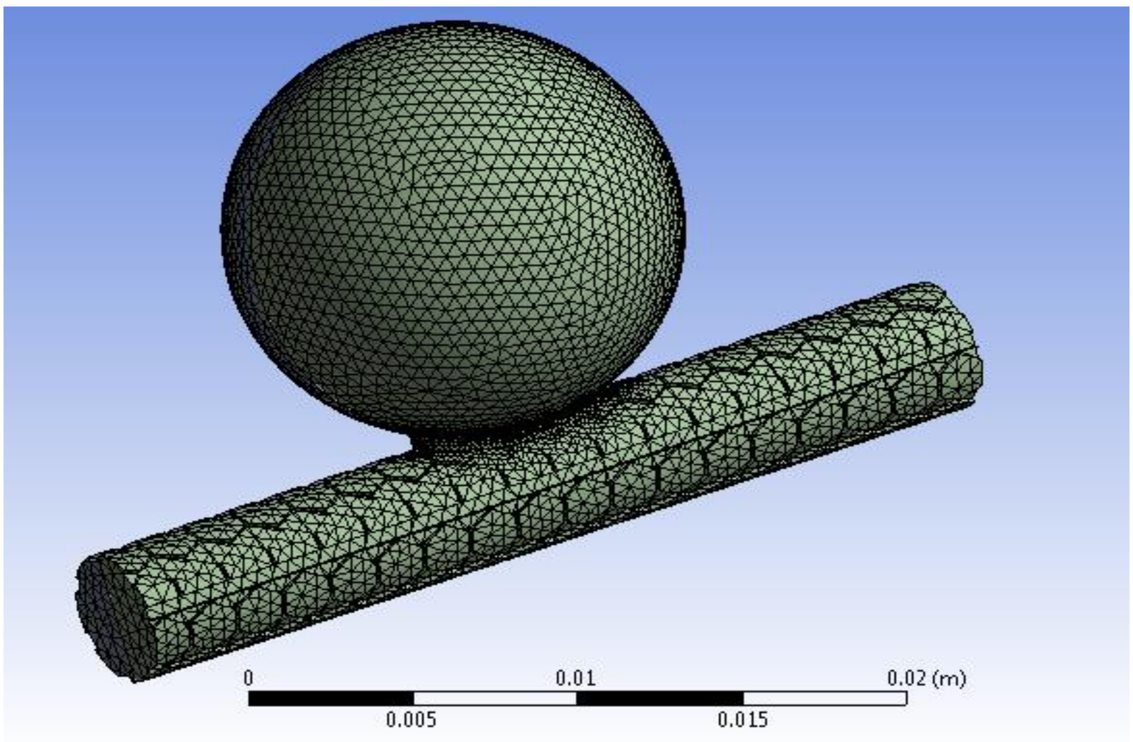
Figure 3.11: Mesh sizing for (i) Renal Artery (ii)Honeycomb (iii)Coronary stent (iv)Medical stent

The meshing geometry for each model are shown:

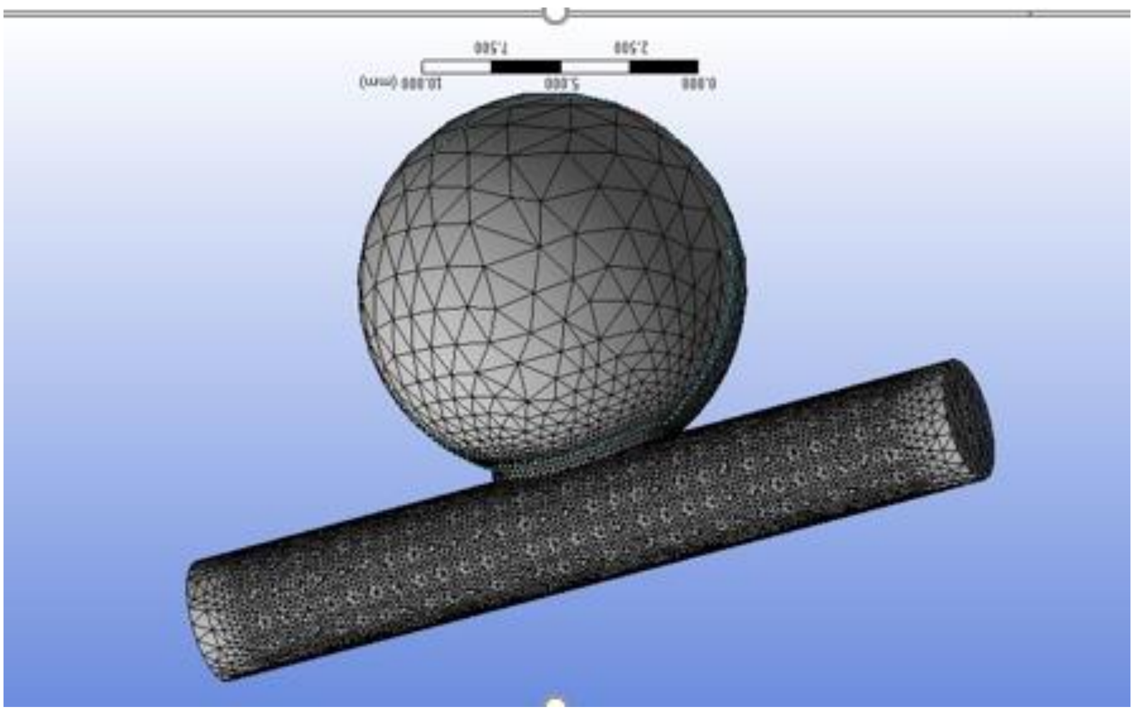

ANSY
R1
Acaden
0.000
5.000
10.000 (mm)
2.500
7.500
Y
Z

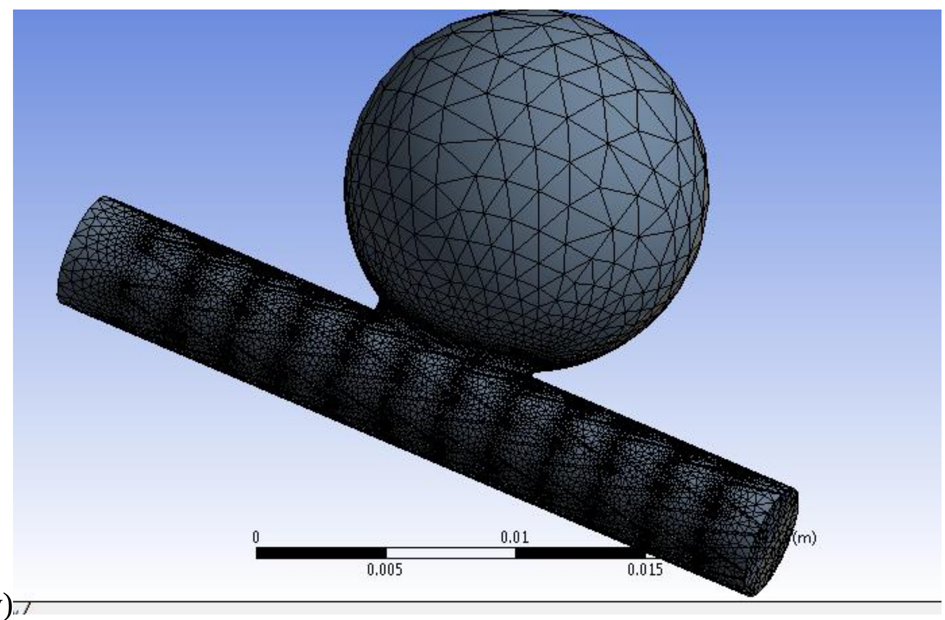
(i)

(ii)


0
0.01
0.02 (m)
0.005
0.015

(iii)





(iv)

Figure 3.12: Mesh Geometry for (i) Renal Artery (ii)Honeycomb stent (iii) Coronary stent (iv) Medical stent

3.7 Ansys Fluent Setup

The Fluent setup used is Serial, Double-Precision (Figure 3.13) . For one-way FSI to be done, the material properties of blood needs to be justified (Figure 3.15). Other than that, transient and steady must be choose, so for Renal Artery and Coronary Stent Transient is used. For Honeycomb Stent and Medical Stent steady is used. Other than that all the model are being put gravitation acceleration parameter which is 9.81m/s^2 (Figure 3.14). The inlet properties used is velocity while the outlet properties used is pressure (Figure 3.16). Dynamic Mesh is used and Smoothing and Remeshing are chosen. Mesh method settings used for Smoothing is Diffusion and the diffusion parameter is 2.

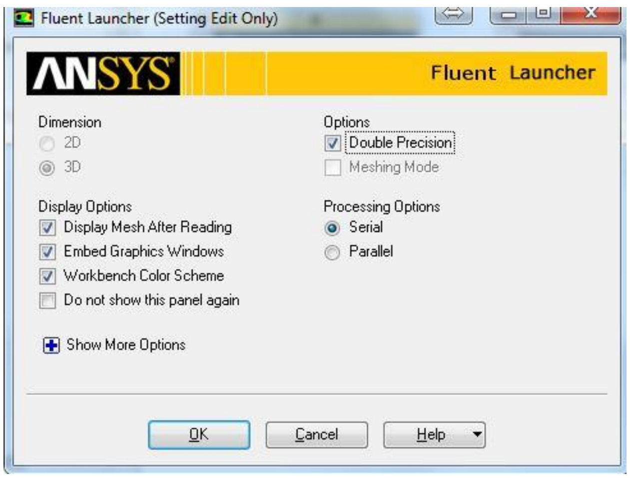


Figure 3.13: Fluent Launcher

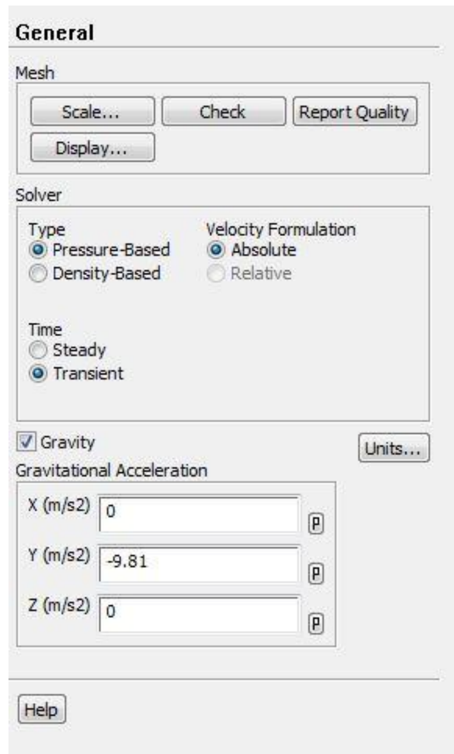


Figure 3.14: General Setup